Adaptive Logistics - Using Complexity Theory to Facilitate Increased Effectiveness in Logistics

Nilsson, Fredrik

2005

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Adaptive Logistics

- using complexity theory to facilitate increased effectiveness in logistics

Thesis for the degree of Doctor of Philosophy

Fredrik Nilsson
Licentiate in Engineering

Department of Design Sciences
Division of Packaging Logistics
Lund University 2005

Adaptive Logistics - using complexity theory to facilitate increased effectiveness in logistics

Lund University
Department of Design Sciences
Division of Packaging Logistics
Box 118
SE-221 00 Lund
SWEDEN

ISRN LUTMDN/TMFL – 05/2004 – SE
ISBN 91-628-6511-0

Printed at MediaTryck AB
Lund 2005
Printed in Sweden

Acknowledgements

In my licentiate thesis I initially asked the reader if he/she would be kind enough to give the text, the thoughts, and the arguments a “chance”, and be open to what is presented. With an open mind I hope that *this* text will at least trigger some thoughts and reflections about how things could be done differently. Furthermore, *this* text might hopefully be an inspiration for further developments of logistics either by agreeing or disagreeing with the presented material. As such, I would very much like the reader to reflect on my thoughts and accept them as they are. What I present here are the brightest ideas, the best formulations, and the best models that I have managed to produce during my research process. I believe that this transformation will go on, and on, and on, and therefore I am certain that in a year from now stronger arguments could (and probably will) be presented after some reflections and new interpretations of logistics, complexity, adaptivity etc. What you will read is the best I can present at this point of time, based on what I have read, done, and reflected on during four years of research. If the timing is right these theories and thoughts will hopefully be a success! ☺

When I look back on the research process I have gone through it becomes very clear that I would not have been able to do it if it had not for my marvelous, fantastic, and outstanding family, friends and colleagues. I owe you all my greatest gratitude and hope that I am and can be equally supportive to you all.

In the creation of the “book” you hold in your hands there are some people who have contributed with their support in several ways and I would like to mention them in particular. Firstly, Professor Gunilla Jönson, my supervisor and coach, who has been the person who has made this extremely interesting and challenging journey possible. The coaching and support you have given have been a source of both inspiration and focus, and you have provided me with confidence in the unorthodox research path I have taken. Thank you! I would also like to thank Dr. Jonas Waidringer for many interesting and inspiring discussions. It is always nice to talk to someone with a great interest in complexity theory and who also believes that that there are more than 24 hours in a day. ☺

I would also like to thank Professor Hans Sarv for your comments and advice during the writing of this thesis. Your insightful advice and probing questions in the final phase of this process were really beneficial; for my own learning process and for the final thesis.

At my division, which is the best workplace I could dream of, I would like to offer my greatest appreciation to all my wonderful colleagues for the fun, laughter, and interesting discussions we have had, and hopefully will continue to have. While you have all contributed in several ways during this research journey, there are some of you I would like to give special thanks to.

First Daniel, who came into my room two days before printing began to ask if he could be of any assistance ☺. My answer is: you have been of great support from the day I started. You have many great talents and an enviable selflessness, which makes you a very “big” man on earth. Thank you for being a role model in life. I know what you have in front of you and I hope that I can be of support. Annika, it is always inspiring to talk to a really optimistic colleague with a great interest in the qualitative aspects of both research and life. Thank you for your aid and support. I hope I can inspire and support you as your “deadline” comes closer. Henrik, we have known each other for several years now, and while it took some years to convince you to start your PhD journey I am glad to have you on the team. Thank you for the support you have given me by reading some of my articles over and over again… The next challenge for us is this nice biking around that Swedish lake ☺. I would also like to thank Fredrik, David, and Magnus, for an excellent master’s thesis. It was interesting and fun to work with you. I wish you the best. Magnus - I express my special gratitude for the discussions we have had, the Java programming lessons, and for introducing me to really good shirts, my shopping problems have been reduced…

To Carl-Henric Nilsson, my colleague at the Technology Management Center, who triggered my interest in doctoral studies and gave me a very solid educational background, especially in PM4 when I first came across the fascinating science of complexity. I look forward to the challenging and joyful developments of the Technology Management Program – which is probably the best education program in the world – and is now destined to become even better! Maria, thanks for all the hours of proof-reading.

To my mother and father; I am grateful for your endless support. Mum - I would like to send my greatest gratitude for the support you have given, during the tough times we have gone through. In comparison to the challenges you have been confronted with and gone through, this research process pales into insignificance. I hope that I can provide you with the support you need and be a source of joy, fun, trust and whatever you may need. And Ingvar, my “big brother,” you have always given me lot of encouragement and attention, thank you.

Josefine, my darling and the love of my life, you have been a great, understanding, supporting, encouraging, listening girlfriend (the type I did not believe existed) during this escalating research journey. Thank you for being such an amazing woman. I have some wash-ups to do…☺

Finally, there are several other inspiring people who have contributed in some way or another during this research journey. Peter Allen, Sten Wandel, Vince Darley, Dick Sanders, Kurt Richardson, Nina Modig, Pehr-Ola Persson, Kenth Lumsdén… and all the others whose names I might not come up with; I sincerely apologize for that but I still thank you all.

Lund, April 2005

Fredrik Nilsson

Abstract

Background: Logistics is gaining increased attention in companies since interconnectivity is increasing, and the interdependence among actors is enhanced due to challenges organizations are facing today. These can be characterized by market changes, novel strategies, and technological improvements. While the logistics discipline has been characterized by an efficiency focus based on positivistic assumptions, the challenges of today require a focus on effectiveness i.e. adaptive logistics based on extended assumptions. In order to move towards adaptability in logistics research and management it is argued in this thesis that theories, approaches and methods developed by researchers and provided for practitioners, must be able to consider and treat more complex conditions. As firms are becoming more complex themselves in their relationships with suppliers and customers, and there is increased turbulence facing almost all industries, this complexity needs to be taken into consideration by logistics researchers and practitioners in order to increase their understanding, and for the sense-making of logistics phenomena.

Purpose: *The purpose of the thesis is to contribute to the further development of logistics research and practice by exploring, from a complexity perspective, how increased adaptation can enhance logistics effectiveness.*

Method: In order to gain knowledge and understanding of how a complexity perspective could impact logistics, philosophically, theoretically, and pragmatically, several methods have been used. Through extensive literature reviews from several disciplines, insights into where the logistics discipline stands today and what type of underlying assumptions dominate the discipline were gained. In order to understand logistics in its “real” empirical setting, a topical study entitled “real logistics” was performed, in which logistics practitioners were interviewed with a grounded theory-inspired

approach. Case studies have also been performed, focusing on issues of effectiveness, and in exploration of how a complexity perspective would provide "better" explanations for making logistics operations more effective. Furthermore, for me to be able provide the logistics discipline with an approach which is "proven" to be applicable and where "operationalization" of the complexity perspective could be achieved, combined case and simulation studies have been performed.

Conclusions: It is the firm conclusion that adaptive logistics is not a concept separated from human-mind and involvement, instead it is a transformative concept realized in the individual and collective sense-making processes guided by assumptions related to both filters. Hence, in order to move towards adaptive logistics it is the conclusion that this is a process involving reflections on assumptions and their impacts on logistics phenomena and processes, and operationalization of a new way of thinking through sense-making methods with close connection to the perceived contexts in question. For the reflective part, theoretical frameworks are needed, which are in line with assumptions similar to real-life experience by managers i.e. of a less mechanical character, with emphasis on the extended assumptions comprised in the complexity perspective. Secondly, in order to operationalize a different way of thinking and acting i.e. change mind-sets to embrace more complex considerations, and provide tangible results in a reasonable time period, it has been concluded that agent-based modeling provides a feasible and applicable method and tool.

Keywords: complexity thinking, complexity theory, epistemology, logistics, logistics systems, paradigm

Sammanfattning

Såväl logistikforskning som tillämpning har länge fokuserat på kostnadssänkning, produktivitet och rationaliseringar, alltså på att ”göra saker rätt” (inre effektivitet). Då logistik ökar i strategisk betydelse inom och mellan företag, ökar också betydelsen av att inte bara *göra saker rätt* utan att ”göra rätt saker,” dvs. yttre effektivitet. De större drivkrafterna som idag påverkar detta ökade intresse för logistik kan relateras till växande kundkrav och ökad konkurrens i vår allt mer globaliserade värld. Samtidigt växer strategier fram såsom fokus på kärnkompetens, ”outsourcing” av funktioner som inte kan ses tillhöra ”kärnan”, fokus på kundspecifika produkter, ökad leveransprecision, nya servicerelaterade aktiviteter, leverantörsnätverksstrategier, tillsammans med koncept såsom ”agile-” och ”lean-” logistik. Vidare har teknologiutvecklingen skapat nya möjligheter för logistiken, såsom Internet, autoidentifieringstekniker, affärssystem. Dessa aspekter (ökade kundkrav/konkurrens, nya strategier och teknologiska utvecklingar) talar för en mer komplex situation som både forskare och praktiker går till mötes. För företag som möter denna stigande komplexitet och samtidigt vill vara konkurrenskraftiga, blir det allt viktigare att satsa på yttre effektivitet än att fortsätta med fokus på inre effektivitet dvs. kostnadssänkningar, rationaliseringar, och förenklingar.

I denna avhandling förordas behovet av nya teorier, angreppssätt och metoder för att kunna öka företags yttre logistiska effektivitet. Dessa skall vara utvecklade och implementerade i verkliga logistiska situationer och inte härledda från naturvetenskap. Då logistikforskningen bygger på positivistiska antaganden såsom linearitet, enkelhet, reduktionism, styrning och kontroll, jämvikt och stabilitet, krävs det förändringar relaterade till dessa antaganden för att yttre effektivitet ska kunna realiseras. Följaktligen föreslås det i denna avhandling att forskares och praktikers inställning och mentalitet till logistik behöver förändras. Denna förändring ska kunna uppnås genom omvärdering av de underliggande antaganden (nämnda ovan) som dominerar logistiskområdet.

Fokus för denna avhandling är att göra logistik mer adaptiv och därigenom öka yttre effektivhet inom logistisk. Begreppet adaptivitet är hämtat ur komplexitetsteorin,

speciellt ur teorierna om komplexa adaptiva system. I denna avhandling definieras adaptiv logistik som: *reaktiva och pro-aktiva aktiviteter och åtgärder som har målsättningen att hantera upplevda avvikelser och störningar samt fokuserade på att öka yttre effektivitet inom logistisk.*

Denna bakgrund leder till följande syfte:
Syftet med denna avhandling är att bidra till den fortsatta utvecklingen av forskning och tillämpning av logistik. Detta genom att utforska, från ett komplexitetsperspektiv, hur ökad adaptivitet kan öka den yttre effektiviteten inom logistik.

Detta syfte är konkretiserat i två mål: dels framtagandet av ett konceptuellt och teoretiskt ramverk för forskning och tillämpning av adaptiv logistisk, är influerat av komplexitetsteorier. Dels i definierandet och utvecklandet av en operationaliserande metod för att realisera av ramverket och därmed adaptiv logistik.

Metodmässigt bygger forskningen på ett flertal metoder. En omfattande litteraturstudie har gjorts inom områdena: logistik, tillverkning, strategi, organisation, komplexitet, kaos, och filosofi. Där till har en ämnesstudie genomförts, vars arbetsnamn var ”Verklig logistik”. I studien har 14 logistikchefer intervjuats om deras dagliga uppgifter, problem, framtidstankar och problem. Två fallstudier har också genomförts varav den senare är en kombination av en fallstudie och en simuleringsstudie. I dessa fallstudier har företagens interna logistikflöden analyserats med hjälp av en simuleringsmetod, agentbaserad modellering, tillsammans med insikter från komplexitetsteorin. Studierna har varit lyckosamma och visat påtagliga resultat för inblandade aktörer.

Det första målet har uppnåtts genom att komplexitetsramverket för adaptiv logistik tagits fram. Detta ramverk bygger på att identifierade underliggande antaganden till logistikområdet utökas med ett antal antaganden, som tillhör ett komplexitetsperspektiv. Exempelvis antas olinearitet, självorganisation, upp-kommande fenomen, subjektivitet, begränsad rationalitet. Då dessa antaganden bättre speglar den verklighet som logistiker upplever kan fokus på dessa underlätta, och skapa mening för inblandade aktörer i olika logistiska sammanhang.

Det andra (operationaliserande) målet har uppnåtts genom användandet av agentbaserad modellering (ABM) som är delvis utvecklat inom artificiell intelligens och objektorienterad programmering, och delvis från insikter ur komplexitetsteori. ABM består av ”mjukvaru-agenter” som avspeglar någon verklig process eller aktivitet. Genom att sammankoppla de ”viktiga” delarna får man simuleringar från vilka man kan skapa scenario, intressanta för de deltagande aktörerna. När agenterna samverkar, uppkommer mönster som dels går att verifiera mot övergripande data, men som framförallt kan ge förståelse för vilka effekter man kan vänta sig av små eller stora förändringar i, till exempel, handlingsprogram eller beslutsprocesser. Vad som är av ännu större vikt ur ett adaptivt logistiskt perspektiv är de samtal detta möjliggör för de aktiva, deltagande aktörerna. Detta kan ligga till grund för förändringsprocesser och förståelse för hur saker och ting upplevs fungera. Två företagsrelaterade fall är presenterade i avhandlingen där dessa aspekter lyfts fram.

Den övergripande slutsatsen från detta arbete är att adaptiv logistik inte är ett koncept i klassisk bemärkelse som går att beskriva i en modell eller i normativa termer. Istället är adaptiv logistik något som realiseras genom omvärderanden av antaganden ur komplexitetsramverket i de transformerande processer som uppstår i kommunikationen mellan deltagande aktörer. ABM är i detta sammanhang ett stöd då det ger insikter, baserat på en relativt hög kompliceringsgrad och utifrån detaljerade agenter, om hur olika delar av logistiska processer kan påverka varandra. I ABM kan några av de utökade antaganden tas med relativt enkelt och på så sätt vara med i den avbildning som ges (exempelvis olinearitet, uppkommande fenomen, begränsad rationalitet, heterogenitet).

Konklusionen är att komplexitetsramverket för adaptiv logistik, där ABM är ett hjälpmedel i förändringsprocessen, kan hjälpa logistiker att prioritera mellan olika insatser och därmed bidra till ökad effektivitet. Vidare är det också slutsatsen att komplexitetsramverket öppnar upp för nya frågor att adressera inom logistikområdet, framförallt rörande situationer där människor och mänskligt beteende är av största vikt, både ur ett värdeskapande perspektiv, såväl som ur ett osäkerhetsperspektiv.

Table of contents

Part III

Part IV

Part V

1 Introduction

Great advances have been made in the field of logistics during the last few decades. Improvements in efficiency and effectiveness have been demonstrated and recognized in all logistics-related areas i.e. outbound transportation, intra-company transportation, warehousing, inbound transport, materials handling, and inventory control. Nonetheless, the majority of these efforts have been focused on efficiency-related efforts; optimality, prediction, planning and control i.e. on reducing uncertainty and complexity in logistics. One apparent explanation for this is the fact that logistics has not been regarded as a strategic issue until the last decade (Kent Jr & Flint 1997; Mentzer, Min, & Bobbitt 2004; Stock, Greis, & Kasarda 1999) which has identified logistics as a mere cost-reducing activity within firms. However, as logistics gains strategic importance, the dimension of effectiveness is becoming increasingly apparent and vital (Kohn & McGinnis 1997). In this thesis efficiency will be defined, in accordance with Porter's (1996) definition, as *doing things right*, while effectiveness will be defined as *doing the right things.* And since *"efficiency is related to resource expenditure necessary to achieve logistical effectiveness,"* (Bowersox & Closs 1996 p.47) there are many costs involved in doing the wrong things right. Kohn & McGinnies (1997 p.54) describe two dimensions of logistics strategy that they found in all organizations, represented in a study they performed. "*One is an integrated orientation that seeks simultaneously to manage logistics flows, coordination, and complexity within the organization and with its external constituencies. The other is a process orientation that seeks efficiency, control, and cost reduction."* The first dimension is that of effectiveness, while the second is the efficiency dimension.

Nonetheless, the efficiency-focused approach has been successful in logistics for many years and has worked relatively well in what have been, from today's perspective, quite stable markets with minimal global exposure, relatively long product life cycles and with slow information and communication capacities. While this description was an illustration of the past, today the situation is different and we can say with great certainty that the situation of tomorrow will be slightly different if not radically different. Some of the challenges organizations are facing today can be characterized by market changes, novel strategies, and technological improvements. These are listed below:

- **Market changes**
  - *Increased customer/consumer demands.* There is a trend in industry that the requirements and demands from customers are increasing in scope (Caridi & Cigolini 2002; Flint & Mentzer 2000; Kehoe & Boughton 2001). Not only are demands on time, cost and quality (of products) in focus, but additional services (Bovet & Martha 2001), environmental issues, and ethical questions have become more important in the customer/consumer arena. At the same time, the demands from customers in terms of customization and service are increasing. Today, the value propositions for companies are shifting toward adding service dimensions that, in addition to the product features required, give the customer accessibility to the product based on the customer's demands and requirements. While time, cost and even quality can, in principle be quite easily quantified and made to fit into the realm of mathematics, the service dimension, as well as those of environment and ethics, is far more difficult to quantify under deterministic and mathematical conditions. The current dilemma is that posed by the tasks of balancing efforts in doing the right things for customers/consumers, and doing things "mathematically" right.
  - *Increased competition.* In order to meet increased demand from customers, firms add extra services to their products. At the same time, this invites new firms to challenge existing ones when the barriers for entry into the market are lowered. Meeting expectations and demands is a qualifier but the real order winners are when these demands are exceeded. Is the reality this then: that even though the trend is shifting towards a customer/consumer pull philosophy, technology push will still be the joker in exceeding expectations?
  - *Globalization.* In some ways distance is no longer a barrier while emerging markets give firms new opportunities to lower costs etc.

Globalization provides new opportunities in the way resources and assets can be shared worldwide and targeted in more dynamical ways. Mentzer, Min, and Bobbitt (2004 p.613) state that "*the more global the competition in an industry, the more critical logistics capabilities are to firm success.*" Thus, globalization brings a new set of requirements on and challenges to several business activities such as transportation, packaging etc. In this regard, Vidal and Goetschalckx (2000 p.95) state that decisions related to global logistics operations "*are not easy decisions, especially at the international level, where exchange rates, duties, transfer prices, taxes, cash flow, information flow, trade barriers, and government regulations constitute complicating factors, along with such traditional engineering factors as cost, capacity, and timeliness.*" Is it possible, as tradition would have it, to gain control over global processes and activities, or do we need novel ways to both understand and handle the phenomenon of globalization?

- **Novel strategies**
  - *Customization.* This represents a specific way to satisfy customer demands regarding time, cost and quality (traditional logistics) on the one hand, and service on the other. This trend might imply that a wider spectrum of products, activities etc. is the result companies are facing, thereby increasing variety. Is the logistics paradigm ready to confront such reality or will it be the limiting and reducing aspect in tomorrow's competition?
  - *Core competence/activity focus – outsourcing.* One major trend in the majority of industries today is the emphasis on retaining core activities and letting someone else do the rest. This was also Henry Ford's policy, albeit on a smaller scale; car production was best achieved if each worker along the line was specialized in his/her task(s). Today the trend is similar, at least in theory, when companies specialize in specific parts of the 'controlled line'. Bovet and Martha (2001 p.236) emphasize this and state, "*outsourced relationships provide efficiency, as each player*

specializes in its own métier”. In other words, outsourcing ensures that a new ’controlled line‘ is created, although on a larger scale (Nilsson & Wallin 2002). However, the outsourcing process might cause the outsourced activity to lose its previously strong connection with other internal activities, resulting in poorer overall business performance (Doig et al. 2001). One question facing any outsourcing decision maker is how to know if it is the right thing to outsource in order to gain efficiency?

- *Supply/demand chain/network management.* Due to increased competition in several industries, the literature available predicts that future competition will be between supply chains, or better described supply networks, rather than between individual companies (Christopher 1998; Cox 1999a; Kehoe & Boughton 2001; Lambert, Cooper, & Pagh 1998; Lee, Padmanabhan, & Whang 1997b; Souza, Zice, & Chaoyang 2000; Walters 2004). The network in which firms are involved will be the source of competitive advantage (Gulati, Nohria, & Zaheer 2000; Kogut 2000). Consequently, the logistics capabilities for a specific firm will then lie in the relationships it has with other firms in its business context. Stock, Greis, and Kasarda (1999 p.38) emphasize that *“in this new competitive environment, logistics must be accorded a high strategic priority and cannot be viewed merely as a cost of doing business.”* While future competition will be between supply networks, the question is if these are just a new name for “big companies” or do they represent a new and different business paradigm?

- *Lean production/logistics.* Increased leanness has resulted in more cost-efficient flows in both production and logistics, however, it has also increased companies’ vulnerability to disturbances. Svensson (2003 p.765) states, for example, that *“the dependence between the companies’ inventories and disturbance in inbound and outbound logistics flows has become substantially higher due to the implementation of lean supply chains.”* How lean can logistics become and at what price?

- *Agility*. This being a rather novel concept in logistics which have been given a considerable amount of attention (Narasimhan & Das 1999; Naylor, Naim, & Berry 1999; Prater, Biehl, & Smith 2001; Weber 2002). Shankar (2001 p.81) states, for instance, that *"in the future, reducing costs and increasing revenues will depend on the ability to react seamlessly and quickly to customer needs and adjust procurement, production, inventory, transportation, and customer service systems accordingly."* However, as Prater, Biehl, and Smith (2001 p.827) state, *"the introduction of factors that increase supply chain agility may increase supply chain uncertainty and complexity."* Does agility imply new business logic or is it just a quick response to handle increasing demands i.e. the same as usual but faster?

- **Improved technologies**

  - This dimension impacts the competitive market place by giving the opportunity for firms to increase their adaptability through real-time updated information (Hale 1999), and since logistics is often technology driven (Mentzer, Min, & Bobbitt 2004) the dimension of new information and other technological innovations will certainly impact the competitive arena. However, is there a limit to this increased flow of information? Can it lead to a situation where the information is stored somewhere but it has reached information overflow from a people perspective? Furthermore, while computer systems are being instantly updated with data and information, how can the people who are supposed to receive and/or access the information and interpret it, be continually updated?

    - Internet and electronic commerce. Shim et al. (2002 p.113) state that *"in the 21st century, the Internet, the web, and telecommunication technology can be expected to result in organizational environments that will be increasingly more global, complex and connected. … a radically different thinking is required; … thinking that must include consideration of much* *broader cultural, organizational, personal, ethical and aesthetic factors."*

- Enterprise resource systems. Kehoe and Boughton (2001 p. 585) state that *"the variety of manufacturing planning and control systems in operation across any one supply chain adds complexity to the efficient flow of information."*
- RFID[1] and other auto-ID technology. McFarlane and Sheffi (2003) state that more advanced auto-ID technologies (such as RFID) represent a major opportunity to improve traceability in supply chains. Furthermore, Hellström (2004 p.93) states that *"RFID technology in packaging is a new phenomenon and companies, …, might not fully realize the potential of the technology."*

Putting all these aspects together, i.e. those of market changes, novel strategies and improved technologies, the potential of increased complexity might be regarded as an undesirable but still highly noticeable consequence of these aspects and others. These challenging aspects are all interdependent and interwoven since novel or improved technologies can revolutionize some of the strategies used in conforming to customers and create new customer requirements and vice versa.

In this increased complexity, due to the predominance of positivistic assumptions underlying the logistics discipline[2], such complexity should, by means of reductionistic principles, be decomposed into simplified and controllable units, and the goal would be to eliminate it in the longer perspective (Lewis & Suchan 2003). For example, Lambert and Cooper (2000 p.72) state: *"controlling uncertainty in customer demand, manufacturing processes, and supplier performance are critical to effective supply chain management."* However, this increased complexity, viewed

[1] Radio Frequency IDentification

[2] There are several authors who declare that the logistics discipline relies first and foremost on a positivistic or post-positivistic-oriented epistemology, for example Mentzer and Kahn (1995), Gammelgaard (2004). A further developed discussion can be found in paper one (see appendix one) and in Nilsson (2003).

through another set of glasses, may bring great opportunities for logistics improvements and innovations. The choice is, and will be, in *"the eye of the beholder"* i.e. the researcher or manager trying to make the best of the present and future situations.

Both logistics researchers and practitioners certainly agree that the description above concerning the challenges organizations are facing, is influencing the logistics discipline and at least making the situation perceived more complicated if not more complex. Before going further an explanation of the distinction of complicated vs. complex may help the reader through this thesis. Complicated can be defined as "*something that is difficult to deal with or understand"* (Cambridge International Dictionary of English). The word complex can be defined as *"not easy to analyze or understand"* (New English Oxford Dictionary); *"consisting of interconnected or interwoven parts*" (in Bar-Yam 2001), or *"involving a lot of different but related parts"* (Cambridge International Dictionary of English). While these two concepts from a lexicographical standpoint seem to be quite similar in meaning, the following distinction will be made in this thesis in accordance with how Allen (2000b p.79) addresses the issue of why situations or phenomena are hard to understand or analyze:

1. *Either the situation considered contains an enormous number of interacting elements making calculation extremely hard work, although all the interactions are known.*
2. *Or the nonlinear interactions between the components mean that bifurcation and choice exist within the situation, leading to the possibility of multiple futures and creative/surprising responses.*

In this thesis the first alternative will be referred to as a complicated situation, while the second will be defined as a complex situation. A complicated process or phenomenon can be decomposed and reduced into solvable parts and therefore it follows that with such an ontological standpoint the positivistic paradigm prevails. Thus, the quest is to unfold or find real interactions, and then optimal solutions can be provided. On the other hand, a complex process or phenomenon involves paradoxes involving both time and identity based on human perception, interpretation, and action. Furthermore, when dealing such processes or phenomena, there are no aspirations to find optimal configurations, only transformative changes into emerging situations and contexts.

This apparent difference in how a situation or a phenomenon is perceived i.e. as complicated or complex, may have major consequences for how logistics issues are approached and dealt with. The apparent consequence of regarding logistics phenomena as complicated is that the researcher's or practitioner's mind-set is focused on the fact that the problem or situation in question can be handled by reducing problems to solvable units, and by using mechanistic assumptions of how the parts work and are connected. With such an epistemological assumption in mind, *"better management is often seen as simply running the "machine" faster or more efficiently"* (Allen 2000a p.1). For example, Chen and Wang (1997 p.606) conclude in the context of large scale steel production that *"cross-functional operations can be optimized and overall optimality can be obtained."*

In contrast to the positivistic and mechanical assumptions that underlie the dominant planning- and control-focused efficiency paradigm, the perceived reality in real-life logistics contexts today is filled with unforeseen events, different perceptions, changing market demands and expectations, accidents, breakdowns, irregularities etc. Consider the following comment made by a manager of a leading automobile manufacturer:

> *"A few years ago, our engineers mapped a supply chain of a small assembly [by] tracing it all the way back to the mine. From that exercise, we demonstrated the benefits of supply chain management, and we set out to manage the supply chain as a system. Frankly, we have not been able to do it. The problem was, as soon as we came up with a strategy for managing the chain, the chain changed on us – we got new suppliers and new relationship configurations. It took a lot of effort to map one supply chain, and we could not possibly map it every time something changed"* (Choi, Dooley, & Rungtusanatham 2001 p.352).

And, as Robertson (2003 p.61) states *"if the business world is viewed as being complex, it is inappropriate to consider models developed under paradigms of* *equilibrium, stability, and linearity to produce an analysis of a turbulent environment."*

> **Thus, in this thesis it is proposed that in order to improve logistics effectiveness new theories, approaches and methods need to be developed and executed in the real-life context.**

It is important here to dispel the notion that efforts in efficiency-enhancing philosophies through planning and control are not valuable. These approaches and methods are, and will be, valuable in some situations and in some contexts, however, in logistics research and practice there is a need to rethink the situations and the contexts where mechanistic assumptions are really valuable.

However, this change of theories, approaches and methods might not be enough in efforts to enhance the effectiveness in logistics. The major reason relies on the fact that the dominant thinking in logistics research predominantly relies on a set of positivistic and mechanistic assumptions. Lewis and Suchan (2003, p.312) state that *"examining the language in the published research …, it becomes clear that the dominant or root metaphor of logistics researchers is the organization as a machine and its members as rational actors."* Additionally, as a result of the former it follows that what is taught in logistics education programs and MBAs is in line with the dominant thoughts in the discipline i.e. positivistic and mechanistic. As Kehoe and Boughton (2001 p.587) state, concerning new paradigms in planning and control across manufacturing supply chains, *"although organizations will need to fundamentally change the way they do business, the barriers lie with the business processes rather than the technology."* Mears-Young and Jackson (1997) claim that it might be useful and beneficial for logistics researchers to be more self-reflective about what foundations the methods and provided solutions stand on and the implications this implies.

> **Consequently, in this thesis it is proposed that a change in the mind-set of logistics researchers and practitioners is needed. This will be achieved**

through a reassessment of the dominant mechanistic and positivistic assumptions that most logistics theories, approaches and methods are derived from and rely upon today, in order to increase logistics effectiveness.

The issue of mind-set is highlighted by Christopher and Towill (2001 p.236) when they discuss agility as a novel way to handle volatile demand and uncertainty in supply chains. They state that *"agility is a business-wide capability that embraces organizational structures, information systems, logistics processes and in particular, mindsets."* While the article mentions the aspect of mind-set, it provides no further discussion on what the issue of mind-set means for logistics or supply chain management. Rather the authors' focus is set on the more tangible aspects related to information systems and logistics processes. What is proposed in this thesis is that by not considering a shift in mind-set effectiveness, the potentials of improvement efforts are heavily reduced. It is important at this stage to point out that the research described here does not propose to replace existing systems with yet another new suite but seeks to establish an enhanced way of both researching and managing logistics operations.

Since management of logistics is, to some extent, similar to other kinds of management there are of course similarities in how different types of problems are being treated. However, logistics is by nature a discipline where a mechanistic approach has been successful since the major benefits firms exhibit from logistics are time and place utility of products (Bowersox & Closs 1996; Christopher 1998). Bowersox and Closs (1996 p.25) state that "*the basic proposition is that regardless of size and complexity, logistical systems can best be understood and designed in terms of performance-cycle structure and dynamics."* Dynamics which relates to time can easily be divided into time intervals and measured quite easily. Logistics structure, which can be seen as related to a spatial dimension, is also rather easy to divide into separate units of both measurement and activities. There is, for example, a measurable distance from Copenhagen to Stockholm. Both measurements of time and distance are of an objective character and fit easily into a paradigm based on positivistic beliefs. Axelrod and Cohen provide a good explanation for the success of the mechanical approach when they state: *"No doubt, machines and hierarchies provide easier metaphors to use than markets and gene pools. So it is no wonder that most people are still more comfortable thinking about organizations in fixed, mechanical terms rather than in adaptive, decentralized terms"* (2000 p.29). Van Ackere, Larsen and Morecroft (1993 p.413) exemplify the mechanically and positivistically influenced approach by stating; *"We are all used to the idea that automobiles, ships, aircrafts, office buildings and bridges need careful design to achieve their purpose. But there is much less awareness that business organizations too are 'designable'."*

There are, of course, several logistics operations taking place in supply networks i.e. operations related to time and place, that under certain circumstances can possibly be simplified on an aggregated level into mechanical terms. However, while logistics managers and practitioners are of the opinion that today's common logistics concepts, methods and tools have made it possible to control and monitor a great number of factors within and among firms, they are confronted by the difficulty of understanding and acting when things happen that are of an "unusual" character. This means that priorities are to be made between different improvement efforts and decisions are needed to be made instantly (appended paper three). Furthermore, while technological improvements have made everyday work easier when nothing unusual or new happens, they have made life more difficult when such things do happen (ibid.). A logistics manager at a global retail company expressed it as follows:

> *"the situation is becoming more complex due to tighter margins, rationalization efforts, and increased cost efficiency demands. At the same time support systems are becoming more complex and since they are highly integrated and detailed it has become more and more difficult to get a holistic view and when something happens it is very difficult to understand what caused it to happen or where the outcome of it will have effects."*

Thus, in order to meet the challenges from increasing market changes, novel strategies and improved technologies, logistics efforts should increase their focus on doing the right things i.e. on effectiveness. The great emphasis for efficiency has led to focus on cost reductions. Walters (2004 p.227) states that *"not only is this* [focus on cost-led efficiency] *constraining, but also it has to be shown not to be in the shareholders' interests: cost reductions typically have a negative impact on customer service and this, in turn, has the same impact on revenues."* As several researchers have stated, logistics capabilities are a source of competitive advantage when taken beyond the efficiency function (Bowersox, Closs, & Stank 1999; Lynch, Keller, & Ozment 2000; Mentzer, Min, & Bobbitt 2004; Morash, Dröge, & Vickery 1996). In addition, the emphasis on efficiency in lean logistics thinking has set out to reduce any "waste" to be found. In the lean process, redundancy in logistics processes has been seen as "waste" and as such should be eliminated. Consequently, this has led to more vulnerable logistics processes and supply chains. The leaner and more interconnected supply chains become, the more likely unforeseeable events, dynamic effects, mistakes or accidents in one part affect the other parts in the chain. And as Weir (2004 p.529) states *"the point is not whether these events should happen or whether they happen frequently or rarely. The point is that they do happen."* In other words, there is a need for approaches and methods with a focus on the unforeseeable which cause situations that may be devastating for business i.e. making logistics more adaptive. With an effectiveness perspective on leanness, dominating reductionstic philosophies may be rethought and some redundancy in logistics processes seen as useful. Moreover, as Weir (2004 p.524) declares *"redundancy in complex systems that apparently permit inefficiency may also be the source of adaptation and learning."* While focusing on effectiveness may in the short term lead to decreased efficiency, a more adaptive logistics capability has the potential of increasing effectiveness.

Another aspect in regard to the effectiveness of logistics is the fact that while managers consider it quite easy to find several processes and activities that can be improved i.e. made more efficient, it is far more difficult, and therefore more interesting, to understand how activities and processes affect each other and to know where the increased leverage can be found. It might not always be the most obvious or the most intuitively correct decisions which create the best outcome of the efforts put into a situation or improvement effort. Thus, the effectiveness dimension distinguishes itself from the traditional, efficiency perspective through its focus on the relationships and the connectivity of a number of interdependent heterogeneous resources and activities related to a firm or a supply chain and the prioritization of the resources and activities. Furthermore, emphasis on effectiveness focuses on the need of both researcher and practitioners to gain an understanding of the correlation between processes and activities interwoven in the situations and contexts being addressed. From this understanding a potential of how things can be done differently is realized. Additionally, an emphasis on effectiveness and adaptation also addresses the issues of non-linearity since research proves over and over again that small changes in parts of a system create sometimes huge changes in other parts and sometimes no changes at all. These are two areas of great importance for the effectiveness dimension.

1.1 Topic of interest

The main topic of interest in this thesis is the process of making logistics operations/processes more adaptive and effective. The concept of adaptation is derived from the complexity theory, especially from complex adaptive systems theories. The theories on adaptation from the science of complexity are mainly derived from biological and ecological contexts i.e. involving non-human populations, where the adaptation has been defined as adjustments to environmental changes (Kauffman 1995). This notion may not always be applicable to human beings since our self-consciousness and our intentions add dimensions to our behavior where human beings are anticipating the future differently from other living organisms (Checkland 1993). However, complex adaptive systems theories provide a solid foundation for living organisms since they rely on organic assumptions i.e. less mechanical and positivistic assumptions. Furthermore, while the majority of research on complex adaptive systems is within natural science, there is a growing research population which applies complexity thoughts to organizations and other social phenomena[3]. A further discussion of complexity theory can be found in chapter ten

[3] The complexity theory has been used to understand and explain phenomena such as knowledge management (McElroy 2000; Stacey 2001), organization science (Anderson 1999; Lewin 1999; Lewin & Regine 2000) strategy (Beinhocker 1999; Pascale 1999; Tasaka 1999), and manufacturing strategy (McCarthy 2004), mergers and acquisitions (Allen, Ramlogan, & Randles 2002) to mention but a few.

and a more thorough description and discussion of complex adaptive systems are provided in my licentiate thesis (Nilsson 2003).

The use of the concept of adaptation in this thesis is contextualized to human and human organizational settings. Furthermore, it is in line with the denotation Axelrod and Cohen (2000) make; namely that activities and actions aimed at, or that may lead to, improvement by some means i.e. they are of a nondeterministic character since the performers have no knowledge concerning the real impact in the future, are considered adaptive. In other words, adaptive logistics involves both reactivity and pro-activity in terms of improvement efforts based on individual decisions and actions, aimed at managing perceived disturbances and deviations, and increasing logistics effectiveness. This leads to the following definition of adaptive logistics

> *The reactive and proactive activities and actions aimed at managing perceived deviations and disturbances, and increasing logistics effectiveness.*

In order to move towards adaptability in logistics research and management it is argued in this thesis that theories, approaches and methods developed by researchers and provided for practitioners, must be able to consider and treat more complex conditions. As firms are themselves becoming more multifaceted as their relationships with suppliers and customers are, together with the increased turbulence facing almost all industries, the complexity facing logisticians is a fact. This complexity needs to be considered when approaching logistics processes and phenomena in order to increase understanding and for the sense-making of logistics phenomena. Furthermore, a focus on adaptability may help firms to increase their ability to handle perceived deviations and disturbances but also to increase their understanding of what type of conditions are necessary to increase logistics effectiveness. However, for such changes to be made the shift in mind-set for researchers as well as practitioners is regarded as crucial.

1.2 Research questions

In order for a shift in mind-set the following questions need to be addressed, and several assumptions in regard to these needs to be reassessed in the logistics context:

- How are logistics phenomena being regarded in theory and practice? As complicated or complex?

This question has an ontological dimension since it relates to how the world is perceived. Our ontological stance has direct consequences for the way we approach and deal with logistics knowledge creation i.e. our epistemological considerations. It follows therefore that, while researchers and practitioners agree that logistics issues and phenomena are complex or at least complicated, the ensuing problem is then what assumptions we make in order to deal with this complexity. In other words, if the complexity can, relatively easily (i.e. with enough resources and time) be reduced into manageable linear approximations which can be put into planning and control systems, which in turn rely on refined measurements of objective facts about chosen areas of business performance. In this case the epistemology is based on ontology where the issues and phenomena are of a more or less complicated nature i.e. positivistically oriented. Another ontological and epistemological stance is that the complexity of logistics issues and phenomena has to be interpreted with an extended set of assumptions which are built on the beliefs of that we can only understand a part of any larger phenomenon and only impact certain aspects observable or defined for the phenomenon in question, without knowing exactly what the consequences will be, that is doing our best with respect to the overall complexity that confronts us. Furthermore, the phenomena are characterized by several paradoxes which are the realm of our daily efforts and that means that as time goes by our identities change in transformative ways. In my licentiate thesis (Nilsson 2003) it was concluded that when applying a complexity perspective to logistics several phenomena can be identified rather easily in logistics practice i.e. in real-life logistics, but these are not being addressed or treated in the current logistics literature. Phenomena such as emergence, coevolution, and self-organization are not treated at all. Furthermore, non-linearity, heterogeneity and bounded rationality are addressed in some cases but when used are simplified to fit into technical systems i.e. they are put in simplified models which are comprehended by means of mechanistic assumptions and can therefore be validated mathematically. The distance between reality and the theories and models is therefore quite great and the question is:

- If logistics phenomena are regarded as complex, what implications does that have on the knowledge produced, the methods used and developed to improve and explain logistics, the approaches applied, and the tools used to aid logistics researchers and practitioners?

The ontological and epistemological assumptions are prerequisites for the methodological and method-related assumptions and choices which are being made (Burrel & Morgan 1979; Morgan 1983). Consequently, starting out from this paradigmatic discussion about assumptions has direct implications for the approaches, methods and tools to be pragmatically used when a more complex paradigmatic view lies as the foundation. This raises the following questions:

- How can this new complexity-inspired mind-set be “operationalized”?

- What type of novel approaches can support and help logistics decision-makers in generating increased effectiveness i.e. gaining most leverage in their improvement efforts?

- In addition, what type of approaches, methods and tools can be used to deal with perceived unscheduled dynamics i.e. everyday changes?

1.3 Purpose

> *The purpose of the thesis is to contribute to the further development of logistics research and practice by exploring, from a complexity perspective, how increased adaptation can enhance logistics effectiveness.*

While this is the overall purpose of the thesis, it is rendered concrete in the two objectives presented below.

> *Objective one: To develop a conceptual and theoretical framework for logistics research and practice with focus on logistics adaptation and effectiveness influenced by theories of complexity.*

However, while insights from complexity theory provide increased understanding of logistics processes and a helpful framework for modeling, in order to motivate logistics researchers and managers and implement such an approach into tangible and understandable results some kind of method is needed. The reason for a method is that my research has pointed to needs being identified for managers to be able to evaluate different scenarios of the behaviors of their organizations, simulate policy changes or change in control mechanisms in order to understand and even consider a new way of thinking.

> *Objective two: Define and develop a methodology which can guide and aid the operationalization of the complexity framework in logistics.*

1.4 Research justification

Logistics is being given increased attention in companies and in research and, as stated above, is gaining strategic importance as supply chains or, more aptly named, supply networks are the realm of today. The majority of research produced is nevertheless positivistically influenced and what are mostly used by logistics practitioners and taught to managers on educational programs are simplified, normative models based on mechanistic principles. Nonetheless, as Gammelgaard (2004 p.484) declares *"the use of alternatives to positivism should at least be investigated in logistics research"* and Arlbjørn and Halldorsson (2002 p.22) question this single paradigm of positivism by stating: *"if we take this view for granted, we may produce a unilateral view of logistics knowledge that only focuses on objective and observable phenomena."* Stock (1990; 1997) and McGinnis, Boltic and Kochunny (1994) argue that logistics researchers should study and consider other disciplines to determine whether developments within the logistics field constitute progress. Stock (1990 p.6) explains that logistics needs to be seen more holistically and he states that *"current academicians and practitioners will have to see themselves as change agents and work to break apart the provincialism of traditional logistics."* However, while there are researchers who suggest new paradigms to be explored and used in the logistics discipline, others claim that such efforts are less valuable and, on the contrary, troublesome especially for the pragmatic part of logistics. One reviewer comments on appended paper one (see Part V) *"Let researchers go on with such discussions as long as they like, but let logistics managers live on with the positivistic paradigm of reality!"*

Nonetheless, there might be several reasons for such diverging arguments and numerous arguments about why and how further development of the logistics discipline should proceed. Dooley and Van de Ven (1999 p.369) propose four reasons for why organizational scientists have not included more complex and non-linear dynamic models when researching on organizational change. Since logistics is performed in both intra- and inter-organizational contexts the reasons might also apply to the logistics discipline.

- *First, cognizance of more complex behavior, different from both linear behavior and white noise, is relatively new …. It will take some time for these ideas to disseminate into the operational range of actual theory development.*

This might be referred to as inertia for change. In the organizations I have been involved with, one of the major reasons for the way certain processes or activities were performed was based, after some reflection, on the fact that the rationale for how some activities was performed was based on tradition i.e. how people had done it for many years. This might be the same for the logistics discipline as a whole. As Kuhn (1996) argues, researchers entering a discipline, and thereby a research paradigm, are often compelled to use the common terminology, norms and beliefs provided by people e.g. professors, managers, colleagues etc. already within the discipline. However, as Näslund (2002 p.327) states; *"An interesting question is: if researchers within a certain academic discipline do the same kind of research as everyone else within the discipline then how useful will that research be?"*

- *Second, issues of control (via structures, strategies, and processes that constrain behavior and thus complexity) dominate the tradition of management practice (and thus theory). Mechanisms of control are easier to understand and operate if they are made "linear" as opposed to non-linear or high dimensional.*

As discussed earlier it is far simpler to explain supply chains as four black boxes in a row, set up equations describing the flow of products down-stream and information up-stream, than consider multiple views and values from each firm, function or group of people involved in the “actual” network which the model might represent. Furthermore, it is easier to deal with linear relationships and causality rather than have to consider both causality relationships and correlations from among a vast number of influencing factors characterized by non-linearity. In addition, one cannot be sure that the essential factors are grasped. Lewis and Suchan (2003 p.312) state that *“logistics research may need a growth-inducing language about logistics managerial behavior, a new set of theoretical constructs that will help researchers reframe and thus "resee" their thinking and research designs in ways that help them break from variance theories and the larger positivist paradigm.”*

- *Third, perhaps contrary to Kuhn's assertion (1970) that researchers seek out the most challenging problems, organization researchers (like researchers in many other disciplines) have tended to go after the "solvable" problems first, in order to establish some legitimacy in the field.*

Such an approach is safe in its nature since it will reinforce basic assumptions and beliefs within the discipline and provide more arguments for certain issues which, with certainty, will be generally accepted within the field. Furthermore, as Mintzberg (in Snowden and Stanbridge (2004 p.144)) points out, simplified design, planning and positioning strategies can be seen as *“tailor made for management consultants, ably to fly in, apply a recipe using large teams of analytically trained consultants and then move on to the next generation.”* However, as several researchers have highlighted there are challenging problems in most disciplines that are of a “not mainstream” character. These need to be addressed from several perspectives, using unorthodox methods, in order to be understood and dealt with. Gammelgaard (2004 p.479) argues for example that *“application of more methodological approaches will strengthen the discipline in terms of new research questions and answers, just as it may have a practical relevance.”* Furthermore, Lewis and Suchan (2003 p.296) promote *“the need for process theories and an interpretivist framework to understand better the behavioral complexity or dimensionality of supply chains.”* Finally, Trim and Lee

(2004 p.473) state that *"if management researchers are to produce new insights into complex management problems, they need to think in terms of being innovative. Furthermore, management researchers need to have the confidence to challenge basic assumptions relating to interpreting research outcomes, and what constitutes appropriate research."*

- *Fourth, we propose that researchers attempt to avoid more complex behavior, especially behavior considered "random" (pink and white noise), because the empirical finding of white noise is taken as a failure of the research venture.*

Here white noise could represent the irrationality, from a scientific perspective, human beings would bring if it were included in perfect models of technical systems. In logistics there is an avoidance of such soft factors related to human behavior; Russel and Hoag (2004 p.102) state that *"social and organizational sources of complexity in IT implementations have thus far attracted little research attention from logistics and supply chain scholars."*

In conclusion, this thesis is an attempt to confront basic assumptions and give new perspectives to the logistics discipline in order to address complex phenomena and problems apparent in both logistics research and practice i.e. where human involvement is prevalent. Furthermore, it is also an effort to challenge the logistics paradigm with a different, unorthodox approach to handling contemporary everyday problems based on an extended set of assumptions i.e. encouraging logistics researchers to opt for the complex and challenging problems observable in logistics processes. Finally, it is an attempt to contribute to the growing amount of research and practice that has realized the limits of the traditional mechanical paradigm. The machine cannot be run faster because it is not a machine; organizations and thereby logistics are alive and living freely and creatively.

1.5 Demarcations

In the manner of Stacey, I will not be referring to chaos theory in this thesis for the following reason. Stacey (2003 p.326) states *"In chaos theory the term "chaos" has a precise mathematical meaning."* Strogatz (1994) defines chaos the following way;

"chaos is aperiodic long-term behavior in a deterministic system that exhibits sensitive dependence on initial conditions." Since logistics processes involving human beings whose identities and, consequently, values evolve and are transformed through time, chaos theory cannot be considered.

1.6 Definitions

A **complicated** process or phenomenon will be defined as a process or phenomenon of many connected parts which can be dissolved and reduced into solvable, simplified parts where sufficient knowledge can guide control and ensure optimization of chosen parts.

A **complex** process or phenomenon, on the other hand will be defined as being constituted of interwoven and interdependent phenomena where human and organizational identities are perpetually constructed as time elapses. The process is characterized by paradoxical situations of efficiency/effectiveness, control, optimization and cooperation, creating sometimes surprising responses and, on occasions, degrees of predictability.

In this thesis **efficiency** will be defined, as *doing things right*, while **effectiveness** will be defined as *doing the right things*.

The following definition is provided for **adaptive logistics**: *The reactive and proactive activities and actions aimed at managing perceived deviations and disturbances, and increasing logistics effectiveness.*

1.7 Thesis outline

The thesis is divided into five parts focusing on I) theoretical reflections on logistics research and practice, II) implementation issues and empirical experiences, III) methodology, IV) research framework and results and finally, V) appended papers. Furthermore, the licentiate thesis, entitled "A Complex Adaptive System Approach on Logistics – Implications of adopting a complexity perspective" (Nilsson 2003) is also a part of my doctoral thesis.

Part I

In Chapter 2, the logistics discipline is first examined from the perspective of being complicated or complex i.e. in relation to the first research question. Furthermore, a brief overview of what has been written about logistics and supply chain management with complexity theory as a base is given. In Chapter 3, logistics is viewed from a complexity perspective, and issues in logistics are examined, especially those which involve human beings. Teleology is also brought into the discussion and argumentation as a concept for the analysis. A reassessment of logistics assumptions is provided in the subsequent chapter, Chapter 4, where paradoxes in logistics are discussed and the consequences in research and practice of not considering aspects of these provided i.e. in relation to the second research question. Finally, in Chapter 5, a summary of this first part of the thesis is presented.

Part II

This second part of the thesis is divided into two chapters, where the first, Chapter 6, is designed to discuss how the complexity perspective can be "operationalized" i.e. the methods and tools which can provide guidance and aid when using the complexity perspective in real-life settings. A brief assessment of common methods and tools in logistics is provided followed by the introduction of agent-based modeling as a facilitator for "implementing" thinking aligned to the complexity perspective. In Chapter 7, empirical descriptions and experiences are provided and evaluated in real-life settings; the aim is to illustrate the potential the complexity perspective has in combination with agent-based modeling in addressing effectiveness dimensions within logistics and operations contexts. Here, adaptive logistics principles are elaborated on. Finally, in Chapter 8 a summary for Part II is provided.

Part III

In this section the research process is described and reflected on in Chapter 9. A reflection on research approaches is presented and how these have evolved during the research process. Thereafter, the methods used are presented and evaluated together with some of the major choices made. Appendix 1 is complementary to this part since a further reflection on research approaches to logistics is presented. A dominant approach to logistics, namely the systems approach, is critically examined here and put in perspective from two complexity theoretical approaches or perspectives, complex adaptive systems and complexity thinking. A comparative discussion of their appropriateness and usability for different types of problems and contexts is provided.

Part IV

Chapter 10 is where the complexity framework is presented. This chapter providesa synthesis of the discussions and results obtained from the former chapters. Furthermore, the complexity framework is the emergent outcome from this research endeavor and the starting point for further developments. Finally, in Chapter 11, theoretical, methodological and industrial conclusions are drawn and implications for researchers, practitioners, and teachers in the field of logistics are provided. Further research is then presented in Chapter 12.

Part V

In this part of the thesis appended papers are presented. These represent integral parts of the research findings. These are:

Paper 1: **Simplicity vs. complexity in the logistics discipline - a paradigmatic discourse.** Presented at the NOFOMA Conference, Linköping, Sweden, June 7-8, 2004. Published in the NOFOMA 2004 proceedings.

Paper 2: **Logistics Management from a Complexity Perspective.** Published in The ICFAI Journal of Operations Management, vol. 3, No.2, 2004.

Paper 3: **Logistics Management in Practice – toward theories of complex logistics**. Submitted to the International Journal of Logistics Management (IJLM)

Paper 4: **Combining Case Study and Simulation Methods in Logistics Research.** Presented at the 9th International Symposium on Logistics, Bangalore, India, July 14-17, 2002. Published in the ISL proceedings. It is one of the papers that the ISL organizing committee has chosen to invite to be submitted to a Special Issue of The International Journal of Production Economics (IJPE).

Finally, appendix includes reflective discussions concerning three research approaches, namely; systems theory/approach, complex adaptive systems approach and complexity thinking.

Part I

In the present century we are suffering from the separation of science and philosophy which followed upon the triumph of Newtonian physics in the eighteenth century."
Yvor Leclerc (in Prigogine (1997 p.6))

2 Reflections on complexity in logistics

As discussed in my licentiate thesis, the quest of developing the logistics discipline, with a more theoretical foundation, is something several authors have called for (Arlbjørn & Halldorsson 2002; Dunn & Seaker 1994 ; Garver & Mentzer 1999; Mentzer & Flint 1997; Mentzer & Kahn 1995). However, since logistics has been operational in nature with a focus on efficiency, when a theoretical foundation for logistics is being developed the underlying assumptions need to be reassessed. This is to provide a theory which is applicable to and fruitful for the discipline as a whole i.e. one which also considers the dimension of effectiveness. Furthermore, in this development, the issue of simplification i.e. how simplified can logistics phenomena be without losing value for those involved, as well as the issue of complexification i.e. under what conditions a logistics phenomenon can be regarded as complex, are of central importance in creating value and gaining understanding for people involved.

As one reviewer commented on one of my papers, that *"there are several disciplines and theories with focus set, not only on reducing complexity but on accepting it and trying to overcome it"*, and I fully agree with such a statement. The disciplines referred to by the reviewer were statistics, game theory, fuzzy logic. I would like to add other highly influential theories which are used in the logistics discipline; systems theory, cybernetics, agency theory, transaction cost theory, to mention but a few. However, the point is, that to some extent, they are all based on a set of assumptions which have not always allowed themselves to be verified empirically, without great approximations. Furthermore, these theories provide rather vague explanations for phenomena such as self-organization, emergence, co-evolution, and paradoxes in everyday logistics practice and management. What these positivistic and mechanistic assumptions theories provide is knowledge based on models and explanations which are valid and fit snugly into a world with phenomena which are perceived as complicated. However, as stated in the second research question; how well do this knowledge and associated models and explanations, provide understanding and guidance when the phenomena of interest are perceived as complex? Before this question is addressed a brief assessment of whether the logistics reality is treated as complicated or complex may provide the reader with a reference frame for the rest of the thesis.

The perception of supply networks and logistics as being complex is emphasized by several authors (Bowersox, Closs, & Bixby Cooper 2002; Christopher 1998; Cox 1999a; Lambert, Cooper, & Pagh 1998; Lumsdén, Hultén, & Waidringer 1998; Tan 2001). However, the complexity often addressed in common logistics literature is interpreted in this thesis as complicated, not complex. The major reason for this interpretation is that complexity is, in most logistics literature, addressed as being derived from an interpretation of logistics systems which are difficult to understand since they consist of a great number of parts, connections, and flows. For example Milgate (2001 p.107) observes that *"complexity should be viewed as a deterministic component more related to the numerousness and variety in the system."* i.e. logistics systems could and should be heavily reduced and simplified in order to be dealt with. Hence, complexity in logistics is defined out of quantifiable measures.

The dominating positivistic principles in the logistics discipline, promoting the assumption that logistics phenomena are regarded complicated, are further exemplified when logistics literature is examined. For example, Narasimhan and Jayaram (1998), in their study of relevant variables or key decisions which impact supply chain management effectiveness, state that *"the discussion of and inquiry into supply chain integration must center on causal linkages that exist among key strategic decisions along the supply chain"* (1998 p.580). One of the results of their study was that, based on a statistically significant linkage between manufacturing goal achievement and external customer responsiveness, they suggest that in the translation of customer requirements, specific manufacturing objectives should be pursued. The way this is going to be done is through delineation and refinement of manufacturing goals in the strategic integration process which executive management is responsible for. Finally, it is *"communicated through a top-down approach to the functional levels"* (1998 p.593). From this it thus follows that causality is of central importance and top-down command and control behavior are promoted.

Furthermore, another assumption apparent in logistics research and practice is simplification through reductionism, which also propounds a complicated world view rather than a complex one. In a number of articles, for example, Childerhouse and Towill (2003a; 2003b), Towill (1999), Towill, Childerhouse and Disney (2000), it is argued for simplified material flow in supply chains. They argument in their writings for 12 simplifying rules where these rules are based upon the fundamental theoretical and practical work by Jay Forrester (e.g. Forrester 1961) and Jack Burbidge (e.g. Burbidge 1962). Towill (1999 p.11), the original author, explains the objective of the 12 simplicity rules as follows: *"... emphasis is on 'clean' i.e. unbiased and noise-free information flows; time compression of all work processes; achievement of consistent lead times; choice of smallest possible planning period; adherence to the schedule i.e. elimination of pockets of 'Just-in-Case' materials, selection by simulation of the 'best' supply chain controls; and finally, matching the simulation model to the real work process via process flow and information analyses."* Childerhouse and Towill (2003, p.18) declare that the concept of seamless supply chain is *"simple in nature and based on a control engineering approach."* All the twelve rules are based on reducing, simplifying, unifying, eliminating assumptions such as rule seven; *"elimination of all uncertainties in all processes"*, and rule twelve where *"all players should think and act as one"*.

There are several more examples found in literature where it is rather easy to identify a belief in a "complicated" logistics reality which needs reductionistic and simplifying assumptions in order to "run the machine faster." For example Shim et al. (2002 p.119) state; *"historically, most of the research effort in operations research has been concentrated on development of new algorithms to solve problems faster."* A further argument supporting this statement of complicatedness is to be found in appended paper one (see Part V).

The next step in this thesis is to provide a brief overview of other researchers who have used complexity theory (or chaos theory) in logistics, supply chain management and operations management. This will help the reader to position this research alongside other people's thoughts and suggestions.

2.1 Complexity theory in Logistics

One of the first authors who used complexity theory in the logistics context is Richard Wilding. In his article “The supply chain complexity triangle” complexity is described as uncertainty involved in supply chains, and according to Wilding (1998b p.599) this complexity is derived from, *”three interacting yet independent effects.”* These are deterministic chaos, parallel interactions and demand amplification. These effects cause complexity in the logistical processes based on uncertainty in the supply chain. Wilding has also contributed with another article entitled “Chaos theory: implications for supply chain management” (Wilding 1998a) in which it is concluded that a supply chain can exhibit the characteristics of a chaotic system.

Other researchers who have used complexity theories in the logistics domain can be found at Chalmers University of Technology in Sweden. A number of texts have been published and one of the earliest is a paper written by Lumsdén, Hultén and Waidringer (1998). They describe complexity in logistics as being caused by the uncertainty of customer demands and time needed for subprocesses. Furthermore, three other aspects are addressed regarding the complexity of logistics, namely; a large number of system states, a heterogeneous system, and distributed decision-making. They conclude that there is a need for *“better models of logistical systems… [that] lead to better predictions of the behavior of real systems”*(ibid. p.171). Furthermore, they state that *“logistic systems are complex adaptive systems. They are heterogeneous socio-technical systems with a large number of actors and the systems are influenced by a large number of variables that can have values within a great interval and which often show a stochastic behavior.”*

In his dissertation a few years later Waidringer (2001) provides a definition of logistics complexity: “*Transportation and logistics systems’ complexity resides in the nature of the network, process and stakeholders. It is a measure of the possibility of modeling these properties and their dynamic interaction in a way that allows for implementation of control mechanisms, forcing the system under study to meet required service, cost and environmental demands.*” (ibid. p.115).

In the texts from the groups above, complexity, which has arisen in the logistics systems, is derived from mainly universal and external aspects which can be objectively viewed, and are global phenomena for these systems. However, the impact the parts within these interconnected and interdependent systems have on each other in creating the global phenomena, are not emphasized to a great extent. It should thus be mentioned that Lumsdén, Hultén and Waidringer (1998) address the issues of distributed decision-making and that logistics systems are socio-technical systems which I will later return to.

In the Journal of Operations Management, Choi, Dooley and Rungtusanatham (2001) demonstrate how supply networks should be managed if we recognize them as complex adaptive systems (CAS) instead of only systems. They set out to answer the ongoing debate about system-wide optimizations based on the on the general agreement in the current literature that individual firm optimizations will create suboptimization for the whole supply network. They argue that this has led to a situation where *"many firms have spent increasing amounts of time, money, and effort in an attempt to predict and control their extended supplier system"* (2001 p.351). In their examination of CAS three foci are considered apparent, those are: a) an internal mechanism, b) an environment and c) coevolution. Within these the authors define roles, characteristics, and behavioral phenomena so that for the internal mechanism there are *agents* and their *schema*, with *self-organizational* behavior and *emergent* outcomes. Furthermore, *network connectivity* and *dimensionality* are aspects which describe dependence and autonomy for the agents. The environment is characterized as a *fitness landscape* with a more or less *rugged surface* depending on its *dynamism* i.e. the changing of underlying interaction patterns. When it comes to the issue of coevolution, aspects such as *quasi-equilibrium* (the balance between complete order and incomplete disorder which is referred to in the current literature/the literature available as "the edge of chaos" (Pascale, Millemann, & Gioja 2000)) and *state changes* of system and subsystems are addressed. In addition it is emphasized by the authors that the change is of a *non-linear* type towards a *non-random future,* meaning that the future is not totally random; however neither can it be predicted in a deterministic manner. Based on a conceptualization of supply networks as complex adaptive systems the authors put forward several propositions such as the proposition that *"Successful implementation of control-oriented schemes (e.g. ERP. JIT II) leads to higher efficiencies, but it may also lead to negative consequences such as less than expected performance improvements and reduction in innovative activities by the suppliers."* Furthermore, they propose that firms *"that deliberately manage their supply network by both control and emergence will outperform firms that try to manage their supply network by either control or emergence alone."* They finally conclude that order and control in supply network are of an emergent character, not, as proclaimed in the literature available today a predetermined one. This control is generated with simple, non-linear behavioral rules in the local context where the agents operate.

Another research group which have used complexity theory in logistics research are Olav Solem and Stig Johannesson in a number of texts. Their approach is different from former ones in that they claim that the *"complexity perspective does not set out to give recipes on organizational practices, but rather offer an understanding of the life of the organization"* (Johannessen & Solem 2001). Their research aims at building a stronger focus into logistics organizational issues and to that aim, the emphasis on the human and social aspects of logistics becomes a central issue. Instead of talking about complex adaptive systems, a complex responsive process perspective is taken and this complex responsive process perspective is mainly derived from Stacey (2001). In the article "Logistics Organizations: Ideologies, Principles and Practice" (Johannessen & Solem 2002) they argue for the usefulness of understanding underlying teleological and ontological assumptions, and the ideologies of action and organizational practice. This could have implications for organizational change and competitive power. In their research they identify four logistics organizational ideologies; the machine ideology, the process ideology, the socio-technical ideology, and the network ideology. They declare that in the machine and socio-technical ideology change is something which produces instability in organizations and this is bad. If the organization can be keep stable, optimality, meaning some thing good, can be achieved. On the other hand, the authors declare that in process ideology change is related to customers' behavior on the free market. There is a wish for predictability and stability shown through long-term planning activities performed and the belief is that change is outside the organization. Finally, the network ideology *"assumes that by joining a network, intentions are good and that these intentions stay fixed for long time periods."* Johannessen and Solem conclude that *"in order to understand how novel ideas and practices emerge and transform modern logistics organizations, complexity theories together with established logistics theories should be taken into account"* (ibid. p.41).

Johannessen (2003) investigates the thought processes logistics organizations are based upon, how change phenomena are understood, and how strategic knowledge and strategy are explained and understood, all this from a complex responsive process perspective. It is argued that the process perspective can provide meaning, explanation and understanding of how relations between people affect the patterns of logistics action. In the thesis a definition of logistics from a complex responsive process perspective is provided: *"Logistics is complex processes of relations between humans, nature, technology and resources that interact and unpredictably self-organize into emerging paradoxical patterns with value creating potential"* (2003 p.87). Furthermore, it is concluded that logistics may be regarded as a social object, created in transformational processes by people in the movement itself. This transformational process can be understood by *"paying attention to phenomena like self-organization, emergence, paradox and unpredictability"* (2003 p.42).

These texts interest me since they provide a "radically" different view of logistics, something that I would argue is very different from the other logisticians who have used complexity theory to shed light on logistics. The process perspective is interesting and the discussion provided of systems theory and its limitations in explaining logistics activities and change is profound. However, in the logistics context I think that there is more to do on "implementing" or making use of this suggested process perspective. Furthermore, I believe that there are phenomena and situations in logistics where the process perspective is complementary to the dominating positivistic and systems thinking in logistics; indeed combinations of these insights might provide value for both research and practice in the field. That is in line with the purpose of this thesis.

	Wilding	Waidringer et al.	Choi et al	Solem and Johannesson
Phenomenon to study	Supply chains	Transportation and logistics systems	Supply Networks	Change processes in logistics organizations
Theoretical base	Chaos theory	Complex adaptive systems	Complex adaptive systems	Complex responsive processes
Aims and purposes	The complex responsive process perspective serves as a powerful theoretical approach for explanations of logistical patterns of action.	The research is expected to generate better models of logistics systems, and thus lead to better predictions of the behavior of the real systems.	Bring the observation of supply networks to the next level i.e. to recognize them as complex adaptive systems.	Explore strategy and change in logistics organizations, provide understanding for strategy and change from a complex responsive process perspective.
Conclusions	Supply chain can exhibit the characteristics of a chaotic system. Deterministic chaos, parallel interactions and demand amplification cause complexity in logistics.	The measures of network complexity, process complexity and stakeholder works well as indicators the for complexity transportation and logistics systems. Complexity could be used to meet the demands for more sophisticated approaches, methods and models for logistics systems.	Balance between control and emergence, control found in simple, local rules. Supply networks are complex adaptive systems. Supply networks emerge rather than results from purposeful design by singular entities.	Logistics as social objects, created and recreated in the transformational movement by people. The complex responsive process perspective serves as a powerful theoretical approach for explanations of logistical patterns of action.
Publications:	(Wilding 1998a; Wilding 1998b)b)	(Lumsdén, Hultén, & Waidringer 1998; Waidringer 2001)1)	(Choi, Dooley, & Rungtusanatham 2001)	(Johannessen 2003; Johannessen & Solem 2001; Johannessen & Solem 2002)

Table 2.1. Comparative and summative list of writings in logistics based on complexity/chaos theory.

3 Logistics from a complexity perspective

Considering logistics as complex means that recognition of human involvement (which is apparent in any logistics process or phenomenon) must be considered when treating logistics issues. While interconnected technical artifacts i.e. physical and information-related parts can be regarded as both complicated and complex to a certain degree, another dimension is added when these artifacts are put into a social context. This means that the subjective and sometimes inter-subjective perceptions and interpretations of decision-makers working with the artifacts increase the perceived complexity of logistics phenomena. In this regard, Rigby (2000 p.181) states that "*the usual focus for improvement in the supply chain has been the optimization of a particular company's inventory or scheduling protocols. […] These systems analysis and redesign methods are excellent at describing and modeling the physical flow of materials, inventory data and demand patterns. However, the human-to-human interaction in network forms of organization has a much higher degree of complexity.*"

Consequently, this thesis takes the standpoint that logistics processes, where human beings are involved, are not simply a sequence of mechanical devices which can be assumed to work along positivistic beliefs, but instead a complex network of living, innovative, creative, and evolving creatures which react and adapt dynamically to their perceived environment, and try to proactively create what they themselves, or collectively with others, find to be beneficial for their own interests. It is in the interaction between people that coherent patterns of meaning and identity are perpetually created. The iterative results of these processes are paradoxical situations where the interests of different groups of people (i.e. divisions, departments, functions or firms) are continually creating opportunities, at the same time as these processes restrain the developments of other processes. This is a perpetual process and as Stacey (2003 p.326) states, there are no levels separating the interacting groups of people, "*only paradoxical processes of individuals forming the social while at the same time being formed by it.*" Conclusively, treating logistics as complex means considering human involvement and the paradoxes created in human interactions.

Consequently, it also means considering the concrete, actual work being done and the mental models created by the humans involved in this work.

In order to further develop these arguments a short discussion of the term *paradox* may be useful for the reader. The term *paradox* can be defined and used in different ways. According to Stacey (2003 p.328) paradox "*may mean an apparent contradiction, a state in which two apparently conflicting elements appear to be operating at the same time.*" With this definition of paradox dealing with a paradoxical situation is a matter of knowledge. With increased knowledge of the paradoxical situation the contradiction can be removed or resolved by deciding that one element is to be preferred all the time. Alternately it can be solved by changing the conditions or the problem, thereby preventing the contradiction appearing again. This is in line with a classical, mechanistic, logistics approach to handling issues which arise in logistics strategies and efficiency-enhancing efforts. The assumption is of a dualistic character. However, the chosen solution to the contradiction inherited in the perceived paradox may lead to counterproductive situations in a wider sense, both in time and in space i.e. the outcomes are not always effective.

Another way to define the term *paradox* is in line with Hegel's dialectical logic. Here the term "*paradox means the presence together at the same time of contradictory, essentially conflicting ideas, none of which can be eliminated or resolved*" (ibid. 2003 p.328). In such a situation there is no way the paradox can be resolved or eliminated by positivistic assumptions and claims, and therefore a different kind of logic is needed; a logic of a dialectic character. Such paradoxes are apparent all the time in logistics research and practice e.g. stability and instability at the same time, assumptions of controlling the uncontrollable i.e. human free-will, optimizations of processes in continual change, processes of reducing uncertainty create uncertainty, processes of learning create more to learn etc. Stacey (2003) points to the example of mathematical chaos where the outcome of a deterministic equation e.g. $x_{(t+1)}= A*x_{(t)}*(1-x_{(t)})$, is both predictable and unpredictable at the same time depending on the value of A. It never repeats its state, however, apparent patterns of the outcome repeat themselves all the time.

In order to not confuse the reader it is important to mention that both types of paradoxes are apparent in logistics: the point to be made explicitly in this thesis is that the second one (from Hegel's thoughts) have so far been of limited use in logistics research and literature and have often met with reluctance in both logistics research and practice.

As declared in the purpose of this thesis, what is proposed is a perspective for logistics research and practice based on an extensive set of assumptions which are more aligned to real-life logistics operations (see Figure 3.1 below), i.e. when logistics is considered complex. An extensive set of assumptions means that those of linearity, reductionism, determinism, rationality etc. found in the middle of Figure 3.1 are still apparent and useful; however, they are of limited use when it comes to logistics operations involving several humans. Instead, assumptions of non-linearity,

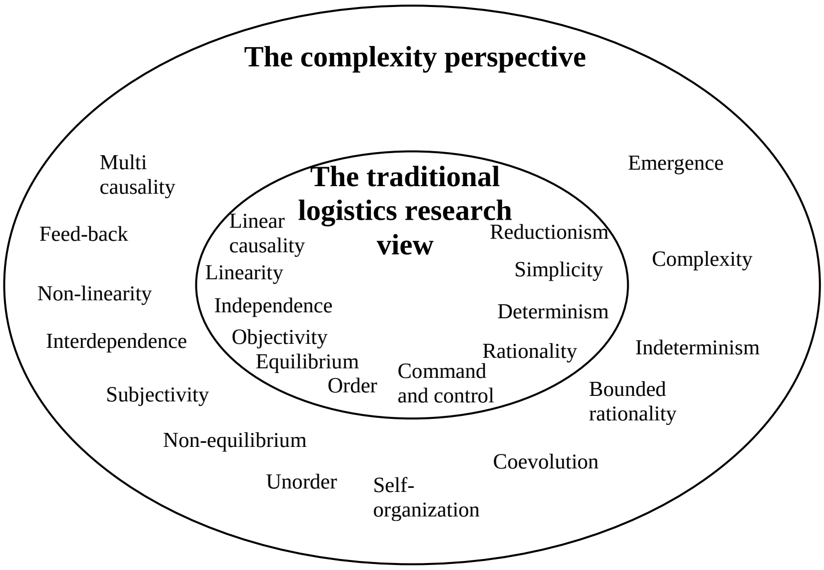


Figure 3.1. The proposed paradigmatic view from my licentiate thesis based on the science of complexity as an extension of the traditional efficiency focused logistics research view. The complexity perspective is here illustrated in a figure derived and modified from Nilsson (2003 p.32) and Dent (1999 p.9).

heterogeneity, bounded rationality, self-organization, emergence, subjectivism, to mention but a few, are central to a complexity perspective and highly apparent in real-life logistics operations[4].

The complexity perspective is in line with some of the thinking Boulding (1956) presented in his article "General Systems Theory – the skeleton of science", which Checkland (1993; 1999) refers to in his works about systems thinking. Boulding (1956 pp.202-205) presents a hierarchy of complexity on nine levels for theoretical discourse. The first level is that of static structure; the second he calls clockworks i.e. dynamic simple systems; on the third level control mechanisms and cybernetic systems are introduced and addressed as the level of thermostat; the fourth level introduces the first living organisms. Here, life in the form of *cells* is distinguished from the former levels of "not-life" and it becomes the level of open systems. Going up the levels, the fifth level introduces what Boulding calls genetic-societal level, where the *"plant"* is the empirical example, in other words this is the botanist's world of research and practice. The next level, level six, represents the animal level, which is characterized by increased mobility, teleological behavior, and self-awareness. The seventh level is where the human being is introduced. Boulding states that *"in addition to all, or nearly all, the characteristics of animal systems, man possesses self-consciousness, which is something different from mere awareness,"* i.e. the human not only knows, but knows that he/she knows. Boulding places social organizations and societies on the eighth level i.e. where human interaction is introduced. *"At this level we must concern ourselves with the content and meaning of messages, the nature and dimensions of value systems, the transcription of images into a historical record, … The empirical universe here is human life and society in all its complexity and richness"* (ibid. p.205). He describes the final level as transcendental, which involves what he defines as the ultimates and the inescapable unknowables. Boulding points out that this level needs to exist in order to represent a

[4] Further discussion of assumptions apparent in the current logistics management and assumptions related to a complexity approach can be found in Nilsson (2003), and article one (see appended papers).

comprehensive structure of systems however, this level will not explicitly be dealt with in this thesis and instead left for the reader to make his/her own mind up about.

The point that Boulding was trying to make in defining this hierarchy of complexity levels was that it provided science with new ideas in finding gaps of theoretical and empirical knowledge. The point of this thesis is to give the reader a perspective of logistics where the efficiency-focused paradigm built upon mechanical assumptions, at best, handles logistics at the third level i.e. that of thermostat with control and cybernetically derived principles. Checkland (1993; 1999) exemplifies the insights in the management context by stating: *"a typical management science model constructed in terms of multiple interacting feedback loops, even if complicated, is only a level 3 model and hence can cover only certain aspects of a management problem at level 8. Management scientists have been known to claim more."* Von Hayek in his field of economics has provided criticism of economic models and theories which he claims are highly influenced by principles and procedures from physical science i.e. of the first three levels. He states that the approach to *"imitate as close as possible the processes of the brilliant successful physical science,… is an approach which has come to be described as the "scientistic" attitude – an attitude which, as I defined it some thirty years ago, is decidedly unscientific in the true sense of the word, since it involves a mechanical and uncritical application of habits of thought to fields different from those in which they have been formed"* (1989 p.3). Thus, while I agree with Stock (1997) concerning the possibility of borrowing theories from other disciplines for the purpose of moving the logistics discipline forward, a warning has to be given that such borrowing should be done in a cautious way by assessing the underlying assumptions of the theories borrowed. Otherwise, the temptation to "extrapolate" findings in e.g. physics and biology without critical reexamination of their applicability will continue to create over-simplified models, not appropriate for the contexts and problems they are applied to.

The connection to the complexity perspective presented in Figure 3.1 is illustrated in table 3.1. The assumptions listed in the inner ellipse are comparable to the first three levels of complexity in Boulding's hierarchy, while the assumptions listed in the extended perspective (the outer eclipse) are added on as the complexity increases. This is also to say that the inner ellipse represents complicated phenomena and problems and the outer represents complex ones. While some of the assumptions listed in Figure 3.1 are discussed in my licentiate thesis (Nilsson 2003) and appended paper one, further discussion and exemplification of some of these will be provided in this thesis. The reason is that it provides the reader with a more comprehensive picture and the argumentation in this thesis especially concerns the implications the extended assumptions i.e. a complexity perspective, have on certain logistics situations. Also provided are reflections on the extended assumptions as to how they can be pragmatically dealt with in the logistics context. Furthermore, discussions concerning how the future can be treated in logistics processes and apparent paradoxes identifiable in logistics i.e. other aspects of a complexity perspective, will be put forward. All in all, this discussion will provide, theoretically and conceptually, a more comprehensive description and discussion of adaptive logistics.

Level	Characteristics	Aggregated assumptions	Logistics examples
1	Static structures	Linear causality, linearity, independence, objectivity, equilibrium, order, determinism, simplicity, reductionism	Seamless supply chains, linear programming,
2	Clockworks – dynamic simple systems		
3	Control mechanisms and cybernetic systems	Feedback, command and control, non-linearity, rationality	System dynamics, beer game, business process reengineering
4	Living organisms, level of open systems	Self-organization, coevolution, emergence, interdependence, multi-causality	Rule based i.e. complex adaptive systems
5	Genetic societal level – plants		
6	Animals level		
7	Human being level	Subjectivity, unorder, non-equilibrium, bounded rationality, indeterminism, complexity	Complex responsive processes
8	Social organizations and society		
9	Transcendental		

Table 3.1. Boulding's levels of complexity together with assumptions and illustrative examples from logistics.

3.1 Teleology in logistics

In order to address logistics effectiveness from a complexity perspective one important question researchers have to consider during the research process is how the future is treated. This means considering how the future is reflected in the type of methods used, the results and suggestions made, and in the ontological and epistemological assumptions providing as the paradigmatic foundation. This is especially important in pragmatically oriented research, such as logistics, where the purpose is often to improve, maximize, optimize etc. some kind of business processes or logistics phenomena i.e. something related to activities for future improvement or for future action. In order to address the purpose or future state of any logistics process the concept of teleology may be beneficial in explaining different views on logistics and the consequences that these bring. This is also of importance in addressing the dimension of effectiveness of logistics systems and what the implications assumptions made may have on the actual result. Finally, a reflection of approaches to future development is central to adaptive logistics since it by definition involves both proactive and reactive activities and actions aimed at increasing logistics effectiveness. Hence, based on a teleological standpoint, the understanding of “aimed at” could provide different approaches and create different mind-sets of the people involved in the improvement efforts.

When dealing with future processes or activities, teleology, which Ackoff (1973 p.655) defines as *“the study of goal-seeking and purposeful behavior,”* is a central concept. In the New Oxford English Dictionary, the word *teleology* is explained as *“the explanation of phenomena by the purpose they serve rather than by postulate causes.”* Teleological considerations are important in the research process since they bring up several aspects which have to be borne in mind. Firstly, how is the future interpreted? As a known state in equilibrium – this means that we are able to predict and control our future states – or as an unknown non-equilibrium fluctuation state i.e. that we are heading towards something unknown and uncertain? Secondly, why are we moving into the future i.e. what is the reason for doing anything at all? Stacey, Griffin and Shaw (2000) make a list of four distinctive assumptions as to why a phenomenon moves into the future. Those are in order to realize: 1) some optimal agreement, 2) a chosen goal, 3) a mature form of itself, and 4) continuity and transformation of its identity. Based on this teleology they provide five casual frameworks to deal with the two purposive questions above. These are:

1. Secular Natural Law Teleology
2. Rationalist Teleology
3. Formative Teleology
4. Transformative Teleology
5. Adaptionist Teleology

For the purpose of this thesis the rationalist, formative, and transformative teleological frameworks will be considered in greater detail and a standpoint from the author's perspective will be made. The reasons for choosing these three are as follows:

1. rationalist teleology and formative teleology are primarily found in the logistics discipline since they are closely connected to positivistic assumptions (this will be discussed below).
2. secular natural law teleology is mainly related to natural science since it requires reversible processes and experimental methods. As Prigogine (1997 p.18) states: "*nature involves both time-reversible and time irreversible processes, but it is fair to say that irreversible processes are the rule and reversible processes the exception*." Logistics processes are by nature the rule rather than the exception.
3. adaptionist teleology is related to biology especially Darwinism and neo-Darwinism with focus on the evolutionary processes in nature. The assumptions of entities as individual and that the purpose of life is only survival, make this teleology not applicable to logistics research and practice.
4. transformative teleology is closest to my personal ideas and beliefs and it is the teleological framework I have used in my research. The future is seen as mostly unknown, or as Prigogine (1997 p.18) states, under "*perpetual construction*". Its relevance to logistics might be obvious since it quite accurately reflects people's descriptions of how they perceive daily life.

Furthermore, the connection of the transformative teleology to management of organizations has been established by several authors (Johannessen 2003; Stacey 2001; Stacey, Griffin, & Shaw 2000). It is also strongly connected to some of the thoughts of other complexity theorists (see appendix 1).

Table 3.2 presents the stated characteristics for the teleological framework regarding the chosen frameworks in this thesis, according to Stacey, Griffin and Shaw (2000 pp.52-54).

	Rationalist Teleology	*Formative Teleology*	*Transformative Teleology*
Movement toward a future that is:	A goal chosen by reasoning autonomous humans.	A mature form implied at the start of movement or in the movement. Implies a final state that can be known in advance.	Under perpetual construction by the movement itself. No mature or final state, only perpetual iteration of identity and difference, continuity and transformation, the known and the unknown, at the same time. The future is unknowable but yet re- cognizable: the known-unknown.
Movement for the sake of/in order to:	Realize chosen goals.	Reveal, realize or sustain a mature or final form of identity, of self. This is actualization of form or self that is already there in some sense.	Express continuity and trans-formation of individual and collective identity and difference at the same time. This is the creation of the novel variations which have never been there before.
Meaning	Lies in the future goal	Lies in the past in a enfolded form and/or unfolded future.	Arises in the present, as do choice and intention.
Nature and origin of change	Designed change through rational exercise of human freedom to get it right in terms of universals.	Shift from one given form to another due to sensitivity to context. Stages of development.	Gradual or abrupt changes in identity or no change, depending on the spontaneity and diversity of micro interactions.
Origin of freedom and nature of constraints	Human freedom finds concrete expressions on the basis of reason and ethical universals.	No intrinsic freedom, constrained by given forms.	Both freedom and constraint arise in spontaneity and diversity of micro interactions; conflicting constraints.

Table 3.2. Teleological frameworks according to Stacey, Griffin and Shaw (2000, pp.52-54)

Teleological frameworks i.e. different ways people interpret the future, may be seen as related to ontological issues about our conceptions of the world. Rationalist teleology may be interpreted as being close to a realistic view (Burrel & Morgan 1979) of the world and in line with an analytical approach (Arbnor & Bjerke 1997).

The major reason for this is that the rationalist searches for some kind of hidden order, something that already exists, i.e. an objective reality where everything can be explained in causal terms. Consequently, following this teleology, if Newton-inspired laws are followed, future states can be known in advance. In other words, this view in logistics is realized through in-depth analysis where each reduced and simplified part is examined, and subject to detailed planning, implementation, and rigorous control. From a management and strategic perspective this thinking has its origins in Fayol's writing (1916/1949 in Combe 2004) and further on in the work by Sloan (e.g. Sloan 1963) and Ansoff (e.g. Ansoff 1965).

By liberating some of the strong assumptions of objectivity and determinism related to the rationalist/realist teleology/ontology and considering some subjective aspects, formative teleology comes to mind. Here, reality is created by autonomous beings which have the ability to chose goals for certain phenomena and realize these in their movement into the future. The future state which can be regarded as predefined equilibrium has been chosen and decided on by someone i.e. a human being often to be found in "privileged" positions (e.g. top-management), and therefore the assumptions of command and control have prevailed. I would like to place this formative teleology close to the systems approach in Abnor and Bjerke's (1997) framework, since formative teleology centers around the notion of system and environment, inside and outside.

Finally, transformative teleology is even more subjective in its nature, especially concerning the treatment of the future, while the present still may be inter-subjectively viewed by people or entities which share experiences. Allen states in this regard, that *"evolution is not necessarily progress and neither the future nor the past was preordained"* (Allen 2000b p.101). Transformative teleology takes a step away from the dualistic notion of system and environment, and emphasizes instead the dialectics of an identity-difference thinking where issues of novelty, diversity, and conflict are central. Stacey, Griffin and Shaw (2000 p.155) state that *"novelty means coherent pattern that has never existed before"* thereby differentiating that view of novelty from the notion in formative teleology where novelty is revealed in a hidden form which already exists. Furthermore, they claim that *"diversity and conflicting constraints (that is, power relations) are all essential to the emergence of true novelty"* (ibid.). In transformative teleology movement is paradoxical in that it is both continuity and transformation simultaneously. Furthermore, individuals are forming groups, organizations and societies at the same time as they are formed by these, all arising in the micro details of interaction.

With these teleological frameworks in mind a reassessment of logistics assumptions highly apparent in literature can be discussed for the following reasons:

- Rationalist teleology represents a mechanistic approach since it relies on someone's (often top management) ability to set goals, design realization systems based on rationally behaving individuals who are assumed to behave mechanistically, and then realize those chosen goals. This is the case of much of the logistics literature available, and noticeable in much logistics practice. However when examining logistics processes in real-life settings this thinking often fails. The claim made here is that a rationalist approach does not work for logistics and it seldom provides beneficial results for phenomena where people are involved.
- While in formative teleology some of the assumptions of the rationalist are liberated, there still exists a problematic discrepancy between logistics theory and what constitutes real-life logistics activities. The notion of hidden structures and different levels of objectivity i.e. that a manager has an objective view, that he/she can stand outside his/her defined system, and design the content in accordance to the future goals set for the system, is problematic since it depicts an inside-outside mentality, determinism, and selective predictability (since only a few chosen people have the ability to set goals for the future). While this formative approach might be another dominant belief in the logistics discipline it is argued in this thesis that it should be used with care, and consideration should be given to the contexts and type of problems a formative approach is applied to.
- Transformative teleology represents paradoxical situations and phenomena, with emphasis on change processes in the logistics context. In these

paradoxical change processes cooperation and competition, conflict and agreement, control and the inability of it, order and disorder etc., are present simultaneously and are needed for future development. This framework may be empirically “validated” since it takes into account aspects which are experienced by people on a daily basis. Transformative teleology will be further used and argued for in the complexity framework in Part IV of this thesis.

4 Reassessing logistics assumptions

By reassessing the underlying assumptions of the logistics discipline from a complexity perspective it is my goal to provide insights into, and thoughts on, how central logistics issues such as efficiency/effectiveness, control, optimization, and cooperation/competition can be addressed, understood, and dealt with in a manner which differs from that which is common in logistics today. From such a reassessment process new thoughts on how logistics effectiveness can be enhanced can emerge. In this theoretical discourse some propositions and insights from the logistics framework provided by Mentzer, Min and Bobbitt (2004) in their recent article "Toward a unified theory of logistics" will be used. In their article they use theory of the firm to guide theory development within the logistics discipline. They conclude that *"the role of logistics is to provide the boundary-spanning, demand and supply coordinating, capabilities the firm needs to create customer value to satisfy customers"* (ibid. p.621). In the article several propositions are made concerning the value of logistics and from which logistics capabilities the logistics value is created. The authors proclaim that this framework should guide logistics theory development and state that *"future research is strongly encouraged to challenge and/or refine our view of logistics"* (ibid. p.622). In the framework they define four distinctive logistics capabilities which add value for the firm. These are; 1) demand-management interface capabilities, 2) supply-management interface capabilities, 3) information-management capabilities and finally 4) coordination capabilities. This is much in line with the definition of what Arlbjørn and Halldorsson (2002 p.25) formulate as the hard core of logistics, namely; *"directed toward the flow of materials, information and services; along the vertical and horizontal value chain (or supply chain) that seeks to; coordinate the flows and is based on; system thinking (a holistic view), where; the unit of analysis essentially is the flow."*

4.1 Paradoxes in logistics

Mentzer, Min and Bobbitt proclaim the efficiency and effectiveness dimensions of logistics and propose that logistics capabilities help firms achieve the cost leadership component of competitive advantage through efficiency (cost and capital reduction).

They also propose that logistics capabilities help firms achieve the differentiation component of competitive advantage through effectiveness (customer service). These dimensions might often constrain or come into conflict with each other, thereby creating different types of paradoxical situations. The efficiency/effectiveness paradox viewed from a complexity perspective is thus correlated to and interdependent of other paradoxical situations identified in logistics management such as the paradoxes of control, optimization, and cooperation/competition (see appended paper three for additional). Mentzer, Min and Bobbitt propose, for instance, that "*logistics information management capabilities meet the supply chain operational and strategic information needs …, which leads to optimization of system-wide capital investment*" (2004, p.616). The reasons for addressing these paradoxes (efficiency/effectiveness, control, optimization, and cooperation/competition) are as follows:

- **Efficiency/effectiveness** is the central theme of this thesis and, as set out in the introduction, is important to assess when logistics processes are targeted to be improved i.e. emphasizing doing the right things vs. doing things right. Hopefully, the forthcoming sections will bring more clarity to how the dimension of effectiveness can be further explored and enhanced in logistics.
- **Control**. Highly correlated to an efficiency paradigm is the issue of control. Consequently, by addressing this paradox some central aspects of what types of assumptions creating inertia in and reluctance for a paradigmatic shift toward increased emphasis for effectiveness can be addressed. Hence, the proposition that it is not just a change in focus (as proclaimed in demand management literature), but rather a change in assumptions that is needed for any effectiveness potential to be realized.
- **Optimization** is another belief mainly derived from physical science and a more or less strict mathematical concept that is deeply rooted in logistics. Similar to the paradox of control the underlying assumptions of optimization are of a mechanical character i.e. do not fit all aspects of reality to any greater extent. This is certainly an exception rather than a rule.
- Finally, the great emphasis on **cooperation/competition** is another paradox relatively easily encountered when a complexity perspective is applied to

logistics. Again, this is based on assumptions of equifinality, equilibrium, harmony, order, agreement etc. in logistics. These are all beautiful ideas but still not very realistic since in solely putting emphasis on these assumptions others apparent in the logistics discipline (see appended paper three) such as of power, conflict, subjectivity, to mention but a few, are disregarded.

It is important to point out that this presentation of paradoxes is not an attempt to provide a complete list of paradoxes identifiable in the logistics context i.e. the reader might find several additional examples, he/she might place greater emphasis on others etc. What is presented here are those paradoxes I have regarded to be of greatest relevance during my research process and I freely encourage the reader to add others which he/she has experienced. These four paradoxes will be addressed next, with the paradox of efficiency/effectiveness first out.

4.1.1 The efficiency/effectiveness paradox

As has been argued in the introduction of this thesis, the logistics discipline has a history of efficiency-focused, cost-reducing efforts, something Gammelgaard (1997 p.16) exemplifies by stating that: *"although the field, in particularly in the recent years, has become very wide, logistics management is fundamentally still about controlling the material flow and how to do it efficiently."* Consequently, in order to address the effectiveness dimension, the underlying assumptions dominating the logistics theory and practice must be reassessed i.e. there must be a paradigmatic assessment. One apparent reason is that the question for companies and their network partners is currently shifting from solely focusing on optimizing existing systems and processes, towards creating future improvements i.e. exploring effectiveness dimensions. Robson (2004 p.516) states that *"in a rapidly changing world, with ever-increasing competition, the effectiveness of the improvement processes is almost certainly more critical to long-term survival than the current level of performance of the operational processes."* The overall question addressed by the effectiveness dimension is; what is best for customer satisfaction, firm profitability, and survival? The answer is seldom apparent and it is time and context dependent since changes other actors on the market, the industry, or the organization make will affect the decisions set at a certain point in time. The result is often paradoxical since what is best today might be devastating a few years or months ahead and the decision made may result in unexpected effects not logically derivable in other parts of the division, the organization or the supply network. Alderson (1951 p.19) states for example that an *"executive will not invest a large amount in equipment designed to make this plant the most efficient in his industry today if he knows that much more effective techniques will be available tomorrow. … The executive will act in such a way as not to dissipate the power to act."* Not surprisingly, the logistics literature available is in scarce supply when it comes to effectiveness discussions, but it is full with best-practice cases and solutions (New 1996) aiming at increased efficiency. Only recently has the issue of effectiveness been addressed in demand-oriented literature (see for example Fisher (1997) and Heikkilä (2002)).

There is a growing body of literature which discusses logistics and supply chain management from a customer demand-oriented perspective (de Treville, Shapiro, & Hameri 2004; Frohlich & Westbrook 2002; Vollmann, Cordón, & Heikkilä 2000). The discussion focuses on novel dimensions of the market place such as customer service, customization, etc. and the debate suggests that supply chain management should be renamed demand chain management in order to emphasise the customer as most important for the companies' survival and prosperity (Childerhouse, Aitken, & Towill 2002). In this context Mentzer, Min and Bobbitt hold that there are specific demand-management interface capabilities and make the following proposition:

> Proposition: *Logistics demand-management interface capabilities are customer-focused, multidimensional (i.e. customer service and logistics quality), longitudinal (i.e. before, during, and after sales), and lead to strategic advantage.*

It has been stated and argued by several authors that beyond the efficiency function, logistics is a source for competitive advantage (Lynch, Keller, & Ozment 2000; Olavarrieta & Ellinger 1997). According to Rainbird (2004 p.235) supply chains "*emphasise the efficiencies in the production and logistics processes, while the demand chain emphasises effectiveness in the business."* Lee and Billington (1992 p.66) argue that "*the effectiveness of a supply chain must ultimately be measured by its responsiveness to customers."* Day and Wensley (1988) point to several logistics activities which can provide value for their customers, such as shipping methods, faster delivery of orders, order-handling activities, or choice of technology. Added to these are provision of accurate information (Bowersox & Closs 1996), packaging solutions (Saghir 2004), etc. Bowersox and Closs (1996 p.79) declare that *"in a value-added context, firms can provide unique product packages, create customized labels, create special bulk packaging, offer information services to facilitate purchasing, place prices on products, build point-of-sale displays, and so forth, to stimulate business."* However, while these activities in themselves only serve as concepts and strategies with the potential to increase value and create differentiation, the value will depend on their execution i.e. on the skills of both management and the people who actually produce and deliver items, meet and talk to the customers. In conclusion, logistics capabilities lie in the complex constellation of all of these activities; their exploration, evaluation, execution, and use. Furthermore, the human aspects of logistics become central as do operational day-by-day achievements.

However, while there are several capabilities, competences and concepts with the possibility to offer increased customer satisfaction, their potential might be constrained by mechanistically derived mind-sets, theories, approaches, and methods. In such contexts organizations are treated as stable economic phenomena which best prosper in equilibrium and with the unifying goal of profit maximization (Hopper & Powell 1985) and survival. Consequently, logistics becomes a means for achieving such constraining and limiting beliefs and the underlying assumptions are accordingly transferred to the value-adding features of logistics. This might be critical as logistics focus should be transferred to demand and customer issues.

Realizing the efficiency/effectiveness paradox in the striving for demand-oriented effective research and practice could benefit companies' intentions to satisfy customer demands and thus lead to competitive advantage and survival. It is important to point out that realizing this paradox does not imply or mean "solving" the paradox since that cannot be done. The alternatives will always be unlimited, and choices of what to do and doing that right will prevail. Nonetheless, a realization of the paradox might open up issues of responsiveness and adaptability for people in organizations. However, in order to further elaborate on this paradox and realize any potential of increasing adaptability there are other paradoxes which need to be assessed in the logistics context. The following matter is that of control.

4.1.2 The paradox of control

While logistics theories and modeling approaches used in logistics are also often based on simplifications such as linear causality and determinism, real-life logistics practice is characterized by last-minute changes and rearrangements due to different people's interpretations, accidents, changes in customer demands, machine and computer breakdowns, mistakes etc. This view is supported by Lissack (1999) who states that control and predictive assumptions are paramount in the customary literature on management where objective reality is taken for granted and cause-and-effect relationships are promoted. This apparent difference in theory and practice is paradoxical in its nature and certainly of misleading character in many contexts and situations since reality changes in unpredictably, and sometimes outrageous ways.

Stacey, Griffin and Shaw (2000, p.18), have observed that *"most managers continue to believe that their role is essentially one of designing an organization and controlling its activities."* However, they (ibid. p.4) also put forward another observation which could be regarded as paradoxical to the belief that managers can design and be in control, because several managers agreed that in their day-to-day operations they were *"the ones in charge but repeatedly finding that they where not in control."* Consequently, firms' efforts to manage logistics systems and processes have often resulted in frustration and anxiety (Choi, Dooley & Rungtusanathan 2001), not least for the managers who are supposed to be in charge.

Thus, logistics operations are frequently subject to a rationalistic approach and teleology. Following this logic means that actions should be planned and decided by the executive management responsible for logistics, who have the advantage of viewing the logistics system from "above" i.e. the plan will be based on an objective view of the logistics phenomena. The planned actions are then being properly distributed by the management to the right places where each action is performed in accordance to stated subobjectives i.e. a top-down approach. Furthermore, performance measurements are set for each part in the logistics flow. Hence, the assumption is that someone has the ability to stand outside “existing” systems such as the production system, the inventory system, and the transportation system. In this decision process the assistance of normative methods and models ensure what has to be done. Barnes (2002), in his writing about manufacturing strategy, argues that there are numerous models following Skinner’s top-down approach (e.g. Hill (1995) and Platts & Gregory (1990)). He explains that *“all these approaches continue to view manufacturing strategy within a formulate-then-implement paradigm”* (Barnes 2002 p.1092). Another example is provided by Burcher and Stevens (1996, in Hendry 1998 p.1089) who state that the basic steps in changing a company’s operations toward world-class manufacturing are:

1. *starting point - understanding the current situation;*
2. *objectives - understanding what the organization should look like;*
3. *strategy - building suitable measures of change that will then drive the process forward.*

In the literature available this exploration and evaluation phase is often simplified into a few steps which are of a prescriptive nature. Reflection on such normative and simplified suggestions for the process of deciding the right things to do reveals that there are several questionable assumptions made which certainly create paradoxes in the minds of the decision-makers.

It is important at this point to emphasize that a complexity approach does not claim that planning is not useful, however, it is the emphasis on the planning process among individuals involved in certain projects or processes which is of value, not the actual plan itself. As Allen (2000a p.2) states *“it is this dialogue between successive "systems" and their own inner "richness" that provides the capacity for continuous adaptation and change.”*

In this control-focused logic it follows that logistics management (or other top management dealing with logistics) are also the ones who can chose strategy since they have the ability to set goals for the future. Bowersox and Closs (1996 p.459), exemplify the goal-setting ability by arguing that use of the systems concept in logistics stresses *"total integrated effort toward the accomplishment of predetermined objectives."* The actual determination of predetermined objectives or goals, which are to be implicitly realized, is paradoxical in nature. On one hand, there is a psychological dimension which makes people feel comfortable. This dimension could be regarded as a defense against anxiety (Stacey 2002) with "knowing" and sharing what to aim for with each other, which increases the perception of being in control. On the other, experience tells people that the world will probably change on them at the same time as new opportunities and problems occur more or less randomly. In other words, as discussed in the introduction, the adaptive process, i.e. the process of reactive and proactive improvement behavior, is "double edged" since there is nothing but time which will reveal the actual outcome of any deliberate effort. Barnes (2002 p.1103) concludes that *"the main finding from the research is that manufacturing strategy is formed in a complex process involving a combination of deliberate and emergent actions and decisions."* This finding is supported by studies conducted by Mintzberg (1987). In other words, non-linear relationships of self-organizing character emerge in logistics processes and activities, and sometimes create novelty and innovations, and sometimes chaos and frustration for people involved.

Nonetheless, when a deadline has passed and any follow-up studies and discussions have been carried out, those who set the objectives can agree or disagree about whether they fulfilled their original intentions and as Allen states, *"it is through this process of "post-hoc explanation" that we rationalize events by pretending that there was some pre-existing "niche" that was revealed by events, although in reality there may have been a million possible niches and one particular one arose"* (2000b p.100). Added to this is the statement Johannessen (2003 p.18) makes, namely that *"past is understood and changed by interpretations in the present, and expectations of the future are also constructed in human action in the living present."* Snowden and Stanbridge (2004) postulate that this behavior relies on a confusion of correlation with causation and they point to the retrospective- or post-validation of case material, which suits consultancy approaches where best-practice cases are used to inhibit change in other organizations. They come to the conclusion that *"much research in management science makes a basic error in logic in assuming that because successful companies have certain types of organizational structures, strategic processes or whatever, that the assumption of those organization structures or strategic processes by another company will lead to that company being successful"* (ibid. 2004 p.146). Furthermore, since self-organization is a non-controllable process for any manager and the emerging outcome is unpredictable, implementing other organizational structures, successful processes cannot work, which is described by Stacey, Griffin and Shaw (2000, p.145): *"if managers are choosing what emerges, then it is not emerging"*.

Another limiting factor to the control logic which supports the control paradox is the fact that logistics processes are seldom interpreted the same way by people actually working with the logistics activities within them. In this regard Hopper and Powell (1985 p.429) state: *"there is no such thing as a totally objective and value free investigation."* Nonetheless, common models and most logistics frameworks are based on an objective reality and homogeneity of the constituent parts. In contrast to what is assumed in these models and frameworks, the actions people take in real-life activities are based on the perpetual construction of reality each individual makes i.e. their subjective and sometimes inter-subjective perspective of what they experience. For example, Rigby et al. (2000 p.184) conclude that *"managers' expectations or fears concerning the behavior of suppliers and customers – is as important as data on stock turns or delivery patterns"* concerning the complexity involved in making business processes agile among companies. Thus, the rationality which is often assumed in logistics theories and modeling approaches barely exists in logistics practice due, for example, to people's diverse personal agendas and goals, lack of perfect information, the impossibility of perfectly assimilating all available information, the decision speed needed, the fact that people hold different beliefs or simply do not understand each other. Consequently, in order to capture logistics operations, the bounded rationality the elements within are characterized by should be considered (Darley 1999). Sometimes tiny changes in behavior or activities can escalate into huge effects on customer value or production results, both positive and negative effects. Furthermore, due to increased interconnectivity in supply networks this escalation of details changing is supposed to increase as the interconnectivity brings increasingly complex dynamics. This sensitivity to details is reported as an increasing problem for companies (see appended paper three).

4.1.3 The paradox of optimization

One aspect that has been of interest in mathematics, driven by different fields of physics, is that of optimization. Its mathematical definition can be explained in the following way: a function $f(x, y)$ in this case including two variables *x* and *y* which are defined in some kind of phase space $\Re^n$ defined in *n* dimensions i.e. $(x, y) \in \Re^n$ and in this phase space a maximum or minimum point (depending on what is predetermined) is to be found. Consequently, as argued before in this thesis, since logistics is based on mechanistic principles derived from mathematics the compelling notion of optimization in logistics has been prevalent. For example, when it comes to supply-management interface capabilities Mentzer, Min and Bobbitt (2004) make the following proposition:

> *"Logistics supply-management interface capabilities lead to optimization of the total process of logistics activities, which leads to minimization of system-wide total cost, which leads to competitive advantage."*

The proposition made for supply-management interface capabilities follows mainstream research in logistics and implies, even when "softly" interpreted, mechanical assumptions and a rationalistic and/or formative teleology. The reasons for that are as follows; first, the use of optimization can be interpreted as finding the best solution possible i.e. one seen from someone's subjective perspective (a logistics manager) in a specific context and which is highly dynamically interdependent of other aspects and activities. However, as it is used in the logistics literature available it might also be referred to as a belief in actually finding the best, most objective solution i.e. that there exists (with enough mathematics and physics) a countable optimum hidden in the structures and procedures for any total logistics process. Second, the use of the total process implies another mechanistic assumption; that the all relevant activities and processes can be identified and considered in the process of minimizing system-wide total cost. Again, this assumption of totality relies on objectivity and stable conditions, since any considerations of individual or group perspectives, i.e. subjective or multiple perspectives are not taken into account.

Nonetheless, the great advantage of the proposition above and other similar ones found in the literature available is of course that it fits into the prevailing paradigm which exists both in theory and practice. The use of the term *optimization* in socio-technical contexts is often used by decision-makers and is often the basis for decision-making derived from traditional modeling tools (Shapiro 2001) (e.g. spread-sheets, linear programming, mixed integer programming) which are based on greatly reduced and simplified input and behavior, and can therefore be optimized. The users of the tools then transfer the outcome of the models back to reality in the form of plans. Mears-Young and Jackson (1997) argue that from a logistics perspective, people as well as artifacts, can be engineered in order for the objective of optimization to be realized.

The result of such optimization efforts is repeatedly that effects in parts not directly involved, measured or considered are not addressed, and when efforts are made to sum up the decomposed activities, the real-life result differs, sometimes extensively, from the intended. A truck driver working for one of the major logistics providers in Europe explained that *"when driving a delivery from the north of Sweden to the distribution center in Malmö, nothing is permitted to go wrong. Construct work on the roads is not allowed, truck breakdowns cannot happen, police stops may be much to time consuming, and recovery breaks are heavily limited in time."* Despite the fact that unwanted factors are not "allowed" to interfere in optimally generated model results, these things do happen. Nonetheless, the optimization results in the models created are of course mathematically correct; they are the result of what in the model was intended to be examined, and the results can be generated over and over again e.g. by other researchers. However, as von Hayek (1989 p.5) states *"I confess that I prefer true but imperfect knowledge even if it leaves much undetermined and unpredictable, to a pretence of exact knowledge that is likely to be false. … The credit* *which the apparent conformity with recognized scientific standards can gain for seemingly simple but false theories may, as the present instance shows, have grave consequences.*“ Furthermore, Rigby et al. (2000 p.184) discuss the possibilities of agility in supply networks and states that *“rather than treating … agile networks as a predictable and in some way ‘manageable’, we would argue that a great degree of complexity exists in this domain. This may pose problematic questions for prescriptive accounts that map in some way an "ideal" solution for ‘aligning’ optimal solutions in an agile environment.”*

The reasons for this difference in the optimized outcomes are, among others, that interrelationships and interdependencies are neglected. For example, between inventory and production there are interdependencies affecting the other’s resources and costs such as batch sizes in production versus inventory levels. Furthermore, from a complexity perspective it is not possible to “find” or “map” these interdependencies and interrelationships since they perpetually change, as do the perceptions of those people who observe them. In addition, apparent behaviors such as self-organization, emergence, and adaptation among the people working in logistics processes are not considered (Nilsson 2003). Consequently, in order to further develop logistics capabilities a major distinction needs to be made, and that is the one between technical systems and socio-technical phenomena. For technical systems e.g. automatic production processes, interconnected machines, automatic storage facilities and groups of such, mathematical models may find “validity” and usefulness. However, as technology advances in these systems, several objectives and constraints, which often are conflicting, need to be considered concurrently. According to Karageorgos et al. (2003) most optimization problems encountered in manufacturing and logistics operations are non-deterministic polynomial (NP) problems, meaning that the required calculation time for finding the numerical optimal solution grows at least exponentially with the size of the problem. However, while proposing optimality of total systems Mentzer, Min and Bobbit (2004 p.615) claim that the supply-management interface capabilities also include *“proactive, timely, and creative logistics solutions to situation-, emergency- or customer specific problems.”* Such a statement could imply that human aspects are considered, since proactive and creative solutions to logistics problems do not fit into optimization efforts and therefore suggest the simultaneous impossibility of optimization resolved in the paradox. This shows the dimension when technology is put into a social context.

Consequently, for socio-technical phenomena, in which technical systems are developed, created and used, considerations of other types of behavior are needed. From a complexity perspective this behavior is mostly of a transformational character where the extended set of assumptions (see Figure 3.1, chapter three) needs consideration. There are several beneficial aspects of extending the assumptions and considering a complexity perspective on logistics supply-management interface capabilities. These rely on the fact that by focusing on the effectiveness of different processes instead of today's efforts on efficiency, the dominant cost-reducing focus can be complemented with both profitability-enhancing activities and with higher leverage from improvement efforts. The profit-enhancing activities i.e. effectiveness efforts are restrained in the optimization beliefs since these need a different type of logic. This logic covers human-related aspects such as creativity and innovativeness and from this novel processes and activities can thus be created i.e. different ways of fulfilling customer requirements, and ensuring the satisfaction of other stakeholders involved.

4.1.4 The cooperation/competition paradox

Finally, the paradox of cooperation/competition is another paradox to be found in logistics. It is based on the striving for the *"ideal"* cooperative situation of a supply chain as a single unity with unifying goals, and in that striving subjectivism, power and avoidance of conflict are hidden. I think a vision of an ideal situation and overall harmony is laudable - and I hope that some day it can be realized; however, in today's world one must question how realistic such beliefs are. As Mears-Young and Jackson (1997 p.610) state, *"the aims of logistics rest upon the assumption that all members of the organization can be brought into agreement."* The examples supporting this statement can easily be found; for example, Lambert, Cooper and Pagh (1998 p.9) state that the lack of inter-company consistency in different company structures or differences in naming activities and processes is a *"cause of significant friction and* *inefficiencies in supply chains."* Furthermore Yu, Yan and Cheng (2001) state that supply chain management "*emphasizes the overall and long-time benefit of all parties on the chain through cooperation and information sharing."* Finally, Gentry (1996 p.36) refers to the chain viewed as a whole, *"a single entity rather than fragmented groups."* These statements together with those of other researchers and practitioners predict that the competition of today and even more of tomorrow will be between supply chains or networks, not companies, so that the issue of cooperation becomes even more important. However, Rice and Hoppe (2001) challenge this predictive approach. They argue that the supply networks will not, in most cases, be a group of companies working together as one entity. Instead, there will be suppliers who have customers in several networks and there will also be customers who have suppliers from several networks. Thus, this implies some problems for logisticians if we are to believe in free markets and competition as a means for providing the customers and consumers with best value.

The question of *who really should have unified views and common goals* is never asked. Furthermore, *who should cooperate* is never addressed. In addition, how should the unifying goal be set and achieved? In the literature available it is said the firms which leave the interpretation space wide open for subjective interpretation. In this regard, Johannessen (2003 p.11) declares; "*The everyday conflicts and unpredictability of human relating is not examined and explored, leaving the recommendations seemingly easy and straightforward to adopt and implement in any organization"*

Furthermore, the notion of power is something that is seldom treated in supply chain writing (Cox 1999b; Mears-Young & Jackson 1997), despite the fact that it is a factor which "everyone" finds important and something which has an impact on what really happens within the areas of cooperation and competition (Barnes 2002). *"Logisticians expect the right, apparently, to assume overall responsibility for an activity that affects most of the organisation"* (Mears-Young & Jackson 1997 p.616). Bagchi and Skjoett-Larsen (2003 p.92) provide a good example from theory when they declare that *"the objective of organizational integration is not merely to resolve conflicts, but* *rather to recognize and avoid potential conflicts and/or divergence of interest in advance and device and governance structure to forestall or avoid it."* This fits very well into the realm of a rationalist perspective where the manager is assigned the role of removing ambiguity and conflict to secure consensus, by all means. However, as noted in Bagchi and Skjoett-Larsen study on information and organization integration in supply chains, many of the respondents claimed a fear for probable loss of proprietary information and loss of control in sharing business information with suppliers. In interviews with managers they report that the barriers to integration were; 1) fixed mind-set of managers, 2) lack of trust and the fear of sensitive business information falling into competitors' hands; 3) every member of the supply chain not being equally prepared; 4) loss of control, 5) multiple IT platforms (ibid. 2003). In their conclusions Bagchi and Skjoett-Larsen (2003 p.104) propose that: *"the success of a drive to integrate the supply chain depends on the power, influence, motivation and zeal of the prime mover in the supply chain."* They also propose that a high degree of supply chain integration is not necessarily desirable in all situations. Furthermore, Williams, Maull and Ellis (2002), in their study of capabilities in global aerospace supply webs, report that many companies do not operate within single tiers, which means that required capabilities cannot be assessed easily. Since they are highly dynamic the capabilities are changing depending on the fact that driving factors evolve. Thus, while the overall ideas of unity, harmony, and consensus among supply chain members mean that they should act as one entity, reports from empirical studies bear witness to a different reality.

Nonetheless, the apparent avoidance of discussions and implications of what power means in logistics research and practice is claimed, in this thesis, to be derived from the fact that power does not fit into the underlying rationalistic and positivistic assumptions. Power impacts are difficult (if not impossible) to quantify, and in a world of rational individuals with unifying goals the issues of conflict and power do not "exist." While there are a few researchers who address the power issue in logistics, Cox (1999b) claims that for practitioners in supply chains it is essential to understand the power structures which exist.

From a complexity perspective *"novel organizational developments are caused by the political, social and psychological nature of human relationships"* (Stacey, Griffin, & Shaw 2000 p.124). In other words, generating novel logistics developments is about recognizing both cooperative aspects and those highly apparent in real-life logistics; namely, conflicts, power, and politics. This is also to say that subjective dimensions in logistics are accepted and recognized which means rejecting the belief of equifinality and instead recognizing the idea of continual transformations. Thus, common goals are transformative as well as identities. Hence, acceptance of this transformative nature of change might provide increased understanding of the paradox of cooperation/competition.

To summarize then, what the avoidance of these paradoxes provides is a self-reinforcing belief of running the machine faster. Ignoring the empirically identifiable paradoxical processes which take place on a daily basis, and the effect these have in theories which both researchers and practitioners use and are affected by, results, from a complexity perspective, in less valuable guidance and understanding. One could then ask: Why this great emphasis on an efficiency focus?

There are, of course, several arguments for logistics research and management to focus on doing things right i.e. on efficiency-enhancing efforts rather than on effectiveness. First of all, **it is needed**. There has been much "waste" to be reduced in several logistics-related areas i.e. inefficiencies that were devastating for business. However, as declared at the beginning of this thesis, as turbulence on markets intensifies, the dynamics of market places and industries are escalating, that the question becomes more that of *what* to do, than just doing things fast and efficient.

Secondly, **it is easier**. It is far easier to divide and conquer, i.e. reduce a phenomenon to its "simplest" parts, and from that, approximate linear relationships among the set of "variables" in each sub-system created, than keep as much of the complex phenomena which, nonetheless, are where any efforts decided on should be "implemented". For example Humphrey, Taylor and Landers (1998 p.612) state that *"many current solution methods for determining optimal stocking quantities are* *based on the simplifying assumption that parameters are known deterministically.”* The quantification simplifies matters and with the new technology provided by ERP systems connected with real-time data from processes and activities performed globally, the quantification emphasis is a self-reinforcing process.

Thirdly, **it can be measured.** While it is essentially impossible to measure all the choices which can be made, it is far easier to measure what has been decided on and actually been carried out i.e. for the purpose of doing things right. As is often said; *“you get what you measure”* (Hendry 1998 p.1094), consequently, in line with the mechanistic efficiency paradigm, making an effort in measurable activities or processes is one of the cornerstones in logistics research and practice. However, Robson (2004 p.510) begins his article with the following statement: *“Measurement has become such an accepted approach within organizations that considerable effort is expended in trying to identify "What" can be measured and "How" to measure it. However, few people genuinely challenge "Why" they should measure in the first place.”* He continues by arguing that *“One of the consistent problems with focusing managers and staff on improving the performance of their local processes is that often, the local measurement systems are in conflict with improving the overall performance. This becomes particularly obvious when measures have been chosen on the basis of whatever is the easiest to measure and then used as part of a reward system”* (2004 p.517).

Thirdly, **it can be rewarded**. From the previous statement it follows that a fourth reason to focus on efficiency is that is can be rewarded. Since company bonuses and division audits are typically based on the measurement systems used, a production unit will strive to maximize production utility, inventory units strive for low inventories if promoted, the transportation unit for fast deliveries etc.

4.2 Implications of a complexity perspective on logistics

The implications a complexity perspective has on logistics research and practice is illustrated here by a discussion of one of the main purposes of logistics management i.e. "*to meet customers' requirements*"[5] especially with time and place utility. This is by definition related to adaptation since it demands interpretation concerning customer requirements in both proactive activities and reactive/responsive actions. This is especially the case for logistics managers concerning their efforts in planning and controlling activities needed for customer fulfillment. Since the market is becoming increasingly interconnected, and the amount of available data and information is escalating, there are several factors which might influence customer requirements. These factors affect undoubtedly also the people involved in the actual handling, flow, and storage of products as well as information. This leaves logistics management with great interpretation consequences since emergent phenomena are unpredictable and the managers are not in the position of an observer or designer standing outside the logistics system. Still, they are supposed to plan and control the flows of products and information in increasingly interconnected supply networks. What is needed to handle this paradox of control and other associated paradoxes (such as efficiency/effectiveness etc.) is a more balanced view of planning and control, balanced with considerations to the discussed extended set of assumptions being less mechanical i.e. adaptation, self-organization, emergence, etc.

For logistics research and practice to realize the paradoxes of efficiency/effectiveness, control, optimization, and cooperation/competition, the complexity perspective provides a paradigmatic perspective on logistics activities, based on human and human organizational assumptions, which could furnish novel insights and increased understanding. A central point in the complexity perspective is consideration of the actual work being done on a day-to-day basis. This perspective, which is sometimes referred to as a bottom-up perspective, could act as a complement to the dominant logistics focus on global phenomena and the associated top-down approach related to this. The reasons for such a bottom-up perspective on logistics are several.

- Firstly, since "*the complex whole may exhibit properties that are not readily explained by understanding the parts*" (Kauffman 1995 p.VII), the result is that emergent phenomena formed from the bottom-up i.e. everyday activities,

[5] http://www.cscmp.org/AboutCSCMP/Definitions/Definitions.asp, 20050315.

by local interactions of autonomous individuals and parts, are not being captured. Bonabeau (2002) observes that emergent phenomena may in several cases be counter-intuitive, which makes these emergent phenomena impossible for managers to either plan nor control, especially with the aid of over-simplified models and tools.

- Secondly, the individual level is of major importance for logistics management since it is on this level that actions are performed, and affected by people with free wills. As a result of their actions and the perpetual interpretations of the outcome of other individuals' actions, global phenomena emerge. Allen points out that in the process of sense-making: *"there is a complex and changing relationship between latent and revealed preferences, as individuals experience the system and question their own assumptions and goals"* (Allen 2000b p.83). Bonabeau (2002) states that it is the individuals within firms (and not processes) who make mistakes and cause errors and he goes as far to point to a paradigm shift from spreadsheet- and process-oriented approaches to focus on the individuals. Furthermore, the individuals are the ones who are often involved in customer processes and consequently, their actions along the value-adding flow affect the performance of the logistics processes.
- Thirdly, the processes of self-organization underlie most of the actual work being done (Allen, Ramlogan, & Randles 2002) and from those processes emerges dynamic order, as coherent patterns of behavior which are not controllable from a traditional point of view but are still highly apparent in most situations, especially in those day-to-day activities between meetings (Stacey et al. 2000). Hence, as declared in my licentiate thesis about self-organization *"From a positivistic perspective, self-organization causes uncertainty and since it cannot be effectively controlled, planned or designed it should be reduced, or even eliminated. However, this process of self-organization is in several cases the reason for novelty, creativity and innovativeness"* (Nilsson 2003 p.33), and needs to be considered in order to understand and make sense of logistics processes and phenomena.

Consequently, in order to deal with increasingly faster and more complex contexts and demands i.e. become more effective, what is proposed for logistics research and practice is a shift in mind-set. Park addresses this clearly by stating that *"executives must realize that the old top-down, command-and-control structure is ineffective, and in many cases counterproductive"* (Park 2000 p.61). In chapter ten, the complexity framework for adaptive logistics is presented, which is the proposed framework in this thesis for how to approach such a change process, from a mere formative-, planning-, command-, and control-mind-set to consideration of an adaptive, complex way of thinking.

However, while the arguments and thinking related to an adaptive and complex approach can generally theoretically and conceptually be agreed on by both researchers and managers, a vital issue for the creation of a complexity framework for adaptive logistics is operationalization. The major reason is that they need to be motivated and aided with applicable methods, and often presented with practical implications, in order to understand, accept and even consider the potential implications a complexity perspective may have on logistics activities and business performance. This is the aim of the forthcoming chapter in Part II, 'Putting Theory into Practice'.

5 Summary: Part I

This part of the thesis sets out to answer the first set of research questions provided in the first chapter; namely,

- How are logistics phenomena being regarded in theory and practice? As complicated or complex?

Based on the discussion in this first part the definitive answer to this question is complicated. The major reasons for such a conclusion are:

1. When the complexity of logistics is addressed, in most cases the high number of parts, products, etc. is referred to.
2. Based on the underlying positivistic and mechanistic assumptions it is evident that such assumptions do not find much applicability in the perceived reality researchers and practitioners confront on a daily basis. This is especially exemplified in some paradoxes identifiable in the logistics discipline, for example:
   a. The paradox of efficiency/effectiveness, where the focus on efficiency is and has been dominant in logistics and where the effectiveness dimension has so far gained less attention. Nonetheless, in the demand management movement which has recently started up, the effectiveness of business operations is addressed. However, in gaining this effectiveness it is concluded in this thesis that mechanistic assumptions may be restraining and thus what is needed is a reassessment of assumptions, not only a transfer of assumptions in a new perspective.
   b. The paradox of control which relies on assumptions of linear causality, objectivity, rationality, and top-down mentality which all reinforce the belief of controllability at the same time as reality “deludes” and make life difficult for both researchers and practitioners. The confronting reality can be understood and explained by assumptions of self-organization, emergence, non-linearity, unorder etc.
   c. The paradox of optimization being a third paradox that in an ever-changing context needs to be dealt with. The wishes for optimality in both research and practice need consideration, especially for the type of

phenomena it is applied to i.e. technical versus social. Today, this distinction is not made since suggestions and models on optimizing whole supply chains are presented in the logistics literature.

d. The final paradox of cooperation/competition also sheds light on the simplistic views of supply chains as single organisms. While the overall idea is that of unity, harmony, consensus among supply chain members which should act as one entity, reports from empirical studies show a different reality.

In conclusion, answering the second research question, treating logistics as complex means considering human involvement and the paradoxes created in human interactions. Consequently, it also means considering the concrete, actual work being done together with the mental models created by the humans involved. Thus, this thesis takes the standpoint that logistics processes, where human beings are involved, are not simply a sequence of mechanical devices which can be assumed to work by positivistic beliefs, but instead a complex network of living, innovative, creative, and evolving creatures which react and adapt dynamically to their perceived environment and try to proactively create what they themselves, or collectively with others, find to be beneficial for their own interests.

Part II

If we can do something in practice,
it will probably work in theory.

6 Putting theory into practice

Ontological and epistemological assumptions are prerequisites for the methodological and method-related assumptions and choices which are being made in both research and practice (Burrel & Morgan 1979; Morgan 1983). Consequently, going from the first part's paradigmatic discussion concerning assumptions has direct implications for the approaches, methods and tools to be pragmatically used when a more complex paradigmatic view lies as the foundation. This raises the following questions:

- How can this new complexity-inspired mind-set be "operationalized"?
- What type of novel approaches can support and help logistics decision-makers in generating increased effectiveness i.e. gaining most leverage in their improvement efforts?
- In addition, what type of approaches, methods and tools can be used to deal with perceived unscheduled dynamics i.e. everyday changes?

In order to provide suitable answers to how the complexity framework can be implemented and to how a change in mind-set for people making logistics-related choices can be achieved, this research has revealed that some kind of working method may be of value. There are several methods which are beneficial in any change process, such as workshops, systemic learning and meetings (Sarv & Landborn 2003), contextualization methods such as narrative techniques (Kurtz & Snowden 2003), self-evaluations etc. These methods are useful and researchers/practitioners are encouraged to use them when approaching a logistics phenomenon or problem with the adaptive logistics approach based on the complexity framework. However, there is a growing interest both from academia and industry in modeling and simulation, driven partly by the fact that both software and hardware are being successfully designed to handle large amounts of data rapidly. At the same time companies are measuring and storing large mounts of data from various sources (e.g. production, sales, orders, energy consumption, etc.). Taking these two trends together means that we are now in the situation that we have vast amounts of data, and appropriate software and hardware to process it with. Technological improvements together with increased data gathering in companies open up the field for pedagogical tools which may be valuable in bring about a change of mind-set and provide practitioners with examples of new methods and tools which can handle greater degrees of complication. The use of computerized models and simulations in logistics is not new (see for example Hellström (2004), Disney Naim, & Towill (1997)) and has resulted in solutions produced in several logistics contexts, such as the salesman's dilemma etc.

However, while the use of models and simulations is widespread, there are seldom discussions about the assumptions necessary to transfer reality into these models, since general conclusions about real phenomena are often drawn rather too easily from the results of the models and simulations. An assessment of common logistics tools in this regard shows that, to a great extent, they are based on assumptions of a mechanical and positivistic character. I will briefly discuss some of the "complexity"-reducing frameworks and methods which are currently used in industry and taught on logistics educational programs to a great extent

The traditional approach to logistics and supply-chain modeling and analysis has been carried out by using control theory models (differential equations) and operations research methods (optimization theory, game theory, and statistical analysis). However, most of these are static approaches (Changrui et al. 2002) and are not made for handling the dynamical characteristics of the supply chain (Davidsson & Wernstedt 2002; Swaminathan, Smith, & Sadeh 1998). Parunak (1993 p.2) states that *"the fundamental problem is that schedulers manipulate models of the factory, which are subject only to mathematical laws, while actual shop floor is subject to the laws of nature (primarily physics and psychology) which lead to random events and emergent behavior."*

One of the most widely used methods in logistics research, practice and teaching is linear mathematical programming (Chen & Wang 1997) and one example of its use is to optimize resource allocations in supply chains. Vidal and Goetschalckx (2000 p.96) state that *"there are many articles on quantitative techniques for the improvement* *and optimization of supply chains, and MIP[6] models are among the most widely used techniques."* This is a good example of an applied method based on mechanical assumptions. According to Shapiro (2001 p.85), there are five fundamental properties accepted in linear programming. These are: 1) linearity 2) separability and additivity 3) indivisibility and continuity 4) single objective function, and 5) data known with certainty. Vidal and Goetschalckx (2000) describe assumptions in mathematical programming and mathematical integer programming when these methods are applied to logistics and supply chain management:

- First, customer demand satisfaction is included in most MP formulations by assuming deterministic demand.
- Second, transportation and production costs are assumed to be linear for most of the formulations.
- Third, the calculation of inventory costs in distribution centers, if included at all, usually assumes deterministic demands and deterministic lead times.

Changrui et al. (2002) conclude that traditional modeling methods for supply chains, especially in the present context when agility and responsiveness are increasing in importance, present a number of pitfalls. In particular, they point to the fact that traditional methods "*can consider only determinate and static problem models*" and they continue by stating that "*the restrictions to the models are too many to manage the stochastic factors which are ubiquitous in agile supply chain*" (ibid. 2002 p.1). Larsen, Morecroft and Thomsen (1999) stated a few years that ago that nonlinear dynamics is one of the most rapidly growing areas in science and it has gained interest from a wide variety of disciplines such as economics, biology, physics, and mathematics. Simultaneously, the authors conclude that "*the limitations of conventional linear analysis become more and more obvious*" (1999 p.62).

Another methodology used in the logistics discipline is system dynamics (Forrester 1968; Sterman 2000). With this methodology, complexity in logistics systems is handled by the use of feed-back mechanisms. In system dynamics these feed-back

[6] mathematical integer programming

mechanisms are mainly assessed by simulations since *“mathematical analytical solutions are impossible for exposing the nature of system models”* (Forrester 1968 p.401). The field is currently of great interest, since the increase in computer power has a great influence on simulation capabilities. The beer-game showing bullwhip effects has been researched by several research groups, both empirically and axiomatically (Dejonckheere et al. 2003; Dejonckheere et al. 2004; Lee, Padmanabhan, & Whang 1997a; Lee, Padmanabhan, & Whang 1997b; Souza, Zice, & Chaoyang 2000), and has been played in several logistics educational programs

Nonetheless, *“industrial dynamics is a philosophy of structure in systems”* (Forrester 1968 p.406). This focus on structures illustrates its connection to systems theory with the common assumption that structure drives behavior (Senge 1990). Furthermore, in some models, assumptions of rationality and optimizing behavior of the members are presumed (Lee, Padmanabhan, & Whang 1997b), and the methodology represents a mechanical representation of changes observed in logistics. Equilibrium, however, is not assumed (Allen 2000b). Instead of a single future equilibrium, system dynamics models can reach different types of equilibria, stable or unstable in their nature. System dynamics still represents a deterministic mechanism since the underlying events forming the properties of the whole are represented by their average (ibid.). Its connection to positivism is also noticeable since cause-and-effect relationships are of major importance. In this regard Souza, Zice and Chaoyang (2000 p.352) state that “*With this* [system dynamics] *experimental method, both cause and effect can be analyzed quantitatively.”* Additionally, no heterogeneity is considered among the individual events or parts in the systems i.e. the behavior on lower levels of examination is not addressed. In short, by making assumptions align to a system dynamics approach the researcher also assumes predictability and intervention in the systems under study.

The research behind this thesis indicates that, in order to move towards adaptability in logistics research and management, approaches, methods and models provided for managers as well as researchers, must be able to consider more constraints, conflicting demands and phenomena such as self-organization and emergence. This is because firms are becoming more complex in themselves as well as in their relationships with suppliers and customers, and the advent of increased turbulence facing almost all industries. Furthermore, a focus on adaptability may help firms to increase their ability to handle the unforeseen, but may also increase their understanding of what type of conditions are necessary to increase effectiveness and release the potential of logistics innovation.

What I have found to be necessary are methods and tools which are able to consider and treat more complicated conditions than those of today. This means a relaxation of the positivistic and mechanical assumptions which most of the common tools and methods used are guided by. In order to challenge the present dominant mind-set and even consider other ways of reasoning and thinking, e.g. a complexity framework as logistics logic, other types of implementation tools need to be considered.

While there might be several approaches available to address this change, my research results point to one applicable method in this regard, namely agent-based modeling (ABM). ABM is derived partly from object-oriented programming and distributed artificial intelligence (Jennings, Sycara, & Wooldridge 1998), and partly from insights found in the science of complexity (Axelrod 1997; Holland 1998; Kauffman 1995) and described by some researchers as a *"new tool for empirical research"* (Epstein 1999 p.41).

However, before continuing with the discussion it is crucial to make clear to the reader that I do not believe that agent-based modeling provides any method which can comprehensively consider all aspects of the complexity perspective discussed and described in the first part of this thesis. As Epstein (1999 p.55) states *"agent-based modeling is reductionist."* The ABM methodology should not be regarded as "the solution" to the author's knowledge it is only one of the more useful tools for handling more complicated situations. What ABM provides is a method and tool which can be "better" aligned to the complexity framework than any of the other tools (MP, MIP, System dynamics). In other words, ABM provides the opportunity to handle more complicated situations than stricter mathematical models. Thus, ABM cannot be the single method for a complex phenomenon, but can be used in providing insights and solutions for what can be considered its complicated elements. Furthermore, depending on the purpose of the study or improvement effort, i.e. efficiency or effectiveness improvements, or the phenomena under investigation, the choice of method and tools is essential. In this regard Epstein provides the following motivation; *"The choice of agents versus equations always hinges on the objectives of the analysis. Given some perfectly legitimate objectives, differential equations are the tool of choice; given others, they're not"* (1999 p.52). Shim et al. (2002) state in their article about decision support that active decision support will be the case for the next millennium where the use of software agents is recognized as one of the most promising and the possibilities for greater exploration of models in decision making and support are enormous. For the focus and purpose of this thesis i.e. making logistics more effective, the following subchapter will provide a description and discussion on agent-based modeling and more arguments on why and how it fits into the objectives of this thesis.

6.1 Agent-based modeling

In ABM the focus is on agents and their relationships with other agents or entities (Jennings, Sycara, & Wooldridge 1998). The agents represent real-life components characterized with some degree of autonomy, identified in the context of interest. Parunak, Savit and Riolo (1998) describe an agent as being a software entity with its own thread of control and with the ability to execute operations without being externally invoked. In the logistics context an agent might represent a machine, the order-handling process, inventory handling, trucks etc.; parts of logistics operations which are influenced or affected by individuals. As described earlier, the individuals involved in the logistics operations lacks perfect information, have their own goals, and sometimes their own policies i.e. they are heterogeneous and have bounded rationality. ABM provides a useful method to capture such behavior and the diversity that in real-life operations exists among different activities, individuals or groups of such.

In the logistics context ABM facilitates another characteristic of importance, namely the dynamical distribution of activities in both time and space (Lim & Zhang 2003; Wakeland et al. 2004). Parunak, Savit and Riolo (1998 p.19) state that *“the decomposition of a manufacturing enterprise into a network of firms and the decentralization of control that results make supply chains a natural domain for the use of agent technology.”* This means that with agent-based models and simulations, global as well as local behavior can be analyzed and evaluated. Consequently, validation and verification of any phenomenon being modeled can be carried out for each agent, and for the logistics situation as a whole. As discussed earlier (see chapter 1) the two important aspects of logistics, structure and dynamics, can be dealt with in ABM. Structure involves the distribution of activities in space since it involves physical distances of machines, people, processes etc. which are connected directly or indirectly to some extent. Dynamics, on the other hand suits the change of logistics activities i.e. the flow of products, packages and information from point of origin to point of consumption.

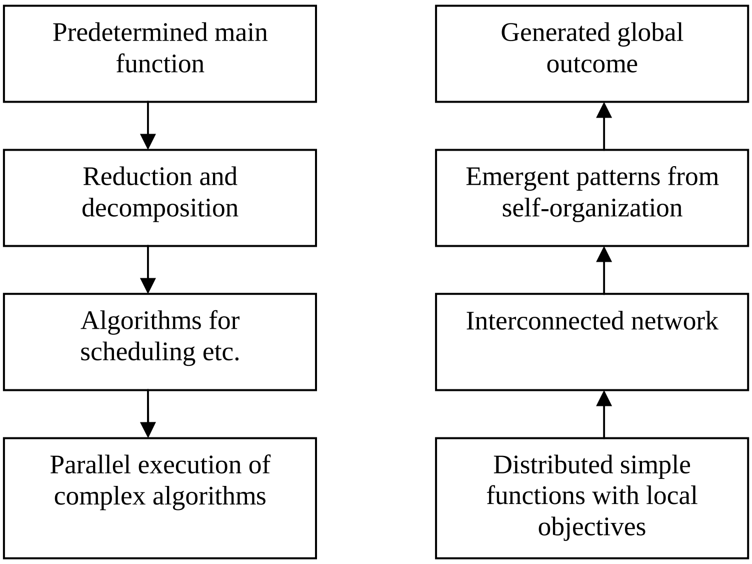
In the logistics context ABM provides a method which can handle real-life logistics operations to a high degree due to the fact that logistics is concerned with flows of goods being realized through dispersed activities in time and space. However, it also provide a more reality-aligned method since features for each agent such as bounded rationality and limited information as well as non-linearity, self-organization, emergence in the interactions among agents, may be considered in the development and use of models and simulations. Bonabeau (2002 p.110) states that in order to understand agent-based modeling *“you first need to understand the concept of emergent phenomena.”*

Another feature of agent-based modeling compared to conventional static approaches, which are often based on mathematical formulations (algorithms, differential equations or similar) with predetermined goal functions, is the bottom-up methodology by which an ABM model is constructed accordingly. In pragmatic research with empirical bounding this might seem to be an advantage, since the quest for the researcher or practitioner developing the model will directly assess activities, machines, and operations on their most concrete level. This means that when it comes to modeling and simulation there is no need to consider the whole phenomenon at once but instead let it be constructed and developed in the process of building the model. Focus can therefore be placed on the local and distributed parts since they may have their own working principles, goals, measurements, and stored data. This focus on the local context facilitates considerations of the heterogeneity of a phenomenon on its lowest level. In this regard, Davidsson and Wernstedt (2002 p.321) state that; *"since local predictions typically are more informed than global predictions, this approach should give better results."*

Reaidy et al. (2003) provide a comparison of conventional top-down oriented methodologies and agent-based bottom-up ones (see Figure 6.1). The top-down methodologies are based on the presumption that knowledge is outside the "system" and someone can measure and analyze the observable phenomenon of interest and from that decompose correctly to different subunits where the subproblems are solved separately. Then as Kreipl and Pinedo (2004 p.83) state *"at the end, the partial solutions are put together in a single overall solution."* Models which are constructed by global performance measures (also called observables (Parunak, Savit, & Riolo 1998)), cannot cope with the dynamics of their constituent parts since the observables are constructed of aggregated behaviors of the whole system (Swaminathan, Smith, & Sadeh 1998). This top-down assumption is inherited from the positivistic paradigm built on mechanistic assumptions and reductionism. In this regard, Kauffman (1995 p.VII) states that *"the past three centuries of science have been predominantly reductionist, attempting to break complex systems into simple parts, and those parts, in turn, into simpler parts."*

Bottom-up methodologies are based instead of a synthesizing philosophy, where the user presumes that he/she cannot understand the whole phenomenon of interest but can observe different activities and processes, and try to understand their behavior and their objectives. These agents (the processes or activities) interact and communicate with other agents and they join to form a coherent whole (d'Inverno &

Luck 2001). Global patterns emerge from these interacting and interrelated networks of agents i.e. a generated global outcome from more or less self-organizing agents.



I. Traditional static approach

II. Agent-based approach based on dynamic interactions

Figure 6.1. Comparison between traditional modeling methodologies and bottom-up methodologies. Derived and modified from Reaidy et al. (2003 p.151).

It might seem to the reader that agents and objects are similar in nature, which they are, however, there are differences in both their construction and execution. Jennings, Sycara and Wooldridge (1998) provide a number of differences between the concepts. The first relates to the degree of autonomy, where an agent embodies a stronger notion of autonomy (Wooldridge 2002). Jennings, Sycara and Wooldridge (1998) define it as "*objects do it for free; agents do it for money.*" Another distinction between object and agent systems is with respect to the notion of flexible (reactive, pro-active, social) autonomous behavior. In general, objects are passive i.e. they need to receive a message or similar in order to become active; agents have their internal mechanism for that (Jennings & Bussmann 2003). A third distinction lies on the model level, where the agents in agent based models are each considered to have their own thread of control whereas in the standard object model, there is a single thread of control in the system (Jennings, Sycara, & Wooldridge 1998).

However, while several arguments can be provided for ABM as a method for assessing dynamic and distributed problems with regard to non-linearity and stochastic aspects (e.g. like those of logistics and operations), there are some aspects which need special consideration. This is mainly because the models cannot create anything themselves, the interpretation of the models will always be related to the developer and user. In this regard, Richardson (2003 p.8) issues a word of warning that *"models are tools that can be used and abused – the best models are worthless in linear hands."*

First of all, it is important to clarify the notion that an agent-based model will only be as accurate as the assumptions and data which went into it. Even approximate simulations based on assumptions related to human behavior can be valuable if treated with care and reflection of the assumptions involved. Stacey, Griffin and Shaw (2000) particularly address this issue of transferring human behavior to rules and procedures in a computer and point out that the rich texture of emotional and embodied relating is lost as is any creative action. Furthermore, any model constructed will only be a model i.e. a simplification of some phenomenon of interest. However, it is also of value to mention that fewer reductions and simplifications are needed when constructing an agent-based simulation than with other approaches common to the logistics discipline. Hence, despite the critics, more real-life behavior can be included, even though it is far from reality.

Another aspect that is disadvantageous is the cost of time and resources in developing the model i.e. gathering data, verifications, testing, and communication. However, the positive outcome of many hours of development is that the model and simulation will be rigorously constructed since any small mistake, any misinterpretations of rules, policies, behaviors or any problems with the data will directly affect the end result. In other words, the process of making the developed model useful demands patience, and deep understanding of the phenomenon being modeled.

Furthermore, in the context of logistics and supply chain management, since ABM simulations are empirically tightly bounded, the models need to be updated on a regular basis with policies, rules, states and other types of data in order to provide enough similarities with the modeled reality to be valuable and useful. This means that providing the models with such information may be a costly step.

6.1.1 Agent-based modeling in logistics and supply chain management

There are a growing number of books and articles in various journals that describe frameworks for using ABM in a range of areas such as logistics and supply chain management (Gerber, Russ, & Klusch 2003; Kaihara 2003; Knirsch & Timm 1999; Santos, Zhang, & Luh 2003; Schieritz & Grossler 2003) and operations management. (Chun, Weiming, & Ghenniwa 2003; Kotak et al. 2003; Lim & Zhang 2003; Zhou et al. 2003). However, few of these books and articles rely on any theoretical framework and even fewer on the science of complexity. I will briefly go through some of these and provide the reader with a discussion of what they proclaim in relation to what this thesis is all about.

Lim and Zhang (2003) introduces a framework for agent-based manufacturing control strategies that integrate process planning and production scheduling as a means of making manufacturing more agile. They define different agents such as production manager agent, resource manager agent etc. and describe the connections among these. In the article a small case study is performed involving six machines but only axiomatic findings are drawn from that. In another article, Ma and Nakamori (2004) use ABM to model technological innovation as an evolutionary process based on constructional selection and environmental selection. They model a set of producers, producing different types of products, and consumers which evaluate and purchase those products based on different requirements. One of the conclusions is that *"ABM and simulation can be used to aid intuition about technological innovation"* (ibid. p.14). Another example is Emerson's and Piramuthu's article (2004), which describes an agent-based framework for dynamic supply chain configuration. Their framework is tested on an example of two types of supply chains; a two-stage with two suppliers and a three-stage type with totally five suppliers. A final discussion is provided where aspects to consider in further developments, such as good will, relationships and inventory are provided. In the international Journal of Advanced Manufacturing

Technology Zhou et al. (2003) investigate agile scheduling models for virtual manufacturing environments with a multi-agent approach. A hybrid architecture is developed that aggregates agents into agent groups with coordinating mediators communicating between the agents within the groups and other agent groups. It is concluded that by using their multi-agent-based hybrid architecture *"the scheduling system will be much simpler and its reliability and robustness can be improved greatly"* (2003 p.984). Finally, Santos, Zhang and Luh (2003) provide a discussion on intra-organizational logistics management where the declare that in general, *"logistics management can be modeled as a distributed resource allocation problem"* (2003 p.338). They refer to earlier developments of ABM frameworks for logistics declare that these are ad hoc, and lacking any precise optimization features. Instead, they propose that Lagrangian relaxation[7] is needed and that through this decomposition of original problems into sub problems can lead to near-optimal or optimal solutions. It is concluded that from their experiments that the solutions produced on E-commerce activities related to intra-organizational logistics management are *"typically near optimal, especially when resources are fully utilized by the consumers"* (2003 p.362).

What all these writings illustrate are interesting results concerning dynamical patterns in and among organizations, however, the examples are very simplified and there are no theoretical foundations on which the frameworks and approaches are derived from, explained by or evaluated with. Furthermore, for most ABM cases found in literature, general results based on axiomatic modeling and simulation examples are provided. Any empirically driven simulations are much more difficult to find in literature, especially where the models have been verified with actual outcomes. Furthermore, the majority of cases in literature simulate issues and phenomena of an economic character i.e. showing patterns, from a company perspective on a strategic, long-term level. Consequently, the implications and recommendations are not applicable to companies when it comes to issues on a tactical and/or operational level.

[7] *"The idea for the Lagrangian relaxation technique is to transform the originally constrained problem into an unconstrained one, for which a solution can be easily obtained, though infeasible for the original problem"* (Santos, Zhang, & Luh 2003 p.341).

6.2 Agent-based modeling in the complexity framework

Viewing modeling and simulation in general, and ABM in particular, from a complexity perspective, reveals ontological and epistemological discrepancies. The whole issue of being able to model any real-life experience or observation provides difficulties in the thinking and assumptions a complexity perspective rests upon. However, as will be explained and discussed in the fourth part of this thesis, the use of ABM in the complexity framework, i.e. as one method in making logistics processes more adaptive and thus increasing effectiveness, is proved valuable and useful. As Lissack and Richardson (2001 p.98) state *"when used wisely, models provide a forum for dialog and discourse – between expectations and results, between model and observation …"* This is the aim of using ABM in the complexity framework, to provide a pedagogical method/tool for enhanced dialogs among the people involved in logistics. In this regard, ABM will be a method and tool for exploring possibilities, not for optimization. Furthermore, ABM provides the opportunity to include some of the assumptions of the extended complexity perspective, and thus provide better understanding of small and "soft" factors involved such as heterogeneity, autonomy, local interactions, distributed decision making, and bounded rationality.

6.2.1 Assumptions in agent-based modeling

- *Heterogeneity.* Agent populations are heterogeneous; individuals may differ in myriad ways – genetically, culturally, by social network, by preferences - all of which may change or adapt endogenously over time. In ABM there is no need to aggregate different agents' behavior into average variables. Since in reality logistics activities (like any activity) are not homogeneous at the operational level, ABM is a powerful tool for including the heterogeneity in these systems. This leads to a situation where the results often provide novel insights which are sometimes counter-intuitive.

- *Autonomy.* There is no central, or "top-down," control over individual behavior in agent-based models.

- *Local interactions.* Typically, agents interact with neighbors in their operating space. Uniform mixing is generically not the rule (Epstein 1999). The ability to make decisions based on information-processing rules creates internal dynamics which are often emergent behaviors which cannot be predicted in advance (Axelrod 1997a). In the words of Parunak, Savit and Riolo (1998 p.10) *"direct relationships among the observables are an output of the process, not its input."*

- *Distributed decision making.* ABM takes decision making, dispersed both in time and in space, into consideration (which manufacturing and logistics activities typically represent). Each agent can be designed to act according to its own goals i.e. the production agent aims at high operational efficiency while a stock agent aims at lowest possible stock levels.

- *Bounded rationality.* The agents do not possess global information, and they do not have infinite computational power (Epstein 1999) which makes them rationally bound. Furthermore, as the behavior programmed into the models is derived from the "observed" reality, human behavior related to performance levels can be incorporated into the models.

- *Emergent behaviors.* Complexity theoretical research shows often that unpredictable behavior on an aggregated (system) level arises from simple rules in the agent's individual behavior, and that slight changes in these rules can have radical impacts on the behavior of the system (Bonabeau & Meyer 2001). Furthermore, Epstein (1999 p.48) states that *"we get macro-surprises despite complete micro-knowledge."* Explaining and understanding the dynamic behavior of a group's or organization's collective behavior is beyond human capabilities. However, with the use of simulations, such behavior can often be rendered identifiable and understandable (Darley 1999).

In summary, ABM methodology provides a potentially useful method in the process of implementing a new kind of thinking, a complexity perspective, in logistics, thereby making logistics more adaptive and increasingly effective.

7 Empirical “assessment and implementations”

Two case studies where ABM has been used are now to be described and discussed. Both cases are based on complexity theoretical approaches, however, while the first case is based on an ABM simulation done by a consultancy firm, the second case is directly related to the complexity approach described in this thesis. As the reader will notice, there is an increasing tendency to include complexity approach as it was developed during the time period of these case studies. In the second case ABM has been used as the facilitating tool to implement new thinking and to guide management at the company in their decisions concerning improvement efforts.

The cases described in this thesis are empirically driven since they all include ABM simulations which aim to mimic actual company behavior on an operational level. The focus is set on the micro-level behavior found on “the floor”, and the models produce macro-level behavior for the case companies. Their primary influence is on tactical management but they also have strategic implications.

7.1 Case 1: packaging company in the UK

In the following section a case study will be provided which illustrates and exemplifies the use of agent-based modeling in an industrial context. For reasons of brevity and confidentiality, some details have been omitted, and focus has instead been placed on the explanation and the result of the simulation model which has been developed. Consequently, the actual figures have been modified in this description.

The case is based on a simulation of a packaging company in the UK where a complexity perspective was used at a plant and in its customer relations. The packaging company was facing increased turbulence since customer demands were changing rapidly at the same time as the costs (particularly warehousing costs) of keeping high service levels were increasing. What the managers in the plant were looking for was a “virtual factory” to test the impacts different policy changes would have on their customer service levels, on their internal logistics and on production. Furthermore, at the end of the development phase two major strategic challenges arose and the model was also used to create accurate simulation scenarios for these challenges. The description of the case will focus on these challenges, since there have been verifications of the actual outcome compared to the simulations conducted three months prior to the actual decisions concerning the challenges being implemented. These two challenges were:

- First, the packaging company's largest customer (Customer A) was expanding its business, which would significantly increase orders and thereby production. The caveat here was that the then current production was close to its maximum and there were different opinions within the firm as to whether it was possible to add any more orders at this point. Any investment in additional capacity was not possible in the foreseeable future and this placed extra constraints on the company.
- Second, the contracts with the packaging company's second largest customer (Customer B) at that time, were supposed to be renegotiated during the fourth quarter of the year. The packaging firm was holding considerable amounts of finished goods inventories (in fact, more than for Customer A) and there had been a history of problems in the relationship with this customer concerning the costs of the flexibility provided through these high inventory levels. The customer demanded high levels of flexibility but was only willing to pay for this privilege up to a point. Some people in the organization questioned the value of having this customer; however, no-one knew the exact cost of the flexibility service provided or the consequences of turning the customer down. The obvious profit margins on Customer B were larger than on Customer A, but these did not take into account the costs of serving these customers.

The key strategy, as described by the plant manager, was one which he and other colleagues believed had made the packaging firm market leader in the northern parts of UK; to offer the best customer service possible. This differentiation strategy meant that the firm had to be flexible in production, inventory stocking, and deliveries to its customers, and probably most importantly of all, had to give the customers consistency in delivering high-quality products, on time and in full. Offering the customers this high service and at the same time not having the assessment methods for finding an appropriate balance, where both customer demands and company profitability were considered and maximized, made the evaluation of the strategy in this challenging situation difficult. The customer service strategy of the packaging company was not, under any circumstances, to be changed since it had set the company apart for several years, making it profitable. In other words the situation was characterized by: a) multiple objectives and conflicting demands, requirements, and constraints, where b) changes in policies could lead to unpredictable changes in performance i.e. emergent behaviors, and c) the system was made up of several interacting operational entities i.e. agents, which d) were dispersed, both in time and space. Accordingly, the situation at the packaging company was quite complex and the applicability of ABM in handling and considering the characteristics of the situation was high.

This led to a situation where contact was initiated with a consultancy firm named Eurobios[8], which uses agent-based modeling and insights from the science of complexity to solve its clients' problems. The approach Eurobios used was the development of an agent-based model which would represent a virtual factory. This would in turn aid the managers in their decision-making processes.

7.1.1 The agent-based modeling process

The project was separated into three phases where the initial phase covered several interviews with personnel, and process mapping of flows and interactions, in order to create the "virtual factory" being asked for. In this phase, a great deal of time was spent on identifying the type of data that was available and establishing how it could be used. The managers and others involved had considerable experience from running the plant and this made them very suited to providing input to the model and evaluating outcomes from the model. Several of them had been working at the plant for more than 15 years. They were great resources for Eurobios to obtain accurate information from. As a final part of the first phase, a preliminary model was built to cover the major features of the plant.

The second phase covered the development of a more detailed model, and the validation of that model. The model could be directly developed based on real data from the year of 2001, thanks to the accurate data provided by the packaging company. The total amount of orders put into the model was approximately 20000 and the number of products was close to 2500. The plant had a total of more than 100 different customers. There was no need to average or simplify any of these orders, products or customers since each entity was modeled. The third phase involved the actual modeling and simulation of different scenarios. One of these simulations aided the management in deciding how to handle the two challenges described above. The result of this simulation will be further presented below.

The agents

The agents identified ranged from orders, machinery and shift plans to decision-making rules. In order to identify appropriate agents, process maps were made of the flow thorough the factory; both the physical flow and the order/information.

Agents were identified in the plant based on their impact on the value-adding process. The agents were constructed on the behaviors, the policies, the constraints, and the state variables that could be recognized for each agent identified.

Plant_Agent =
(AgentID, Constraints, Behaviors, Policies, State)

The following major agents were identified and incorporated into the model:

- Machines (in total 9 machines)
- Sales
- Operations planning
- Warehouse
- Customers

Machine agent. Each machine in the production was considered an agent since its characteristics were significant to the value-adding process. The machines have capacity *constraints,* e.g. maximum operating speed, and operational *behaviors,* e.g.

[8] www.eurobios.com

mean time between failure rates, mean set-up times etc. Furthermore, as the model runs the machine *states* change e.g. occupied, damaged, available etc. In total all 9 machines were included in the model and modeled as separate but interconnected agents.

Sales agent. Within the sales department another value-adding process identified is the incoming order handling process, which is regarded as the sales agent. The order handling process has several *policies*. Dealing with incoming orders means first checking if products are in stock or need to be produced, and whether the particular customer is a stock keeping customer or a ‘make to order’ customer. This leads to *behaviors* which in the former case meant that the warehouse agent has be notified and in the latter case a production order is created to provide the operations planning agent with up-to-date order for scheduling.

Operations planning agent. The operations planning agent’s *behavior* is set to first produce a rough-cut plan and, based on late changes due to changes in orders or late incoming but prioritized orders, a final production plan. *Policies* identified for the operations planning were; 1) latest possible day for delivery, 2) earliest possible day for delivery, and 3) minimum workload day. The last policy (minimum workload day) was of a more complicated character since it meant considering machine and man-hour utilization. A final policy used was to include the priority of certain customers in the production scheduling. The operations planning agent is *constrained* by the capacity in both the machines and the warehouse. By interaction with these agents the decisions concerning when to produce and store an order can be made.

Warehouse agent. The warehouse agent incorporates several aspects and policies for the stock keeping of products. The agent is limited by the capacity *constraints* concerning the amount of products which can be stored. Furthermore, there are important aspects concerning the costs of storing and handling the products in stock, which affect the policies used. Two *policies* which it is possible to change are whether a product should be a stock product or non-stock (made-to-order) product.

Such a change in policy affects the rest of the agents as well and consequently the performance of the whole plant i.e. in customer service terms.

Customer agent. There is a high level of unpredictability in customer behavior i.e. when orders are placed, which products are ordered, in what quantity and when the products should be delivered. Another influential factor is the seasonality of products some customers exhibit. Consequently, an agent is created in the model to represent this highly variable behavior from over a hundred customers.

Model output

The output of the model was designed to mirror the service levels of the company i.e. to measure the effects different policy changes had on successful customer service strategy. More explicitly, output parameters were missed dispatches, warehouse levels in terms of pallets (stock and non-stock items), machine utilization, process man orders, and renegotiated process man orders.

Model verification

The reliability of the model was crucial for the whole management team. Consequently, it was a qualifying requirement that the model could reproduce what was going on in the plant in a manner which was easy to understand. This led to a situation where verification of the model was conducted on several occasions during the development process. This was done by means of workshops with personnel from the packaging company where the previous year was modeled and compared to the real performance in the factory. This calibration of the model was done through several parameters such as actual warehouse levels, actual missed dispatches, hours worked on each machine, etc. After some fine-tuning the model represented and showed the operations which had been done during the year of 2001. The plant manager stated that *"based on the fact that there are several experienced managers operating, and that their business is quite stable, they have found it quite easy to check the reliability of the model compared to the experience and the figures they have concerning the operations."* One of the advantages of ABM was realized here, namely, that model verification could be done on both a micro- and macro-level i.e. each agent's behavior could be validated and verified quantitatively with real data, and qualitatively with discussions of its behavior. At the same time, the macro behavior, i.e. the behavior of the whole plant, could be validated and verified with real data representing service level aspects and warehouse levels.

7.1.2 Simulations of the customer challenge

Based on the model several scenarios were created and evaluated by management. One of the scenarios which were tested was actually a combination of the two challenges, namely increasing production for Customer A at the same time as Customer B was turned down. With the model as decision support the company decided to turn down Customer B since both intuition and results of the model indicated that the flexibility provided for this customer was too costly. Moreover, the model was able to clearly show that, even though there would now be more overall work, the factory could *just* handle the situation – there would be no negative impact on customer service levels. Consequently, a contract with Customer A with its planned increase of products could be agreed on without any major investments in new capacity. This “what-if” scenario was simulated at the beginning of the third quarter, and the results of the simulation model for the fourth quarter indicated that such a decision would have positive impact on profitability. The model estimated a reduction in warehouse levels of 35 percent, and a decline in missed dispatches of 15 percent, which would result in a total decrease of costs of £120 000. These figures are illustrated in the data summary plots in diagrams 7.1a and 7.1b below.

Diagrams 7.1 a, 7.1 b. Data summary plots from simulation runs of the two challenges facing the company. The square in the right corner shows the current situation and the square in the left lower corner shows the simulated result of turning down Customer B and increasing the production for Customer A. The diagrams show missed dispatches compared to (7.1a) total cost in the left diagram, and in the right diagram (7.1b) total warehouse levels.

All in all, this led to a situation where, during the busiest month of the year, the company produced 10 percent more compared to the same month the preceding year at the same time as the costs were lowered by 13 percent. Added to this was a decrease in distribution and stock-keeping costs of almost 30 percent (internal magazine 2002). In total, this meant that the result for that month was increased by more than £100 000 (ibid.). While it is a fact that some of these decisions concerning the customer and production changes would have been made without the input from the model, several of the decision-makers expressed their opinion that *“the model provided us with understanding and indicators of what could happen which made the decisions much easier to make.”*

	Model predictions (three months in advance)	Actual outcomes
Missed dispatches	- 15%	n.a.
Warehouse levels	- 34%	n.a.
Overall costs	- 12%	- 13%
Distribution and stock-keeping costs	- 49% (stock keeping costs)	- 30%
Improved result for simulated month	£120 000	> £100 000

Table 7.2. Result of model predictions and actual outcome.

7.1.3 Case conclusions and discussion

While the model developed provided guidance for the managers in the change of customers described above, the model was able to create other “what-if” scenarios as well. In that way, as expressed by the production manager, *“It was a good reflection on what they have thought about but not knowing what the consequences in missed dispatches, levels of stock-keeping units etc. would be.”* Another result of the modeling and simulation process was that it made the managers start to examine, as the plant manager expressed it, “sacred cows”. For example, one thing the management was interested in was the number of shifts that would be most beneficial for business. Several scenarios were tested showing what impact different shift alternatives had on inventory levels, missed dispatches, and machine utilization. However, in the follow-up interviews with people involved from the packaging company it was explained that none of the people involved from the packaging company know very much about ABM and complexity theory and there is no interest whatsoever in it either. This was an interesting reflection since it means that the knowledge gained from this process was merely of a quantitative character on the figures, not on the adaptive dynamics within the factory, and the qualitative aspects of policy changes and management styles involved in the daily communicative processes.

7.2 Case 2: Unilever, Sweden

This combined case and simulation study has taken place at Unilever, Sweden, where a complexity perspective was used with agent-based modeling as "operationalization" method to create more understanding and improvement efforts on service levels without any major costs associated. In the initial discussions with managers at the company several opinions and arguments were provided by people responsible for different functions of the company i.e. inventory, production, production planning, marketing, sales, and supply chain management. There was a debate among the functions concerning how to keep total costs low while at the same time increase the level of customer service. The debate focused particularly on costs in inventory versus the costs in production. Furthermore, questions were raised about how the company forecast reports influenced the actual results concerning service levels and production efficiency i.e. set-up times, batch sizes etc. The purpose of this combined case and simulation study conducted at Unilever was to create, from the company's perspective, an applicable and usable tool for the management to evaluate different scenarios with. This case was conducted in cooperation with three master's thesis students.

In order to gain insights concerning the different problems which the managers in the company provided arguments for, a complexity perspective was used, and an agent-based model was developed. In this case there were several reasons for this combination i.e. the complexity perspective together with ABM:

- The situation was characterized by several different entities which had access to limited information and with more or less influence on the company operations i.e. heterogeneity and bounded rationality existed.

- Parallel activities were taking place and decisions were made by several people in different parts of the company i.e. discrete activities and decentralized decision making.
- The situation was resource-constrained i.e. there were limited resources in terms of money as well as time.
- Different performance measurements were used in different parts of the company, which on a company level were in conflict, since some of these constrained each other.

Furthermore, in this specific case Unilever had specific requirements for the modeling process, based on earlier modeling efforts within the company:

- The company wanted a customized model, similar to their operations, and one which they understood i.e. not a general model derived from common computer programs. In this regard, it was easier to build a model which fitted into the company's operations than to tailor the company's operations to an existing model.
- The company wanted a flexible model which could be extended to other functionalities and entities at a later time.

7.2.1 The agent-based model

Within the company several agents were identified and designed to represent the Unilever supply chain operations. These were found in production, in production planning, in inventory, and in the market. The overall design of the model i.e. the agents and their connections is shown in Figure 7.1.

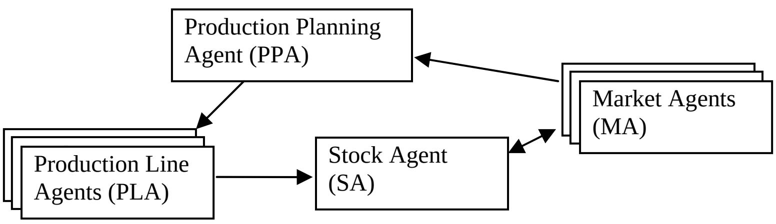


Figure 7.1. Illustration of involved agents and their interconnections.

Concurrent to the agent mapping process, data for the simulation model was collected in three different ways; interviews, observations, and document studies. Several interviews were conducted with managers responsible for logistics (in-bound, out-bound), supply chain management, operations planning, production, and inventory. In addition, observation was carried out in order to examine the daily behavior of the people involved in the actual activities performed within the company. Three investigators were on site at least once or twice a week during four months, and carried out follow-up interviews, participant observations and ordinary observations on several occasions. At the same time quantitative data was gathered from all functions and put into the database for the model. Data from January 1^{st} - March 21^{st} 2004 was put into the model. The reason why this period was chosen was primarily that it had been quite a stable period and there was sufficient data available to verify the results.

The model aimed to mirror the actual operations as accurately as possible, including enough details to provide valuable insights, however, without being too resource- and time-consuming i.e. the question of decomposability became central. The issue of decomposability was solved by the type and amount of data available. Within the organization there was a general belief that adequate data was quite easy to obtain. However, when it came to data collection for the model the situation was rather different. There were different types of data for certain processes and no data for others. This led to quite considerable efforts being needed to structure data, and necessitated several meetings with staff from different functions within the company. The model was built in Microsoft Visual J++ 6.0.

The agents represented the different activities and processes which were observed in the company. The reason for the chosen set of agents was derived from the data available and the abstraction level needed to enclose the real operations in a resource- and time-efficient way. It was later shown that the chosen decomposition of the system was enough to mirror the operations at the company and produce valuable scenarios which had great impact on both costs and service levels.

Each agent was specific and designed according to its state, constraints, policies, and rules in the following way:

FMCGAgent = {state, constraints, policies, rules}

The production. Ten production lines were designed as specific agents, Production Line Agents (PLA),

$P = \{PLA_1,\ldots,PLA_{10}\}$

with specific characteristics:

$PLA_i = \{S_1,\ldots,S_i; C_1,\ldots,C_j; P_1,\ldots,P_m; R_1,\ldots,R_n\}$

The reason why ten PLAs were needed was that every production line had unique properties, such as speed, products produced, and changeover time. In addition, there existed unique properties for each product when produced on a specific production line. All ten production lines in the factory were included.

The rules of each PLA are:

- R1: when production list is received from the PPA (Production Planning Agent), the production sequence is updated.
- R2: When a full pallet is produced it sends the pallet to the SA (Stock Agent).
- R3: If a PLA is not producing and a production list exists, the following steps are carried out:

  a. The next item in the production list is removed.

  b. The line is set to produce the next item and calculates the change over time.

  c. The time to produce a pallet is calculated.

  d. The state is set to "*Producing item*".

  e. The agent goes inactive until the changeover has been effected and the first pallet is produced.

Otherwise (if no production list exists), the PLA goes inactive until a new production list has been received

PLAs are connected to the PPA and the SA. A PLA could theoretically decide to change the order in which it wants to produce products, but in reality the policy is that it always produces in a way which is predetermined by production planning.

However, the produced quantity of a product, although set by the PA, is finally a result of the PLA's operation due to its state and constraints.

The stock. The Stock Agent (SA) represents the collective activities which take place in the storage facility, and if not there is not enough available room, it also covers any extra facilities which are needed to keep stock i.e. capacity is expanded if needed, however, at a higher cost. The SA is connected to fourteen agents; the PA, the three MAs, and the ten PLAs (see Figure 7.2). It is designed in the same way as the other agents but with its own specific characteristics. The SA is governed by the following major rules:

- R1: When items are received from the PLAs, it registers them as part of the stock. Arrival time, quantity, position in the storage, specific products maturity time, and expiration dates for products are stored, with dates in order to ensure that no old items are shipped to customers. If the storage is full, the items are registered as "overflow stock" i.e. a higher cost facility is enabled since in reality other facilities have to cover such events.
- R2: When an/the order is received from the MA (market agents) the following is done:

a. The quantity of correct items in stock is checked i.e. excluding items not matured (the products need to be matured before being dispatched to customers) and out-of-date items.

b. If the stock contains the necessary items, the items are delivered (deleted from the stock) and a variable, "items-delivered" is increased. If the SA cannot fill the order, a variable, "not-delivered items", is increased.

- R3: When it is time to update the database the SA sends a simplified version of the stock to the database. This simplified version does not contain any information concerning out-of-date items nor items which are not matured see above, only the total quantity of each product. This is the way the communication between stock and planning takes place in reality.

Production planning. The policies of the PPA (Production Planning Agent) can be described as follows: Once each Tuesday the PPA takes the stock balance from the planning system database. Once each Sunday a production list is sent to the PLAs.

The rule for making up the production list is the following:

- R_1: For each PLA in the system, the PPA finds out which items to produce according to the following sequence:

a. *Start hour* of production for item is estimated. This is based on a predetermined sequence for each PLA.

b. The quantity to produce the following week is calculated according to the following steps:

1. Calculating the safety stock cover to set via the start time by formula: *cover = (cover setting *7 + start hour / 24) / 7*
2. The quantity of the item in stock is set to the start value.
3. The quantity produced or planned to be produced that week is added.
4. The forecast quantity of the current week, the subsequent week (the week of production) and for *cover* weeks is added.
5. If the result is equal or greater than zero, there is no need to produce anything the following week.
6. Otherwise, the quantity to be produced is the same as the negative value of the result.
7. If the quantity is less than the smallest batch quantity permitted, the quantity to be produced is set to the minimum batch quantity.

c. The PPA checks if the same item is planned on another production line.

d. If that is the case, this quantity is subtracted from the calculated quantity.

e. If the quantity to be produced is greater than zero, and the line has available planned utility, the item with its calculated quantity is added to the production plan.

f. If the estimated utility exceeds maximum utility allowed, the quantity is reduced to match the maximum level of planned utility.

The batch setting is checked for each of the items in production plan. If the batch setting is set to “split”, the quantity is divided into two production occasions in the production plan. This happens only if a quantity is two times greater than the minimum batch quantity.

The market. The Market Agents (MA) are designed identically, however, they use different data sets i.e. state and constraints are different. The policies and rules the MAs follow can be described as follows: Once each Monday the MA gathers information about the weekly orders. There are two rules for doing this (depending on the parameter settings):

- R1: actual sales of the same week from sales history or
- R2: estimated sales from forecast data with item- and country-specific forecast error calculated by means of a Gaussian distribution.

The weekly orders are divided into daily orders using a uniform distribution algorithm.

Once each weekday (Monday to Friday) at noon. each MA sends a message to the SA, with the orders of that particular day, containing the quantity of each item ordered.

7.2.2 Model verification

Before any simulations began the model had to be verified. The verification process was divided into two parts: microverification and macroverification. The purpose of the microverification was to ensure the individual agent’s behavior, while the purpose of the macroverification was to confirm that the model created a reasonable result compared to real data. The microverification involved meetings with everyone who was represented in some way as an agent in the model. For example, the behavior of the production planning agent, who is one person in reality, and the computer system the company have for production planning, were verified during two meetings. During the first meeting the set of states, constraints, policies, and rules was agreed on and during the second meeting the computer simulation was run and the PPA was verified by the person himself. The same procedure was done for the other agents as well.

The microverification process helped to guarantee that company employees involved felt confident that the model actually worked. At the same time, the complexity approach was communicated to and considered alongside the behaviors in the microverification and the results from the macroverification.

The macroverification was conducted with a reference scenario which would mimic operations during the period from January 1st - March 21st 2004. It was a requirement from staff at the company that the reliability of the model should be very high in order for them to the place their trust in the outcomes of the scenarios created later on. In discussions with the different managers involved a set of output parameters was decided on, to be used as verification of the model. These were: 1) number of products in stock, 2) service level (on-time-in-full deliveries), 3) production utility, 4) total cost and 5) storage balance on Sunday evenings. These output parameters were also used to evaluate forthcoming scenarios. The reference scenario was run several times (> 30) and the distribution of the runs was evaluated and an average was used to compare the reference scenario with real data (see table 1 for comparison at the end of the simulation). This was done together with staff from the company, the supply manager, the production manager, the production planner, and the stock manager.

7.2.3 Scenarios

The output of the model resulted in several scenarios which were evaluated and discussed by the management team involved. Two of these will be described next. Table 7.3 (see below) provides the result of these two simulation runs compared to the reference scenario created in the verification process.

	Reference scenario	Scenario 1	Scenario 2
No. of products in stock	6000	5900	6300
Service levels	-	+ 0.8 %	+ 1.6 %
Production utility	68%	+ 5 %	- 0.5 %
Total cost	-	+ $650000	+ $30000

Table 7.3. Result of reference scenario and the simulation results from two scenarios.

Scenario 1. In this scenario, the batch size in production was split in half; since management argued that this would make the company more responsive to customer orders. The result of simulation shows that, while the service level increases, costs increase considerably at the same time. The increase in cost derives from more cleaning of machines, increased people involvement, and as a consequence of more changes, increased product wastage.

Scenario 2. In scenario 2 another issue discussed by management was tested; namely, the change in production planning from Wednesdays to Fridays and with an addition in safety stock policy from 1.2 weeks per item to 1.3 weeks per item. What this would provide is more updated production lists, which would be closer to actual orders. The increase in costs is minimal at the same time as the increase in service levels is significant.

7.2.4 Case conclusions and discussion

Even though the model is quite simple i.e. no advanced algorithms or optimization efforts, results such as the ones described in table 7.3 provided the managers involved with new insights into how to approach changes in different parts of the company. These results have had an impact on actual operations, and indications show that service levels are increasing in accordance with the results from the second scenario since the managers agreed to change their planning policy with guidance with this scenario. However, even more importantly, during the process of development of the model, the complexity approach gave the managers a new reference frame for discussing and improving business performance. They had to understand each other's perspectives and real-life operations i.e. how production set-up times were decided, how planning was done, what the costs were for full inventory levels etc. In a follow-up interview, the Nordic supply chain manager explained that the scenarios created have had an impact on the way system-wide effects are discussed in the company i.e. how intuitively correct changes need to be evaluated with a more holistic perspective since they might have other, unwanted, effects on operations.

8 Summary: Part II

In the two cases described in this part of the thesis, features such as heterogeneity, non-linearity, and emergence, have had significant impacts on the understanding and interpretation of the result by the people from the companies involved. The results so far have shown that ABM facilitates the understanding of assumptions of a more complex character and provides a useful method for an adaptive approach to logistics.

In their study of simulation studies in operational research and management, Shafer and Smunt (2004) found that in 20 operation management-related journals from 1970 to 2000, computer simulations were used in 600 articles. Of these they found that 85 (14 %) were empirical in nature i.e. where empirical data was used or the study was motivated by problems identified empirically. In this thesis, two cases are provided with high empirical relevance at the same time as a theoretical foundation is established which opens up the potential for theoretical generalizations.

As discussed in this thesis and verified in the cases conducted, the applicability of ABM is especially great when phenomena of interest are:

- dynamic systems distributed in time and space,
- made up of many interacting parts i.e. agents,
- where several objectives and often conflicting constraints exist, and
- where emergent phenomena could be exhibited.

These characteristics are suitable for logistics operations, since logistics involves many interacting parts e.g. machines, vehicles, actors, facilities etc. which are distributed in both time and space, and where the properties of these change over time. Furthermore, logistics operations often have several objectives and constraints, which are frequently in conflict with each other e.g. service levels vs. costs, smooth production vs. low inventory levels. The advantage of ABM here is that simulations promote simultaneous analysis of manufacturing and logistics operations from several management and organizational perspectives. Finally, the ability to encompass emergent phenomena makes ABM applicable to, and useful for, modeling and simulating manufacturing and logistics operations. As demonstrated and proven in complexity-related research over and over again, systems constituent of interacting agents/parts exhibit behaviors on an aggregated level which are often impossible to predict and which are sometimes counter-intuitive. Since emergent phenomena are the collective or aggregated pattern of interacting agents, such phenomena must be modeled from the bottom-up, which ABM exemplifies.

An evaluation of the identified advantages of ABM found in literature based on the cases shows that, in general, several of the advantages were verified. These were:

- *Similar to real-life events.* The great advantage of the model, as expressed by the people involved in the efforts, was that it was directly comparable to the actual activities carried out in their operations. They quickly understood what was happening in the model and could easily contribute with more suggestions for fine-tuning, at the same time as they were given some insights into the emergent behaviors the model provided in several different "what-if" scenarios.
- *Include heterogeneity.* Since the models were based on long periods of production, inventory, sales, and forecast data it meant that information such as actual output from machines, actual orders set etc. was incorporated and not replaced by either average or random values. Furthermore, each machine and operation was treated as a single unit with its own characteristics when it was incorporated into the model. This heterogeneity applies to customers as well, since some of them have seasonal patterns and others behave in different ways e.g. call for late changes in both quantity and type of products.
- *Decentralization.* In the models both sales agents and operations planning agents made decisions based on unknown changes in orders and machine breakdowns. In other words, decision making dispersed both in time and in space was considered and used in the model.
- *Scalability.* As a result of the successful implementation and usage of the model at the packaging company (in the UK), it was decided to expand the model and to include other plants in the latest version. This was possible since ABM designs allow developers to add or remove agents or systems of agents without needing to start over again. Each plant model could be developed separately and calibrated to incorporate specific behaviors and data

for each and every machine, warehouse, sales department, production planning function etc. Similar discussions have been held with the other case company.

Part III

This research journey had a purpose, but no specific plan where to go, no apparent means and methods to use, and no specific activities to carry out, only a set of "simple rules" to follow:
explore the theory of complexity, go to places (theories, concepts etc.) where most ideas and thoughts can be learned and use the means and methods needed, bring back insights and knowledge of how complexity theory can improve logistics.

9 Research journey

The research conducted for this thesis has been of an explorative character. While an overall framework was set in the beginning of the thesis work including complexity theory and its applicability for improving logistics processes the research path has gone from mathematical complexity i.e. linear analysis, nonlinear dynamics, chaos theory, stochastic processes, trough systems theory, strategy and organizational theory, to agent-based modeling, object-oriented programming and philosophy.

I did not consciously set out with the view of using and applying agent-based modeling – it simply became my facilitator as a number of influences operated over the period of the research. I nevertheless believe that I have arrived at rich, if somewhat personal, understanding of logistics improvement efforts which addresses the challenge of integrating a novel perspective and mindset with a facilitating methodology into the logistics discipline.

It is common knowledge that the research topic and purpose do, and should, influence the choice of research strategy, research methods etc. While performing research that is focused on efficiency (which I regard the majority of logistics research to be), the whole purpose is to make a certain process, function or operation better or faster by reducing uncertainty/complexity i.e. directed towards a specific goal or set of goals. That is doing things right. However, research focused on effectiveness, i.e. doing the right thing, requires a wider perspective since there is no specific predetermined goal or set of goals. Instead, it is important that open, multi- and trans-disciplinary and explorative research approaches and strategies are used and developed during the research process. Since it is likely that insights may be drawn from many disciplines for a certain type of problems and contexts, especially when people are explicitly involved in the research core, a multi-/trans-disciplinary approach is mandatory.

9.1 Paradigmatic reflections on my research approach and process

The aim of this chapter is to provide the reader with a reflection on the paradigmatic change process which I have gone through during my research. The discussion begins with one of the dominant approaches to logistics research, namely systems approach, from which my paradigmatic research stance began. However, during my research process two other paradigmatic approaches gained from the complexity literature; first complex adaptive systems and thereafter complexity thinking, have gained my interest and conviction. The purpose of this discussion is to provide the reader with a perspective on my view of these approaches and how they have emerged during the research process. Furthermore, for wider appreciation of the complexity framework presented in the subsequent chapter, this discussion is valuable and useful.

In logistics it is claimed that the dominating paradigm relates to the positivistic one and other research paradigms are less emphasized in the literature available. Gammelgaard (2004) uses Abnor and Bjerke's (1997) methodological framework for evaluation of logistics research approaches. Thus, Gammelgaard categorizes logistics research as being analytically, system- and actors-based. The analytical approach can be compared to Burrel and Morgan's (1979) realist view and positivistic paradigm. The actor approach, which in Abnor and Bjerke's framework lies at the other extreme, ontologically and epistemologically, can be compared to Burell and Morgan's (1979) nomialist view and anti-positivistic paradigm. According to Gammelgaard there is very little research in logistics that is actor-based.

The systems approach is often placed between the other two approaches. In Arbnor and Bjerke's terminology it is the holistic perspective which is the basic argument when separating the systems approach from other methodological perspectives. While I do not feel really comfortable with such definite categorizations I leave it to the reader to draw the boundaries (if this can be done) between the different approaches. However, it is apparent in logistics literature, theory and practice, that the concept of systems and systems approach is prevalent and it has been regarded as *"natural when dealing with supply chain issues"* (Simchi-Levi, Kaminsky, & Simchi-Levi 2000 p.2) at least since the 1960's (Kent and Flint, 1997). This was also my point of departure and my earlier texts are based on a systems approach (Lindholm & Nilsson 2001; Nilsson & Jönson 2002). However, as time went by I observed several occasions when the system concepts did not provide me with any clarity or understanding. Aspects I especially found problematic in systems theory were:

- the apparent heterogeneity identifiable in any logistics phenomenon, particularly when human aspects are considered, which were averaged in many situations in systems approaches.
- subjective dimensions which I sensed from initial company visits and observations often had great impact on actual results produced.
- other aspects related to human behavior such as power, conflict, cooperation, creativity; aspects I could not find explanations of and understanding for in systems theory. They still represented aspects of importance in the logistics-related situations I experienced.

With my increasing insights into complexity theory, the theories of complex adaptive systems gained my interest. Complex adaptive systems theories are what I regard as the natural extension of systems theory and the systems approach. My licentiate thesis is based on insights gained from complex adaptive system (CAS) theories and I believe that these provide a solid ground for further developments of the logistics discipline, as discussed in my licentiate thesis (Nilsson 2003). Furthermore, the logic and assumptions of CAS are beneficial in the development of agent-based models i.e. in dealing with issues of a complicated character. Nonetheless, while the assumptions underlying CAS relate to the extended complexity perspective (see Figure 3.1, chapter 3), what I experienced from further empirical examinations and from daily life could not be understood or explained solely by CAS concepts and assumptions. The CAS theories were not derived from studies of human/social systems, but from studies in biology, chemistry, and other areas of natural science. Hence, researching logistics, where human involvement is at the core, needs more than only perspectives, theories, and frameworks which are able to consider and provide understanding for the complicated part of logistics.

Consequently, the studies of CAS were followed by another field in complexity theory, complexity thinking, which I feel represents an ontological, epistemological, and teleological step away from both systems approach and theories, and the complex adaptive systems theories. This field is rather new in complexity science; most of texts published on it date from 2000 and onward. Complexity thinking (CT) differs ontologically, epistemologically and teleologically from both systems theory/approach and CAS. Ontologically, the underlying belief is that of unorder and subjectivity; epistemologically, of heuristics or anti-positivism; and teleologically, of a transformative nature. For the interested reader, in appendix 1 a presentation is provided of these paradigmatic views, followed by a comparative analysis of them based on the assumptions presented in the complexity perspective in chapter 3 (see Figure 3.1).

9.2 How have I done it?

In order to gain knowledge and understanding of how a complexity perspective could impact logistics, philosophically, theoretically, and pragmatically, several methods have been used. Through extensive **literature reviews** from several disciplines, insights into where the logistics discipline stands today and what type of underlying assumptions dominate the discipline were gained. In the literature study, specific focus on complexity theory has been used in order to provide insights for the first objective of the thesis, namely for making logistics more adaptive and effective. In order to understand logistics in its “real” empirical setting, a **topical study** entitled “real logistics” was performed. Here, logistics practitioners were interviewed with a grounded theory-inspired approach (see appended paper three). **Case studies** have also been performed, focusing on issues of effectiveness, and in exploration of how a complexity perspective would provide “better” explanations for making logistics operations more effective. Furthermore, for me to be able provide the logistics discipline with an approach which is “proven” to be applicable and where “operationalization” of the complexity perspective could be achieved i.e. the second objective of this thesis, **combined case and simulation studies** have been performed. The appended paper four will specifically address this combined approach of both case and simulation studies.

In my choice of methods I have tried to use the best parts of several different methods. This is supported by Bjerke (1981) who states that a scientist may have some basic assumptions and base his/her research on the chosen approach, and then use techniques and methods from other approaches to give the study as much rigidity and dignity as possible.

9.2.1 Literature review

The ongoing literature review which has been carried out during the research journey can best be characterized as opportunistic but purposeful in its nature, since I have tried to gain many perspectives on both logistics and complexity theory. This has meant that for the logistics part I have focused my literature reviews on major journals such as *Journal of Business Logistics, International Journal on Physical Distribution and Logistics Management, International Journal of Logistics Management, An International Journal on Supply Chain Management*, with complementary insights from the operations management area and specific journals such as *International Journal of Operations and Production Management, Journal of Operations Management, European Journal of Operational Research*. For the complexity theoretical part of my studies, besides several books written by key authors[9] in the field, a number of journals have been scanned repeatedly. These include: *Emergence*, and *Complexity*. For the agent-based modeling literature a number of books have been used, and several articles related to business applications, especially logistics and supply chain management, have been used. Furthermore, based on the fact that journal review processes are sometimes time-consuming, in order to obtain information about latest technology and improvements, conferences have been attended and conference proceedings examined.

9.2.2 Topical study

This study set out to discuss with logistics practitioners what logistics meant for them on a daily basis. This was in order to develop logistics theory and methods which were applicable to, and useful for, practitioners in their daily handling of logistics-related issues, and to gain perspectives on logistics from the practitioners' points of view, which can be insightful for researchers within the discipline. A topical study was chosen since the investigation focused on a specific type of practice i.e. logistics, and was not bound to any particular company or industry. As Ellram (1996 p.99)

[9] (Axelrod & Cohen 2000; Bar-Yam 1997; Gell-Mann 1994; Holland 1998; Kauffman 1995; Prigogine 1997; Wolfram 2002)

states; topical studies *"investigate more focused activity, yet within a less distinctly bounded area."*

This topical study was found to be valuable in order to provide understanding of, and insights into, what real-life logistics activities are and how these are perceived and handled on a daily basis in industry. This was in order to align the complexity framework with real, contemporary logistics activities and problems for the purpose of creating a useful framework for researchers and practitioners in further developments of increasing the effectiveness of logistics, by making it more adaptive.

The method chosen for this study was qualitative in its nature and inspired by grounded theory. The reasons for this choice were

- research reports on daily logistics efforts, issues and handling is scarce. The literature on logistics has mostly focused on how things should (or could) be done i.e. providing normative models for how logistics would ideally work. In addition, these models are often conceptual in their character.
- a need to gain a deep understanding of logistics in a contemporary, real-life context and of how it is perceived by logistics practitioners, especially in their daily work. The goal was to obtain a comprehensible picture of an ideographic type including all aspects the respondents shared with me, i.e. not simply a list of logistics activities or similar.
- To gain several perspectives of logistics in different contexts i.e. the subjective perceptions people have about logistics in their own strategic and operational environments.

The topical study was done through an inductive qualitative method inspired by thoughts and insights from grounded theory (Glaser & Strauss 1967). While the grounded theory methodology offers several qualitative approaches for data gathering, the main method in this study was semi-structured interviews based on a number of topic areas, which evolved over time. A more extensive description of the method is provided in appended paper three.

9.2.3 Case studies

The case study method has been used as another method in this thesis in order for me, as investigator, to gain a deeper understanding of the chosen research phenomena (Stake 2000). The case study method focuses on understanding the dynamics present within single settings (Eisenhardt 1989; Ellram 1996). This means that in case studies the focus is directed towards numerous variables and relationships in their contemporary setting covering a majority of conceivable aspects which are available i.e. the case study is ideographic. This makes it different from, for example, survey methods where only a few variables in a large population are normally studied, giving the research a nomothetic character. According to Yin (2003), the case study method has a distinct advantage in situations when: "*a "how" or "why" question is being asked about a contemporary set of events, over which the investigator has little or no control.*" Such a description fits well into the conditions the phenomena of interest in the case studies have provided.

Case selection

The two cases in this thesis were both manufacturing companies, chosen for their accessibility and their mutual interest in the research questions, making this more an opportunistic sample, rather than a random or purposive one. By opportunistic I mean that the cases came to me e.g. contact was initiated with the production manager at case company two after a presentation we both attended. This type of sampling is referred to as self-selection sampling (Saunders, Lewis, & Thornhill 1997) and has been used in logistics research (see Knudsen (2003)). The common denominator for both cases was the fact that there were people interested in new ways to improve their operations i.e. companies interested in novelty and improvement. Furthermore, people within the companies revealed that they did not have any good overview of their operations and therefore, as they described were "*in need for a system-wide understanding.*"

While the two cases are different in nature i.e. they represent different contexts, different research questions, and different phenomena of interest, the common denominator aspect is that they both reflect situations where the effectiveness dimension is wanted and needed, instead of the efficiency focus often found in the organizations. They both are good examples of situations where complexity could be perceived since paradoxical explanations, emergent phenomena, and self-organizing aspects influenced the operations. Each case will briefly be described here since more specific aspects of data collection, and other case specific procedures, are presented for the reader where the cases themselves are presented in the thesis.

Case one

The first case (see chapter 7.1) was conducted at a packaging company in the UK in 2003, where a consultancy firm named Eurobios[10] hade performed a modeling and simulation project the year before (2002). As mentioned before, Eurobios uses agent-based modeling and insights from the science of complexity to solve its clients' problems. The following objective was set for this study of effectiveness improvement using agent-based modeling at the packaging company:

To evaluate of the use of agent-based modeling and its theoretical foundation, complexity theory, in an industry context, namely the packaging plant in the UK.

In order to obtain sufficient information and understanding of the situation at the plant and of the impact of the model on the organization, a case study was conducted. The goal was to explore and explain the usefulness of the ABM approach from a pragmatic point of view. The case study method was chosen based on the following reasons:

- First, the investigation needed an ideographic approach, since a great many aspects and perspectives needed to be considered and understood.
- Second, there was a need to gain understanding and deep insights (Merriam 1994; Stake 2000) into the operations from a "bottom-up" perspective, i.e. what the people actually were doing at the plant and how this was transferred into the model.
- Finally, the case study method was used to obtain a holistic picture of the overall processes and operations at the assembly plant (Ellram 1996).

The motivations for conducting a case study at the packaging company are as follows:

- It was foremost an exploratory study aimed at exploring and gain understanding for the usefulness of ABM in logistics – not to compare if ABM at one company or plant is better or worse than at another company.
- The phenomenon of interest i.e. an ABM simulation with the use of complexity theory as the foundation, has taken place at the plant.
- Accessibility
  - Access to the plant and to people involved for interviews has been provided by the packaging company since a good relationship between our division and the company exists. The contact was the plant manager.
  - Access to data as well as to the simulation model was established during the project since the consultancy firm became involved in the research project. As output from this an article on the subject has been written by the managing director at Eurobios, Vince Darley, and me[11].

A case study protocol, as well as a case study database, were initially created and further developed during the process. Multiple methods for investigation and sources of information were used at the packaging plant in order to gain as deep an understanding as was necessary for the phenomenon of interest. These were; three days of on-site observations and discussions, semistructured interviews with the plant manager and the project manager, internal documentation of the project, and consultancy reports from Eurobios. The interviews were not recorded on tape, however, they were transcribed within two hours of the meetings and in follow-up meetings they were checked for misunderstandings etc. Furthermore, meetings were held with the model developers and staff from Eurobios who were responsible for the project. The people at Eurobios also provided me with a copy of the simulation model. This gave me the opportunity to evaluate the model and in follow-up meetings

[10] www.eurobios.com
[11] Entitled: "Improving decision-making with agent-based modelling - experiences from a packaging company." In the review process for publication in the International Journal of Operations & Production Management

with people from both the packaging company and Eurobios, discuss certain aspects to ensure greater understanding on my part.

Case two

The second case came into being after reflections on the former case. While interesting results were obtained for how ABM and insights from complexity theory could be used for improvements of effectiveness at the plant, it was also concluded that the people at the plant seemed not to be changing their approach to their work. As mentioned, the people at the packaging plant were impressed with the insights the model had provided them with concerning the strategic decision of changing customers, and what effects it had on the operations. However, it was only seen as a technical software tool which the consultancy firm had provided them with. There were no signs or thoughts of mind-shift or any rethinking of how to communicate better or how to assess the effectiveness of their operations. Instead, investments were focused solely on efficiency-enhancing efforts such as set-up-time reductions. The model provided a cause-and-effect scenario for the company but no meaning in a wider sense. Furthermore, since the modeling efforts i.e. data collection, model construction, verification and scenario generation, had already been handled, it was of interest to become a part of the model development. All this led to a search for a third case which through serendipity became a project at Unilever involving three Master’s thesis students, Fredrik Hedlund, Magnus Loodberg, and David Wajnblom (Hedlund, Loodberg, & Wajnblom 2004). A combined case study and simulation study was conducted, as described in the case description (see chapter 7.2).

	Case 1	Case 2
Phenomenon to study:	Implementation and use of ABM simulation	System-wide effects of policy changes
Company	Packaging company	Fast-moving consumer goods company
Pragmatic context	Operations and in-bound logistics	Production, warehousing and planning
Major topic(s)	ABM	ABM and the complexity approach
Major method	Case study	Combined case study and simulation
Major insight	Potential of ABM in large technical systems, need for a framework	The interactive and communicative patterns of interactions among the company people. The usefulness of ABM as an operating and pedagogical tool to gaining interest in company-wide issues and communication among people involved

Table 9.1. Overview of the two case studies in this thesis.

9.2.4 Simulation studies

As described in chapter 6, Part II, ABM simulations have been used and developed in this research in order to be facilitators for “operationalizing” a complexity approach in the organizations being studied. The simulations are described in more detail in the case descriptions. In this section, a discussion of modeling and simulation will be provided as a general framework. It should also be mentioned that a more thorough description of the combined case study and simulation study approach which have been used in case three is to be found appended paper four (see Part V).

According to Banks (1998), simulation is an “*imitation of the operation of a real-world process or a system over time*”. The flexibility of simulation methodologies readily lends itself to modeling real-world scenarios (Shafer & Smunt 2004) however, the simulation model will always be an abstraction from reality (Will, Bertrand, & Fransoo 2002). Nonetheless, there is a distinction between simulation, and modeling developments. In a simulation effort one strives for realism at the expense of simplicity, while in a modeling process a modeler strives for simplicity at the expense of realism (Andersson 1999). In order to capture the real-life behavior in a simulation the researcher needs to possess a great deal of knowledge about the characteristics of the system under study. Dealing with real-life processes i.e. where “irrational” behavior can be identified as well as non-linearity, dynamism, interdependencies, feed-back and autonomy, is always done in a subjective and context-dependent way.

This generation of context-dependent models has both advantages and disadvantages. Shafer and Smunt (2004 p.354) in their discussion of further research conclude that "*combining the power and flexibility of simulation with empirical data can be one of the most effective ways to help bridge the often present gap between academic rigor and managerial applicability.*" However, they especially emphasize the generalizability of the research result that academia requires i.e. that reported studies should not be mere consultancy projects. In this regard I agree with such requirements since several articles on ABM simulations are mere descriptions of the simulations made (see the discussion in chapter 6.1.1). What these articles suffer from is lack of theoretical support and context. Theoretical generalizations can be made from simulation studies if assumptions and results are put into a theoretical context. This is, for example, the case in this research, since ABM has been chosen and developed for its applicability in facilitating the complexity approach developed as the theoretical framework. The models themselves perhaps provide value for the organizations involved, however, seen as a methodology relying on the assumptions provided in the complexity framework theoretical generalizability is facilitated.

In order to motivate the use of simulation such as ABM, the phenomenon of research interest requires a relatively high degree of complication? This complication can be the result of several interacting and interdependent parts, where these parts are affected by several objectives and constraints, and where the behavior of the phenomenon cannot be distinguished from the behavior of the individual parts, but instead in the relationship among them.

Part IV

Not the end, only a different perspective and approach at the beginning of its transformation.

10 The complexity framework for adaptive logistics

In this chapter, a conceptual framework for logistics research and practice will be presented i.e. the accomplishment of the first objective of this thesis. This framework is a synthesis of the theoretical and paradigmatic discussion provided in Part I and the pragmatic aspects of operationalization discussed in Part II. Hence, the purpose is, from insights of complexity theory and thinking, to provide a framework for adaptive logistics, which should facilitate increased effectiveness in logistics.

This framework relies on two different perspectives, defined as perceptual filters, researchers and practitioners consciously and/or unconsciously use when they deal with logistics issues. The filters represent how reality is viewed; as complicated and as complex. It important to emphasize that the framework is based on the dialectic assumption that both filters are present simultaneously, hence their relative importance changes, as contexts and situations do. Thus, the complexity framework is multi-ontological, emphasis multi-perspectives, and is multi-paradigmatic. It is also important to point out that this presentation and discussion is not an argumentation for which filter or perspective is the better or which is truer. There is no question that interesting and valuable insights have been and are being gained from both of these filters, however, this is an effort to highlight the circumstances they could be used in.

The aim of the framework is to provide meaning and understanding of the conditions under which different types of assumptions and thus theories, approaches, and methods are applicable for the type of problem at hand i.e. when extended assumptions might bring more beneficial explanations and guidance to a certain issue, and when more mechanical or systemic assumptions can be applied to a logistics problem. This is the case both for the researcher and practitioner dealing with logistics issues.

The framework is illustrated in Figure 11.1 where the filters have been separated in the figure for pedagogical and illustrative reasons. How the framework can be used will be described below, however, first an explanation of the characteristics of the filters will be provided.

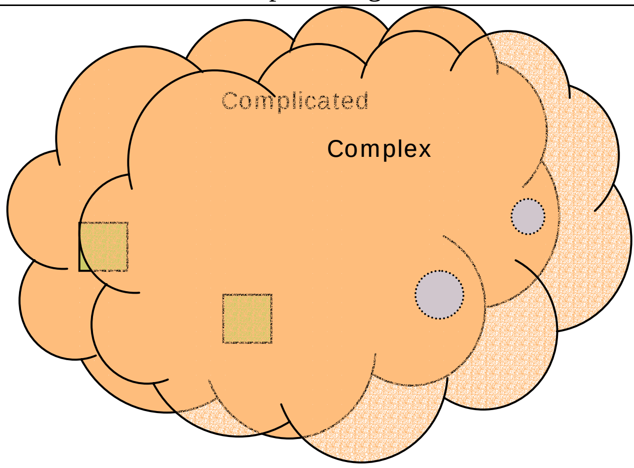


Figure 11.1. The complexity framework

10.1 Filter one – the complicated perspective

Through this perceptual filter, the world is perceived and acted upon as being mostly derived from positivistic beliefs of cause and effect i.e. there is an underlying assumption of order which is hidden but is to be found in system structures; we only need more knowledge. In relation to this last aspect of knowledge is the assumption that we might not know everything since we have our own *métier*, but by knowing who knows what, we are able to gain knowledge about, *in principle*, everything. The teleology is formative, thus future goals can be attained. The quest for researchers and practitioners to solve problems is to identify causal relationships among identifiable and measurable factors. Most theories and models developed and used are based on concepts of systems and/or networks, and from this it follows that descriptions and explanations of phenomena are mainly done with illustrations or exemplifications of the connections which exist between parts of a phenomenon i.e. they are based on content. Other theories and models used are based on process thinking in attempts to change the traditional functional thinking and focus on the core of logistics, namely the flow. However, formative teleology prevails since the processes addressed are deliberately designable, and most improvement efforts are still focused on resilience and/or robustness i.e. when a process is affected by something it should go back to its "normal" state again.

Measurability is prevalent here since within this filter science relies primarily on objectivity and accessible objects of interest. Furthermore, research and practice are driven by the belief that what is measured gets done. Both effectiveness and efficiency are emphasized, however, efficiency is the dominant aspect since it fits the positivistic beliefs rather well. While optimality is seen as almost unattainable due to the limits of analytical and mathematical concepts and tools, and due to people’s intellectual limits, the discussions in practice and in literature are often based on the notion of making processes optimal, or that suboptimality is bad. The notion here is also that all uncertainty is harmful and should be eliminated together with aspects of conflict, power, misunderstanding, disagreement etc. since these very aspects hinder the development of “true” supply chains.

Self-organization is assumed. However, based on formative teleology the belief is that by finding or establishing simple rules self-organization becomes a new mechanism for management to control and direct people towards stated goals. Hence, a complex adaptive systems perspective relates to this complicated filter, even if CAS encompasses highly complicated aspects connected to organic and emergent phenomena.

Within this filter there are islands of extremes when it comes to assumptions and expectations (illustrated as squares in the complicated part of Figure 11.2). Within these islands mechanistic principles are believed to solve all types of problems i.e. this is “pure” positivistic or analytical epistemology.

10.1.1 Islands of simplicity

These “islands” of simplicity could be regarded as the ultimate goal in the complicated world view. Here, true knowledge is to be found since valid and reliable facts of cause and effect are the realm; knowledge is absolute. One could say that humanity has been able to solve the puzzle, the pieces are in place. From a logistics perspective, on these islands in the complicated reality, the wish for controllability is achieved; supply chains act as great ones where the involved actors are unified for a common derived goal. Since control has been achieved and common goals clarified, optimality of operations is attainable and thus maximum efficiency is the outcome. The assumptions on these islands of simplicity in the complicated world view are those of linearity, determinism, reductionism, rationality, objectivity, context independence, and order.

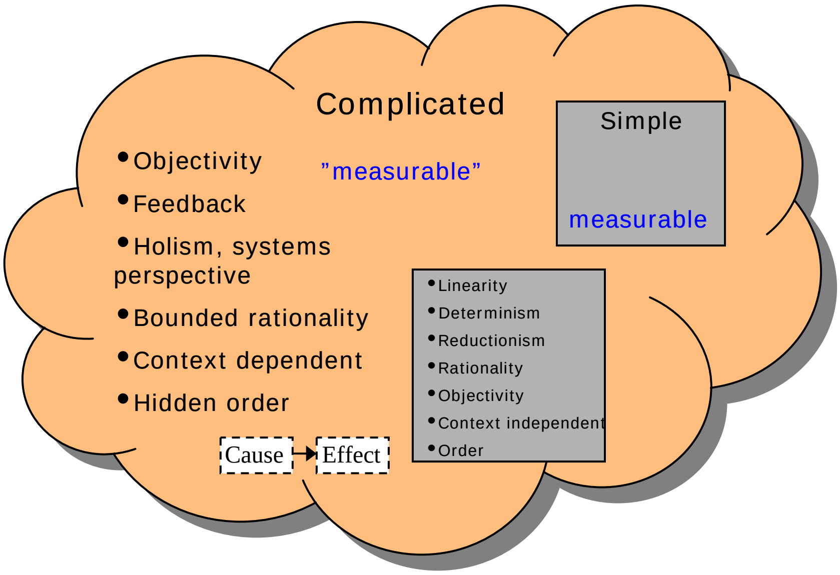


Figure 11.2. Characteristics and assumptions associated with the complicated filter within the complexity framework.

10.2 Filter two - the complex perspective

With the complex filter set on the world (see Figure 11.3), the set of assumptions made are extended and of a dialectic character. With this filter many unknowable phenomena are considered as often being related to choices made in daily situations. Therefore, even if knowledge which explains the phenomena in question can be gained in the future, the situations are contemporary. The perceived order and structure in e.g. logistics phenomena, are the result of self-organizing processes created in the interactions of the people in their efforts to make logistics operations work on an everyday basis. However, this order cannot be controlled, only influenced or stimulated by attractors in its context. This makes unpredictability for exactness impossible at the same time as patterns of order can be exhibited and can guide further development when the history related to a phenomenon is examined. Furthermore, based on our multiple identities i.e. manager, leader, expert, father/mother, son/daughter, husband/wife, etc. the roles we have change as we are affected by events and happenings which trigger feelings and thoughts more or less connected to any one of these identities. In other words, paradoxical situations and perceived states are the realm in this world view.

It is also with this filter that meaning and value are considered important aspects and with those comes the subjective dimension of humanity which, despite positivistic science's reluctant attitude towards it, is still highly apparent when any logistics phenomenon or problem is examined. In other words, there are always people involved with their own goals, values and meanings and these significantly affect the results which can be expected, however this cannot be mapped or predetermined since attitudes, values, meanings, and goals change as time goes by. Hence, the context is constantly evolving. This means that coevolutionary aspects are present and highly influential and the teleology is of a transformative nature. From this follows the impossibility of measure and measurement. The main assumptions of this filter are subjective paradoxical situations of determinism and indeterminism, rationality and bounded rationality, objectivity and subjectivity, order and unorder, all at the same time.

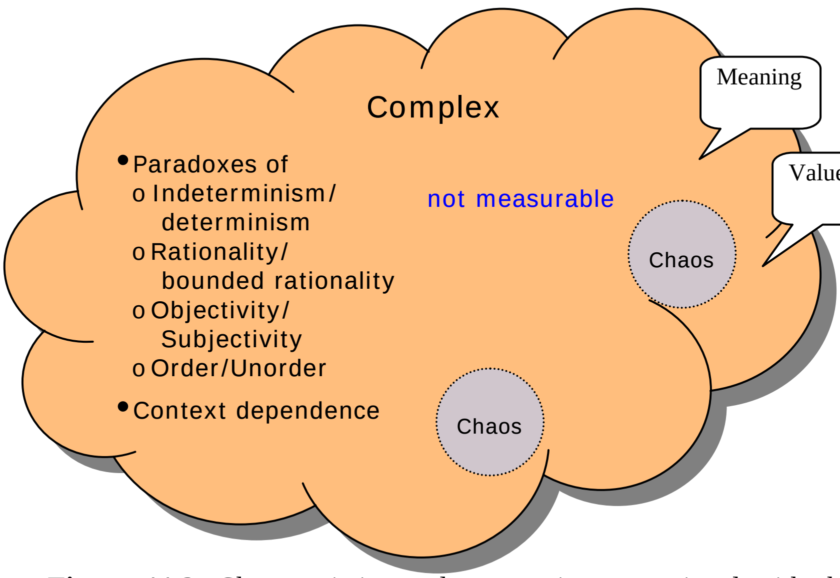


Figure 11.3. Characteristics and assumptions associated with the complex filter within the complexity framework.

10.2.1 Islands of chaos

When reality is viewed through the complex filter there are the “islands” of chaos i.e. where there is no order, no control, and no apparent solutions present at all. These are represented in the figure (see Figure 11.3) as gray circles in the complex area. Examples from the company in this case are when accidents happen or when major contracts are lost. This chaos can also be of a purely subjective character, as we may experience traumatic events which occur at untimely and unexpected moments such as accidents, death etc.

To exemplify this framework and put its use into context, one of the case companies could act as an example. If we take a specific production unit in this company i.e. machine no. 1, it can be more or less optimized towards some kind of predetermined goal which is measured by, for instance, its throughput volume per time unit. The result of such an effort is higher efficiency of machine no. 1 and in this firm high efficiency is promoted by the head management team. The machine and its functions can be described by mechanistic assumptions and even if there are people involved (which there always are,) the routines they work by fit to this mechanical picture. In other words, this type of problem can be perceived as pragmatically independent the human mind. This type of phenomenon and issue (i.e. optimization and efficiency-enhancing efforts) fits the islands of simplicity.

If the perspective is widened to include several production units, which with a systems approach means expanding the system boundaries, the situation is initially somewhat complicated. This is the case for any production manager who is responsible for a production unit which includes more than one machine. With the same set of mechanical assumptions in mind, the approach will be to eliminate sub-optimizations by considering all the machines and finding an optimum for them as a system. This suboptimization issue is widely recognized in literature. At this case company there were a great number of machines with more or less different characteristics and usability. This situation is far more complicated than that for one single machine and when examining the possibility of optimizing the process the number of variables and states which needed to be included increased dramatically.

The problem became soon NP hard and several simplifications needed therefore to be made in such a situation. The description is now of a more systemic nature since it involves feed-back between production units and processes and since there are interconnections and interdependence between the different units i.e. no linear causality assumed *per se*. For example, there is, because of capacity constraints in the buffers between the processes, interdependence in how much can be produced in the machines prior to these buffers. The situation can still be perceived as objective in its nature, and described by its content i.e. machines and the connections among them.

Changing perspective to include other aspects which are highly apparent in organizations i.e. when the human mind is included, the situation becomes different since not only are the machines to be considered, but the people who are responsible for parts of or the whole production have their subjective views on how to run the machines. As the production manager is responsible for the production as a whole, he/she is responsible for the process of interpreting information from other parts of the company and other companies such as transporters, customers and suppliers and also has to see to it that the products are ready when needed. The situation is now less objective and thus system concepts or process perspectives emphasizing the flow of physical goods and information loses their explaniability power. Hence, with a mere complicated filter the limits of explainability are reached; this calls for other assumptions, such as those of the complex filter. The plant phenomenon can thus be understood and explained by self-organizing processes of people characterized by their own experiences and personal agendas. The emergent outcome created is influenced by involved people's interpretations and wishes in their efforts of handling everyday paradoxes. This is also the situation of everyday work for the case company and for other companies as well (see appended paper three).

These three company perspectives depict the reality confronted by practitioners in daily efforts as well as in improvement efforts within companies and among companies. The first two are what I define as complicated, where efficiency is the major performance indicator. However, within the complicated perspective i.e. when several machines are interconnected and decisions concerning the flow through them are arbitrary due to incoming orders or forecasts and because they create unpredictable dynamics within the production process, the issue of doing the right thing i.e. effectiveness, increases in importance since any choice may cause a perceived “lock-in” situation in some way. While these effectiveness efforts can be argued to be “objective”, at the end of the day, the choice about what to do will be a matter of judgment, argumentation, therefore, as human involvement through decision-making becomes the factual aspect of balancing efforts between doing the right things for customers/consumers, and doing things cost-efficiently right. At this stage of decision making the underlying assumptions of how to handle a situation or problem highly influence its perceived outcome i.e. whether to go for an efficient or an effective solution. This leads in turn to questions concerning whether efforts should be aimed at reducing or handling the perceived complexity? Traditional logistics aims at the former, at reducing complexity, while adaptive logistics targets handling complexity.

10.3 Towards adaptive logistics

Adaptive logistics; defined in chapter one as *the reactive and proactive activities and actions aimed at managing perceived deviations and disturbances, and increasing logistics effectiveness* is realized with the use of the complexity framework, lying as the foundation for approaching logistics problems and phenomena. The adaptive characteristics which need to be assessed to a certain situation, are derived from the appropriate assumptions the situation needs i.e. for technical parts involved, a complicated filter provides guidance at the same time as the complex filter secures that consideration is given to paradoxical assumptions prevalent in human involvement. Thus, adaptive logistics is not a concept separated from the human mind, instead, it is a transformative concept realized in the individual and collective sense-making processes guided by assumptions related to both filters. However, the assumptions of a complex character, often disregarded in normative logistics models and frameworks, are regarded, and recommended, as primary for addressing effectiveness dimensions of logistics. Consequently, adaptive logistics means reconsideration of formative assumptions and as such provides guidance toward a transformative process perspective.

The goal of using the framework is to create meaning and understanding, and from that, through the introduction of the extended assumption, encourage new ways of addressing logistics issues, of operationalizing logistics concepts, of using research and improvement methods, and of addressing effectiveness. In this process ABM provides a useful method as a process tool. By process tool I mean that during both the model creation phase and in the scenarios generated ABM facilitates communication and understanding for effectiveness issues. The ABM model can be detailed enough to include actual behavior of various parts identified in the logistics processes i.e. bottom-up methodology. Furthermore, assumptions such as heterogeneity, self-organization, and non-linearity are taken into account. Thus, more complicated situations can be addressed.

In conclusion, making assumptions related to the complex filter explicit, novel insights might be gained, and perspectives set on both research and practice. This opens up the opportunity to address novel research areas and questions in the logistics discipline, where such research areas and questions have been developed for the context and situation present i.e. for complex contexts and problems as well. This is the focus of adaptive logistics based on bottom-up principles, and realized with the use of the complexity framework.

11 Conclusions

This thesis set out by proposing that the dominating efficiency focused paradigm underlying most logistics research and practice needs to be balanced with greater focus on effectiveness. The reasons for increased focus on logistics effectiveness are several but rely mainly on the interpretation that due to increased interconnectivity among people, companies and societies overall complexity increases, opening up for both enhanced opportunity space as well as risks. In such contexts the issues for logisticians are transforming from traditionally making a process (e.g. transportation, inventory handling etc.) more efficient i.e. doing things right, towards exploring what to do, why doing it and where to do it i.e. doing the right things. From this effectiveness view it has been argued in this thesis, that current available logistics theories, approaches and methods cannot mirror the real-life phenomena logistics practitioners confront. Existing theories, approaches and methods offer a simplified and incomplete view of logistics processes and activities, particularly failing to provide an understanding of the impact of organizational context and for the human involvement apparent in any logistics activity. If logistics practitioners and researchers rely on such simplified theories, approaches and methods, then their effectiveness increasing efforts (both formulation and implementation) will be impoverished due to poor understanding of the logistics process in practice.

However, it has also been proposed that it is not sufficient to provide new theories, approaches and methods in making logistics more adaptive, rather this has to be grounded by a mind-set shift. This change of mind-shift is proposed to be realized through reassessments of underlying assumptions, i.e. the dominating positivistic and mechanistic beliefs underlying logistics needs to be rethought and extended by assumptions more related to human and human organizational issues and phenomena. Hence, the effectiveness dimension of logistics is to gain more focus if mechanistic principles are challenged, and adaptive complex thinking is provided.

It is the firm conclusion that adaptive logistics is not a concept separated from human-mind and involvement, instead it is a transformative concept realized in the individual and collective sense-making processes guided by assumptions related to both filters. Hence, in order to move towards adaptive logistics it is the conclusion that this is a process involving reflections on assumptions and their impacts on logistics phenomena and processes, and operationalization of a new way of thinking through sense-making methods with close connection to the perceived contexts in question. For the reflective part, theoretical frameworks are needed, which are in line with assumptions similar to real-life experience by managers i.e. of a less mechanical character, with emphasis on the extended assumptions comprised in the complexity perspective. Secondly, in order to operationalize a different way of thinking and acting i.e. change mind-sets to embrace more complex considerations, and provide tangible results in a reasonable time period, it has been concluded that agent-based modeling provides a feasible and applicable method and tool.

In this thesis a complexity framework for adaptive logistics has been proposed, which is the emergent outcome of this research endeavor. The aim of the complexity framework, presented in chapter ten, is to provide insights concerning how to handle complexity and uncertainty, both in research and practice. It may even eventually serve as a catalyst for logistics managers in their actions i.e. provide assistance for a change in mind-set. This framework is based on the complexity perspective presented in my licentiate thesis, appended paper one and chapter three in this thesis. The aim of the complexity perspective has been to increase the understanding of logistics complexity, thus making logistics adaptive. Based on several discussions with both logistics managers and logistics researchers it was generally agreed that the complexity perspective is useful and even more importantly, that the concepts and features of the complexity perspective well suit the experiences both managers and researchers have experienced when dealing with logistics issues.

The complexity framework for adaptive logistics is both a sense-making framework for logistics practitioners and guidance framework for researchers when approaching logistics phenomena. As a sense-making framework it aids practitioners in communicating and addressing issues at hand trough the two filters; the complicated and the complex. With these filters, different perspectives on situations or problems can be shared and in the communicating processes understanding can be gained for complicated as well as complex issues.

Concerning the operationalization, in the logistics context ABM provides a method which can handle real-life logistics operations to a high degree, due to the fact that logistics is concerned with flows of goods being realized through dispersed activities as well as decision making, in time and space. Furthermore, it also provides a method that can quite easily be designed to mimic real-life activities since features such as bounded rationality and limited information for each agent, as well as non-linearity, self-organization, and emergence as a result of the interactions among agents, can be considered and included in the development and use of ABM simulations. In both the cases presented in this thesis, these features have had significant impact on the understanding and interpretation of the result by the people involved from the companies i.e. not only logistics practitioners but other people in different functions of the case companies. The results so far have shown that ABM facilitates the managers understanding of assumptions of a more complex character, and provides a useful method in the complexity framework towards adaptive logistics.

It is also concluded that the complexity framework, with ABM as the application, provides a useful and beneficial approach for the understanding for the correlation between activities and processes spread across the contexts being addressed. This means that practitioners using the complexity framework will increase their understanding of how decisions can sometimes escalate into both positive and negative outcomes of high magnitude, and sometimes diminish and consequently have no effect at all on business performance. Consequently, this will in turn help practitioners to prioritize improvement efforts i.e. logistics adaptive capabilities, with the potential of gaining increased effectiveness in the operations.

11.1 Theoretical contributions and implications

One of the major contributions of this research to the world of academia is as an extension of, and challenge to, the foundations logistics research stands on today. While much has accomplished and developed in the logistics discipline, the theoretical developments have been minor, especially concerning the paradigmatic assumptions which currently influence the logistics research community to a great extent. As stated previously, the assumptions made concerning how to approach and transfer knowledge attained from our perceived reality govern the choices of methods used when research is conducted and have, of course, great influence on the results obtained and presented from any research process. The development and introduction of adaptive logistics based on a complexity perspective and complexity thinking to human-related logistics, a paradigmatic discourse that I believe could benefit the further development of the logistics discipline, has been presented.

It has been concluded that logistics theories, approaches, and methods are based on the ontological notion that logistics is complicated. A paradigmatic shift from solely a complicated perspective to a appreciation of both complicated and complex has been proposed and further elaborated on. This suggests an extended set of assumptions as a base for further development of the logistics discipline.

Furthermore, a conceptual and theoretical framework, *the complexity framework for adaptive logistics*, has been developed and presented with the aim of guiding further development of the logistics discipline in addressing effectiveness dimensions. The complexity framework is based on the assumption that effectiveness improvement efforts depending on the context and situation need suitable approaches and sets of assumptions. This is especially the case when logistics phenomena investigated, improved, developed or designed are constituted by people or networks of people, or when people are involved. The optimization of one machine or one process will probably still be best improved and evaluated by means of positivistic principles and mechanistic assumptions. However, these principles and assumptions are less useful in a context of socio-technological phenomena, where an extended set of assumptions may instead be much more useful for understanding, explanation and improvement.

At all levels the overall outcome of a logistics improvement effort is dependent on the nonlinear interactions and processes involved in the structures in question, the particular idiosyncrasies, local situations, and hidden relationships which will turn out to determine the path taken by the dynamic paradoxical processes. In these circumstances the adaptive logistics approach based on the complexity perspective should provide guidance for reflection for both researchers and practitioners.

11.2 Practical contributions and implications

For logistics practitioners an understanding that logistics effectiveness can arise via emergent as well as deliberate routes may enable them to understand why and how their individual and collective actions are part of the logistics improvement process. This should then help them improve the quality of their improvement decisions and actions and thereby improve the effectiveness dimensions of their logistics processes and activities, and hence the performance of their organizations.

The use of simulation and modeling tools which emphasize less mechanical assumptions could increase the understanding, and in some cases the prediction, of complex processes found in industry. ABM has been showed to facilitate the "operationalization" of the complexity framework in logistics. This is done mainly with ABM models and simulations as process-enhancing tools for increased understanding for the people involved, and as a communication "platform" for the organizational participants involved. These contextualization activities and perspective-sharing meetings are important and valuable since they give the people involved time for reflection, communication and understanding. The model in this sense provides a platform for discussions and thus creates a sense-making context where different functions or viewpoints can meet. The cases presented in chapter seven illustrate some of the benefits such models have given the companies studied concerning both their understanding of measurement methods, and as a decision-supporting system for strategic changes in customer relations, production planning, and uncertainty handling. In conclusion, objective two of this thesis; *Define and develop a methodology which can guide and aid the operationalization of the complexity framework in logistics*, has been accomplished.

The combination of complexity approach and ABM has been proven to be a beneficial method and tool to aid logistics and operations decision-makers in their efforts of managing their businesses. Aided by ABM models and simulations, decision-makers can gain understanding for perceived deviation factors often found in reality, such as breakdowns, accidents, and changes of demand, which are heavily reduced, and even ignored, when transferred into most traditional models. As been discussed and concluded in this thesis, there are several aspects or factors found in the field of logistics which are currently oversimplified, neglected and even ignored in the construction of models and optimizations which are mainly based on equations. Thus, the "optimized" solutions from these models mislead managers and practitioners to believe in future scenarios which scarcely reflect reality. Non-linearity is another factor which definitely exists in reality, nonetheless, the great emphasis on and search for linear cause-and-effect relationships in logistics operations are mirrored in both the way things are planned and scheduled, and in the way models used are constructed. Furthermore, the emphasis on perfect rationality in the logistics field also misleads decision-makers, and this assumption is strengthened in the models they use as aids to managing their operations. With the use of ABM the factors of uncertainty, non-linearity, bounded rationality, and emergence are considered and regarded as useful in the creation of models and simulations which better reflect reality than most of the equation-based models used in industry today.

A concluding remark is that one of the major reasons for using ABM is that its relevance for industry will increase since models and simulations will be developed for a chosen system i.e. models and simulations will be context dependent. In addition, the complexity framework with ABM will make research results comprehensible to people in industry and organizations since they can identify themselves more directly with the agents. This is because the agents in the models and the simulations often represent tangible parts in the system being studied (e.g. machines, processes, trucks etc.). Consequently, the complexity approach facilitated with ABM narrows the semantic gap between managers who are supposed to understand and believe the results derived from models, and the modelers who construct them. This usefulness has been identified in the cases provided in this thesis.

11.3 Methodological contributions and implications

Based on the assumption that our ontological and epistemological standpoints guide our choices of methodology, I believe that the reassessment of underlying assumptions in logistics contributes to further methodological development in which aspects of a complex character are dealt with more explicitly. This means that other assumptions will need consideration by the researcher when approaching and conducting logistics research projects, especially in situations where human involvement is prevalent. These assumptions are related to paradoxes in logistics found in daily life and phenomena such as self-organization, emergence, co-evolution, which are difficult, if not impossible, to capture and understand with several of the research approaches and methods used today.

Furthermore, from a methodological perspective a combined method has been developed where case study method and simulation study methods have been combined and produced great synergies and complement each other when logistics research is conducted.

11.4 Implications for logistics teaching

This research process has also involved teaching and has provided some insights into the area of logistics teaching. There is a danger if logistics teachers continue to present normative, greatly simplified, models of logistics management and describe the logistics processes in accordance with simple top-down planning models. The presentation of such more or less idealized theories and concepts is misguiding and provides distorted pictures which students will sooner or later come to reject when placed in real situations. However, when confronting reality the students are not prepared and the lectures once attained was more of a teaching exercise than a learning opportunity. Hence, issues of problem-identification, prioritizations of logistics efforts, human involvement, knowledge of correlation aspects among different activities and processes in companies and supply networks, and logistics ambiguity, are also of importance from a learning perspective and in making students prepared for future challenges. This is not to say that the models of today should be neglected or rejected, but instead a proposed contribution of balancing them with reflections of assumptions and how these can be put into a comprehensive picture where the appropriateness of theories, approaches and methods are driven by the type of problems at hand.

11.5 Valuation

In this part I will address some reflections on possible critics of this research:

It is too general, not detailed and focused enough!

Against these types of comments I would argue that evaluating the thesis results presented from a reductionistic perspective will yield such comments. The whole point of positivistically influenced research is to demarcate and reduce the context and problem into a suitable level where cause-and-effect relationships can be established and explained. Consequently, from such a perspective this research has failed. On the other hand, the purpose of this thesis is to challenge that type of thinking and provide the logistics discipline with another perspective and an extended set of assumptions more applicable to phenomena where human involvement is explicit. Thus, evaluated from this perspective the thesis has hopefully provided insights and an interesting discourse for further developments of the logistics discipline and for increased effectiveness in logistics in practice.

ABM is a typical mechanistic method and it has no connection to complexity thinking!

I would both agree and disagree with such criticism because it depends on how ABM is used. As reported in this thesis, ABM methodology has been used and can be used in a strictly positivistic manner i.e. designed by deterministic principles and constructed with causality relationship. And I would argue that for some types of problems, phenomena, contexts, valuable results could be obtained. However, what is proposed in this thesis is of a more interpretive and transformative character, where ABM simulations are a supporting method to a greater transformative process of understanding the characteristics and changeability in specific problem contexts and are meant to challenge dominant linear thinking in both research and practice. It is important to point out that ABM will only be able to include complicated aspects of processes and phenomena, the complex aspects will always be created in relation to human involvement and interpretation.

12 Further research

It can be argued that good research will produce more questions than those answered. This is certainly the case of this research endeavor. This is only the beginning of a challenging area for further research to consider, at least for me. I believe that there are several areas which would benefit from the complexity framework, the complexity perspective, and the bottom-up methodology and approach which have emerged from this research process. However, I also believe that the fundamental ideas underlying the concepts presented are of value for further research i.e. the reassessment of underlying assumptions in any research endeavor. It can be argued that what we do not understand we cannot acknowledge, and if we cannot acknowledge anything it is much more difficult to do what is needed to change something. It this regard, I believe that there are several disciplines which need occasional reassessment, in order to be updated to the perceived changes in the world around us, and I particularly believe that it could benefit the logistics discipline if logistics researchers made such self-reassessments in research projects.

Furthermore, I believe that there are several areas within the logistics discipline which would benefit from the discussions and results presented in this thesis. Firstly, the field of demand-oriented supply management, where issues of effectiveness are put in the forefront, needs to put greater emphasis human aspects so that they are considered and assumed in the creation of customer value. As relationships seem to become more important in logistics the need for understanding and sense-making increases, and with that follow extended assumptions of a complex character which need to be considered. In this work I believe that studies inspired by the grounded theory methodology could provide renewed insights into important aspects in the interface between logistics services and customer demands.

Second, further research will focus on research concerning interorganizational activities, i.e. extending the cases to include suppliers and customers to a greater extent. By this, increased understanding may be gained concerning how changes at one supplier might affect the downstream operations the customers’ premises. In these interorganizational contexts the issue of sense-making and sharing of perspectives could be beneficial and, thus, the complexity framework for adaptive logistics could act as a communicative framework for the types of issues and problems to be assessed.

Third, further research is needed in further elaborate on the bottom-up approach that used in this thesis. While the ABM approach has been used here, there might be other methods and tolls that can further advance such an approach. The reason, as mentioned earlier, for a bottom-up approach on logistics phenomena is that the common top-down approach used in logistics is based on high level phenomena from a management perspective. This means that one loses the feeling and understanding for the details (which have been showed to have impact on logistics). By the alternative use of the bottom-up approach the actual product, goods or package being transported is the staring point for the investigation and the operational activities performed in its context This way of approaching logistics processes and problems renders packaging logistics as different to the majority of the methodological approaches used in logistics research today. This could benefit further advancements of both packaging and logistics solutions and services, since it is the details that make a difference.

Fourth, research is needed in assessing logistics environmental impacts. In the work done by Abukhader and Jönson (Abukhader 2005; Abukhader & Jönson 2004a; Abukhader & Jönson 2004b) and Nilsson and Jönson (2002) critical arguments raised concerning the major use of life cycle assessment (LCA) in assessing the environmental impacts of logistics activities. LCA provides a typical example of a reductionistic method based on positivistic beliefs. The idea of horizontal assessment provided by Abukhader (2005) can be further enhanced with the application of a complexity perspective, and with the complex filter in the complexity framework the qualitative, subjective, and paradoxical issues related to environmental issues can be brought to the surface. Hence, the analytic, reductionistic LCA method can be complemented with other frameworks based on other assumptions.

Fifth, further research on understanding of logistics opportunities and drawbacks when it comes to sustainable development issues is needed. While environmental issues relate to the first part of the conclusions from the Brundtland Report[12] on sustainable development, two other issues were also addressed (Welford 1995): The second issue was that of equity. Perhaps the biggest threat facing the world is that developing countries strive to attain the economic standards western economies take for granted. Thirdly, sustainable development requires a different time scale than the short-term strategies which businesses and society make use of today. This is the issue of futurity. Long-term considerations and longer planning horizons need to be adopted, and business policy needs to be proactive instead of reactive. This is also an interesting area, and, more importantly, an area which is increasingly confronting us and is challenging to current business trends since new demands on energy use, waste handling, material use etc. may strongly affect the strategies of today. For logistics and supply chain management consideration of these issues is central in the globalization trend where today global transportation issues is not a major issue. Addressing these issues might need a different set of assumptions, perhaps similar to those developed and used in the complexity framework, since sustainable development issues involve human and human organizational aspects, and are also related to issues in the society.

Sixth, from a methodological point of view I support the statements of Näslund (2002); that logistics needs more qualitative research, especially action research. In order to gain more understanding and improve the complexity framework developed for the purpose of making logistics more effective, the action research approach is an area which could be used and thus further developed. A major reason, I suggest, is that actively participating in everyday logistics work will bring insights concerning qualitative aspects such as power, conflict, everyday communication etc. which might be beneficial for logistics research and practice.

Finally, complementary methods to ABM need to be further explored and applied in logistics contexts on logistics phenomena. This might be methods which could be used to further facilitate understanding and sense-making of logistics-related

[12] http://www.un.org/esa/sustdev

situations and phenomena, such as narrative techniques and other contextualizing methods which focus on communication and sharing of experiences and thus on sharing of perspectives. The logistics discipline has, to date, provided several theoretical concepts which focus on how to improve logistics and make it more efficient. The methods addressed here could be beneficial for linking human understanding and sense-making to these concepts and to other methods in the everyday work of the logisticians.

References

Abukhader, S. M. 2005, *Towards horizontal environmental assessment for supply chain and logistics management*, Doctoral thesis, Department of Design Sciences, Division of Packaging Logistics .

Abukhader, S. M. & Jönson, G. 2004a, "E-commerce and the environment: a gateway to the renewalof greening supply chains", *International Journal of Technology Management*, vol. 28, no. 2, pp. 274-288.

Abukhader, S. M. & Jönson, G. 2004b, "Logistics and the environment: Is it an established subject?", *International Journal of Logistics: Research and Applications*, vol. 7, no. 2, pp. 137-149.

Ackoff, R. L. 1973, "Science in the Systems Age: Beyond IE, OR, and MS", *Operations Research*, vol. 21, no. 3, pp. 661-671.

Alderson, W. 1951, "A Systematics for Problems of Action", *Philosophy of Science*, vol. 18, no. 1, pp. 16-25.

Allen, P. M. 2000a, "Harnessing Complexity", *The Complexity Society Working Papers Series*.

Allen, P. M. 2000b, "Knowledge, Ignorance and Learning", *Emergence*, vol. 2, no. 4, pp. 78-103.

Allen, P. M., Ramlogan, R., & Randles, S. 2002, "Complex Systems and the Merger Process", *Technology Analysis and Strategic Management*, vol. 14, no. 3, pp. 315-329.

Anderson, P. 1999, "Complexity Theory and Organization Science", *Organization Science*, vol. 10, no. 3, pp. 216-232.

Ansoff, H. I. 1965, *Corporate Strategy: An analytical approach to business policy for growth and expansion* McGraw-Hill, New York, NY.

Arbnor, I. & Bjerke, B. 1997, *Methodology for Creating Business Knowledge*, Second edn, Sage Publications, Inc., Thousand Oaks, CA, USA.

Arlbjørn, J. S. & Halldorsson, A. 2002, "Logistics knowledge creation: reflections on content, context and processes", *International Journal of Physical Distribution & Logistics Management*, vol. 32, no. 1, pp. 22-40.

Axelrod, R. 1997, *The Complexity of Cooperation - Agent-Based Models of Competition and Collaboration*, First edn, Princeton University Press, Princeton, New Jersey.

Axelrod, R. & Cohen, M. D. 2000, *Harnessing Complexity - Organizational Implications of a Scientific Frontier*, First edn, Basic Books, Perseus Books Group, New York.

Bagchi, P. K. & Skjoett-Larsen, T. 2003, "Integration of information technology and organizations in a supply chain", *International Journal of Logistics Management*, vol. 14, no. 1, pp. 89-108.

Banks, J. 1998, *Handbook of Simulation: Principles, Methodology, Advances, Applications and Practice* John Wiley & Sons, Inc., New York.

Bar-Yam, Y. 1997, *Dynamics of complex systems*, First edn, Perseus Books, Reading, Massachusetts.

Barnes, D. 2002, "The complexities of the manufacturing strategy formation process in practice", *International Journal of Operations & Production Management*, vol. 22, no. 10, pp. 1090-1111.

Beinhocker, E. D. 1999, "Robust Adaptive Strategies", *Sloan Management Review*, vol. 40, no. 3, pp. 95-107.

Bjerke, B. 1981, *Some comments on methodology in management research*, Department of business administration, Lund University, No. 8.

Bonabeau, E. 2002, "Predicting the Unpredictable", *Harvard Business Review*, vol. 80, no. 3, pp. 109-116.

Bonabeau, E. & Meyer, C. 2001, "Swarm Intelligence - A Whole New Way to Think About Business", *Harvard Business Review*, vol. 79, no. 5, pp. 106-115.

Boulding, K. E. 1956, "General Systems Theory-The Skeleton of Science", *Management Science*, vol. 2, no. 3, pp. 197-208.

Bovet, D. & Martha, J. 2001, *Value nets: breaking the supply chain to unlock hidden profits*, First edn, John Wiley & Sons, Danvers.

Bowersox, D. J. & Closs, D. J. 1996, *Logistical Management, The integrated supply chain process*, International edn, McGraw-Hill, New York.

Bowersox, D. J., Closs, D. J., & Bixby Cooper, M. 2002, *Supply Chain Logistics Management*, First International edn, McGraw - Hill / Irwin, New York.

Bowersox, D. J., Closs, D. J., & Stank, T. P. 1999, *21st Century Logistics: Making supply chain integration a reality* Council of Logistics Management, Oak Brook.

Burbidge, J. L. 1962, *The principles of production control* MacDonald and Evans Ltd., London.

Burrel, G. & Morgan, G. 1979, *Sociological Paradigms and Organizational Analysis; Elements of the Sociology of Corporate Life*, First edn, Heinemann Educational Books Ltd, London.

Caridi, M. & Cigolini, R. 2002, "Improving materials management effectiveness: A step towards agile enterprise", *International Journal of Physical Distribution & Logistics Management*, vol. 32, no. 7, pp. 556-576.

Changrui, R., Shouju, R., Yueting, C., Yi, L., & Chunhua, T. "Modeling agile supply chain dynamics: a complex adaptive system perspective", Systems, Man and Cybernetics, 2002 IEEE International Conference on, pp. 1-6.

Checkland, P. 1993, *Systems Thinking, Systems Practice* John Wiley & Sons Ltd, Chichester.

Checkland, P. 1999, *Systems Thinking, Systems Practice - includes a 30-year retrospective* John Wiley & Sons Ltd, Chichester.

Chen, M. & Wang, W. 1997, "A linear programming model for integrated steel production and distribution planning", *International Journal of Operations & Production Management*, vol. 17, no. 6, p. 592.

Childerhouse, P., Aitken, J., & Towill, D. R. 2002, "Analysis and design of focused demand chains", *Journal of Operations Management*, vol. 20, no. 6, pp. 675-689.

Childerhouse, P. & Towill, D. R. 2003a, "Engineering the seamless supply chain", *International Journal of Logistics Management*, vol. 14, no. 1, pp. 109-120.

Childerhouse, P. & Towill, D. R. 2003b, "Simplified material flow holds the key to supply chain integration", *Omega*, vol. 31, no. 1, pp. 17-27.

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. 2001, "Supply networks and complex adaptive systems: control versus emergence", *Journal of Operations Management*, vol. 19, no. 3, pp. 351-366.

Christopher, M. 1998, *Logistics and Supply Chain Management*, 2nd edn, Financial Times, Prentice Hall, London.

Christopher, M. & Towill, D. 2001, "An integrated model for the design of agile supply chains", *International Journal of Physical Distribution & Logistics Management*, vol. 31, no. 4, pp. 235-246.

Chun, W., Weiming, S., & Ghenniwa, H. 2003, "An adaptive negotiation framework for agent based dynamic manufacturing scheduling", *Systems, Man and Cybernetics, 2003 IEEE International Conference on*, vol. 2, pp. 1211-1216.

Cox, A. 1999a, "A research agenda for supply chain and business management thinking", *Supply Chain Management: An International Journal*, vol. 4, no. 4, pp. 209-211.

Cox, A. 1999b, "Power, value and supply chain management", *Supply chain management, An international journal*, vol. 4, no. 4, pp. 167-175.

d'Inverno, M. & Luck, M. 2001, *Understanding Agent Systems* Springer-Verlag, Berlin.

Darley, V. 1999, *Towards a theory of autonomous, optimising agents,* Doctoral thesis, The Division of Engineering and Applied Science and the Department of Economics, Harvard University, Cambridge.

Davidsson, P. & Wernstedt, F. 2002, "A multi-agent system architecture for coordination of just-in-time production and distribution", *The Knowledge Engineering Review,* vol. 17, no. 4, pp. 317-329.

Day, G. S. & Wensley, R. 1988, "Assessing Advantage: A Framework For Diagnosing Competitive", *Journal of Marketing*, vol. 52, no. 2, pp. 1-21.

de Treville, S., Shapiro, R. D., & Hameri, A.-P. 2004, "From supply chain to demand chain: the role of lead time reduction in improving demand chain performance", *Journal of Operations Management*, vol. 21, no. 6, pp. 613-627.

Dejonckheere, J., Disney, S. M., Lambrecht, M. R., & Towill, D. R. 2003, "Measuring and avoiding the bullwhip effect: A control theoretic approach", *European Journal of Operational Research,* vol. 147, no. 3, pp. 567-590.

Dejonckheere, J., Disney, S. M., Lambrecht, M. R., & Towill, D. R. 2004, "The impact of information enrichment on the Bullwhip effect in supply chains: A control engineering perspective", *European Journal of Operational Research*, vol. 153, no. 3, pp. 727-750.

Dent, E. B. 1999, "Complexity Science: a Worldview Shift", *Emergence,* vol. 1, no. 4, pp. 5-19.

Disney, S. M., Naim, M. M., & Towill, D. R. 1997, "Dynamic simulation modelling for lean logistics", *International Journal of Physical Distribution & Logistics Management,* vol. 27, no. 3, pp. 174-196.

Doig, S. J., Ritter, R. C., Speckhals, K., & Woolson, D. 2001, "Has outsourcing gone too far?", *The McKinsey Quarterly* no. 4, pp. 24-38.

Dooley, K. J. & Van de Ven, A. H. 1999, "Explaining complex organizational dynamics", *Organization Science,* vol. 10, no. 3, pp. 358-372.

Dunn, S. C. & Seaker, R. F. 1994, "Latent variables in business logistics research: Scale development and validation", *Journal of Business Logistics*, vol. 15, no. 2, pp. 145-173.

Eisenhardt, K. M. 1989, "Building Theories from Case Study Research", *Academy of Management Review*, vol. 14, no. 4, pp. 532-550.

Ellram, L. M. 1996, "The use of case study method in logistic research", *Journal of Business Logistics*, vol. 17, no. 2, pp. 93-138.

Emerson, D. & Piramuthu, S. "Agent-based framework for dynamic supply chain configuration", IEEE, Hawaii, pp. 168-176.

Epstein, J. M. 1999, "Agent-based computational models and generative social science", *Complexity*, vol. 4, no. 5, pp. 41-60.

Fisher, M. L. 1997, "What Is the Right Supply Chain for Your Product?", *Harvard Business Review*, vol. 75, no. 2, pp. 105-117.

Flint, D. J. & Mentzer, J. T. 2000, "Logisticians as Marketers: Their role when customers desired value changes", *Journal of Business Logistics*, vol. 21, no. 2, pp. 19-41.

Forrester, J. 1961, *Industrial dynamics* MIT Press, Cambridge, MA.

Forrester, J. W. 1968, "Industrial Dynamics - After the first decade", *Management Science*, vol. 14, no. 7, pp. 398-415.

Frohlich, M. & Westbrook, R. 2002, "Demand chain management in manufacturing and services: web-based integration, drivers and performance", *Journal of Operations Management*, vol. 20, no. 6, pp. 729-745.

Gammelgaard, B. 1997, "The Systems Approach in Logistics", Institute for Logistics and Transport, Copenhagen Business School, pp. 9-20.

Gammelgaard, B. 2004, "Schools in logistics research?: A methodological framework for analysis of the discipline", *International Journal of Physical Distribution & Logistics Management*, vol. 34, no. 6, pp. 479-491.

Garver, M. S. & Mentzer, J. T. 1999, "Logistics research methods: Employing structural equation modeling to test for construct validity", *Journal of Business Logistics*, vol. 20, no. 1, pp. 33-48.

Gell-Mann, M. 1994, *The Quark and the Jaguar: Adventures in the Simple and the Complex* ABACUS, London.

Gentry, J. J. 1996, "Carrier involvement in buyer-supplier strategic partnerships", *Carrier involvement in buyer-supplier strategic partnerships*, vol. 26, no. 3, pp. 14-25.

Gerber, A., Russ, C., & Klusch, M. 2003, "Supply web co-ordination by an agent-based trading network with integrated logistics services", *Electronic Commerce Research and Applications*, vol. 2, no. 2, pp. 133-146.

Glaser, B. G. & Strauss, A. L. 1967, *The Discovery of Grounded Theory - Strategies for qualitative research* Aldine Publishing Company, Chicago.

Gulati, R., Nohria, N., & Zaheer, A. 2000, "Strategic networks", *Strategic Management Journal*, vol. 21, no. 3, pp. 203-215.

Hale, B. J. 1999, "Logistics perspectives for the new millennium", *Journal of Business Logistics*, vol. 20, no. 1, pp. 5-9.

Hedlund, F., Loodberg, M., & Wajnblom, D. 2004, *Decision-making using agent-based modeling - A case study of complexity at Unilever Bestfoods,* Master thesis, Department of Design Sciences, Lund Institute of Technology, and Department of Business Administration, School of Economics and Management, Lund University.

Heikkilä, J. 2002, "From supply to demand chain management: efficiency and customer satisfaction", *Journal of Operations Management*, vol. 20, no. 6, pp. 747-767.

Hellström, D. 2004, *Exploring the Potential of Radio Frequency Identification Technology in Retail Supply Chains - A Packaging Logistics Perspective,* Licentiate thesis, Department of Design Sciences, Division of Packaging Logistics, Lund University, Lund.

Hendry, L. C. 1998, "Applying world class manufacturing to make-to-order companies: problems and solutions", *International Journal of Operations & Production Management,* vol. 18, no. 11, pp. 1086-1101.

Hill, T. 1995, *Manufacturing Strategy - Text and Cases*, First edn, MacMillan Press Ltd, London.

Holland, J. H. 1998, *Emergence from Chaos to Order,* First edn, Perseus Books, Cambridge, Massachusetts.

Hopper, T. & Powell, A. 1985, "Making sense of research into the organizational and social aspects management accounting: A review of its underlying assumptions", *Journal of Management Studies*, vol. 22, no. 5, pp. 429-465.

Humphrey, A. S., Taylor, G. D., & Landers, T. L. 1998, "Stock level determination and sensitivity analysis in repair/rework operations", *International Journal of Operations & Production Management*, vol. 18, no. 6, pp. 612-630.

Jennings, N. R. & Bussmann, S. 2003, "Agent-based control systems: Why are they suited to engineering complex systems?", *IEEE Control Systems Magazine*, vol. 23, no. 3, pp. 61-73.

Jennings, N. R., Sycara, K., & Wooldridge, M. 1998, "A Roadmap of Agent Research and Development", *Autonomous Agents and Multi-Agent Systems,* vol. 1, no. 1, pp. 7-38.

Johannessen, S. 2003, *An explorative study of complexity, strategy and change in logistics organizations,* Doctoral thesis, Departement of Industrial Economics and Technology Management, Trondheim.

Johannessen, S. & Solem, O. 2001, "Complexity thinking: A new perspective on strategy and change in logistics organizations", Faculty of Engineering and Faculty of Economics, University of Iceland, Reykjavik.

Johannessen, S. & Solem, O. 2002, "Logistics organizations: Ideologies, principles and practice", *International Journal of Logistics Management*, vol. 13, no. 1, pp. 31-42.

Kaihara, T. 2003, "Multi-agent based supply chain modelling with dynamic environment", *International Journal of Production Economics*, vol. 85, no. 2, pp. 263-269.

Karageorgos, A., Mehandjiev, N., Weichhart, G., & Hammerle, A. 2003, "Agent-based optimisation of logistics and production planning", *Engineering Applications of Artificial Intelligence*, vol. 16, no. 4, pp. 335-348.

Kauffman, S. 1995, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* Oxford University Press, New York.

Kehoe, D. F. & Boughton, N. J. 2001, "New paradigms in planning and control across manufacturing supply chains - The utilisation of Internet technologies", *International Journal of Operations & Production Management*, vol. 21, no. 5, pp. 582-593.

Kent Jr, J. & Flint, D. J. 1997, "Perspectives on the Evolution of Logistics Thought", *Journal of Business Logistics*, vol. 18, no. 2, pp. 15-29.

Knirsch, P. & Timm, I. J. "Adaptive multiagent systems applied on temporal logistics networks", M. Muffatto & K. S. Pawar, eds., International Symposium on Logistics, Florence, Italy, pp. 213-218.

Knudsen, D. 2003, *Improving Procurement Performance with E-business Mechanisms,* Doctoral Dissertation, Department of Industrial Management and Logistics, Lund Institute of Technology, Lund University.

Kogut, B. 2000, "The network as knowledge: generative rules and the emergence of structure", *Strategic Management Journal*, vol. 21, no. 3, pp. 405-425.

Kohn, J. W. & McGinnis, M. A. 1997, "Advanced logistics organization structures: Revisited", *Journal of Business Logistics*, vol. 18, no. 2, pp. 147-163.

Kotak, D., Wu, S., Fleetwood, M., & Tamoto, H. 2003, "Agent-based holonic design and operations environment for distributed manufacturing", *Computers in Industry*, vol. 52, no. 2, pp. 95-108.

Kreipl, S. & Pinedo, M. 2004, "Planning and Scheduling in supply chains", *Production and operations management*, vol. 13, no. 1, pp. 77-92.

Kuhn, T. S. 1996, *The Scientific Revolution*, Third edn, The University of Chicago Press, Chicago.

Kurtz, C. F. & Snowden, D. J. 2003, "The new dynamics of strategy: Sense-making in a complex and complicated world", *IBM Systems Journal*, vol. 42, no. 3, pp. 462-482.

Lambert, D. M., Cooper, M. C., & Pagh, J. D. 1998, "Supply Chain Management: Implementation Issues and Research Opportunities", *The International Journal of Logistics Management*, vol. 9, no. 2, pp. 1-18.

Larsen, E. R., Morecroft, J. d. W., & Thomsen, J. S. 1999, "Complex behaviour in a production-distribution model", *European Journal of Operational Research*, vol. 119, no. 1, pp. 61-74.

Lee, H. L., Padmanabhan, V., & Whang, S. 1997a, "The bullwhip effect in supply chains", *Sloan Management Review*, vol. 38, no. 3, pp. 93-107.

Lee, H. L. & Billington, C. 1992, "Managing Supply Chain Inventory: Pitfalls and Opportunities", *Sloan Management Review*, vol. 33, no. 3, pp. 65-74.

Lee, H. L., Padmanabhan, V., & Whang, S. 1997b, "Information Distortion in a Supply Chain: The Bullwhip Effect", *Management Science*, vol. 43, no. 4, pp. 546-558.

Lewin, A. Y. 1999, "Application of Complexity Theory to Organizational Science", *Organization Science*, vol. 10, no. 3, p. 215.

Lewin, R. & Regine, B. 2000, "An Organic Approach to Management", *Perspectives on Business Innovation* no. 4, pp. 19-26.

Lewis, I. & Suchan, J. 2003, "Structuration theory: its potential impact on logistics research", *International Journal of Physical Distribution & Logistics Management*, vol. 33, no. 4, pp. 296-315.

Lim, M. K. & Zhang, Z. 2003, "A multi-agent based manufacturing control strategy for responsive manufacturing", *Journal of Materials Processing Technology*, vol. 139, no. 1-3, pp. 379-384.

Lindholm, M. & Nilsson, F. 2001, *Strategic Environmental Managment for Manufacturing Organisations - a sustainability model and the competencies and activities needed to move towards sustainable development*, MSc, Department of Business Administration, School of Economics and Management and Department of Construction Management, School of Civil Engineering.

Lissack, M. & Richardson, K. A. 2001, "When Modeling Social Systems, Models - the Modeled: Reacting to Wolfram's A New Kind of Science", *Emergence*, vol. 3, no. 4, pp. 95-111.

Lissack, M. R. 1999, "Complexity: the Science, its Vocabulary, and its Relation to Organizations", *Emergence*, vol. 1, no. 1, pp. 110-126.

Lumsdén, K., Hultén, L., & Waidringer, J. "Outline for a Conceptual Framework on Complexity in Logistics Systems", A. H. Bask, ed., NOFOMA 98, Finnish Association of Logistics, Helsinki.

Lynch, D. F., Keller, S. B., & Ozment, J. 2000, "The effects of logistics capabilities and strategy on firm performance", *Journal of Business Logistics*, vol. 21, no. 2, pp. 47-67.

Ma, T. & Nakamori, Y. 2004, "Agent-based modeling on technological innovation as an evolutionary process", *European Journal of Operational Research*, vol. Article in press.

McCarthy, I. P. 2004, "Manufacturing strategy: understanding the fitness landscape", *International Journal of Operations & Production Management*, vol. 24, no. 2, pp. 124-150.

McElroy, M. W. 2000, "Integrating complexity theory, knowledge management and organizational learning", *Journal of Knowledge Management*, vol. 4, no. 3, pp. 195-203.

McFarlane, D. & Sheffi, Y. 2003, "The Impact of Automatic Identification on Supply Chain Operations", *The International Journal of Logistics Management*, vol. 14, no. 1, pp. 1-17.

McGinnis, M. A., Boltic, S. K., & Kochunny, C. M. 1994, "Trends in logistics thought: An empirical study", *Journal of Business Logistics*, vol. 15, no. 2, pp. 273-304.

Mears-Young, B. & Jackson, M. C. 1997, "Integrated Logistics - Call in the Revolutionaries!", *Omega*, vol. 25, no. 6, pp. 605-618.

Mentzer, J. T. & Flint, D. J. 1997, "Validity in Logistics Research", *Journal of Business Logistics*, vol. 18, no. 1, pp. 199-216.

Mentzer, J. T. & Kahn, K. B. 1995, "A framework of logistics research", *Journal of Business Logistics*, vol. 16, no. 1, pp. 231-250.

Mentzer, J. T., Min, S., & Bobbitt, L. M. 2004, "Toward a unified theory of logistics", *International Journal of Physical Distribution & Logistics Management*, vol. 34, no. 8, pp. 606-627.

Merriam, S. B. 1994, *Fallstudien som forskningsmetod* Studentlitteratur, Lund.

Milgate, M. 2001, "Supply chain complexity and delivery performance: an international exploratory study", *Supply Chain Management: An International Journal*, vol. 6, no. 3, pp. 106-118.

Mintzberg, H. 1987, "Crafting Strategy", *Harvard Business Review* no. July-August, pp. 66-75.

Morash, E. A., Dröge, C., & Vickery, S. 1996, "Boundary spanning interfaces between logistics, production, marketing and new product development", *International Journal of Physical Distribution & Logistics Management*, vol. 26, no. 8, pp. 43-62.

Morgan, G. 1983, *Beyond Method - Strategies for Social Research*, First edn, SAGE Publications, Inc, Newbury Park, CA.

Narasimhan, R. & Das, A. 1999, "Manufacturing agility and supply chain management practices", *Production and Inventory Management Journal*, vol. 40, no. 1, pp. 4-10.

Narasimhan, R. & Jayaram, J. 1998, "Causal linkages in supply chain management: An exploratory study of North American manufacturing firms", *Decision Sciences*, vol. 29, no. 3, pp. 579-605.

Näslund, D. 2002, "Logistics needs qualitative research - especially action research", *International Journal of Physical Distribution & Logistics Management*, vol. 32, no. 5, pp. 321-338.

Naylor, J. B., Naim, M. M., & Berry, D. 1999, "Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain - Strategies for Enriching", *International Journal of Production Economics*, vol. 62, no. 1-2, pp. 107-118.

New, S. J. 1996, "A framework for analysing supply chain improvement", *International Journal of Operations & Production Management*, vol. 16, no. 4, pp. 19-34.

Nilsson, F. 2003, *A Complex Adaptive Systems Approach on Logistics,* Licentiate thesis, Department of Design Sciences, Division of Packaging Logistics, Lund University, Lund.

Nilsson, F. & Jönson, G. 20020, "A system's approach for evaluating environmental effects of transportation", International Meeting for Research in Logistics, Lisbon, Portugal.

Nilsson, F. & Wallin, C. 20020, "Interface Complexity and Relative Power in an Outsourcing Context", Monash University and Victoria University of Technology, Victoria, Australia, pp. 165-170.

Olavarrieta, S. & Ellinger, A. E. 1997, "Resource-based theory and strategic logistics research", *International Journal of Physical Distribution & Logistics Management*, vol. 27, no. 9/10, pp. 559-587.

Park, J. 2000, "Evolving Adaptive Organizations", *Perspectives on Business Innovation*, vol. 4, pp. 59-64.

Parunak, H. V. D. 1993, *Autonomous Agent Arcitectures: A Non Technical Introduction*, Industrial Technology Institute.

Parunak, H. V. D., Savit, R., & Riolo, R. L. "Agent-Based Modeling vs. Equation-Based Modeling: A Case Study and Users Guide", Springer, Paris, pp. 10-25.

Pascale, R. T., Millemann, M., & Gioja, L. 2000, *Surfing the Edge of Chaos - The Laws of Nature and the New Laws of Business*, Paperback edn, Three River Press, New York.

Pascale, R. T. 1999, "Surfing the Edge of Chaos", *Sloan Management Review*, vol. 40, no. Spring, pp. 83-95.

Platts, K. W. & Gregory, M. J. 1990, "Manufacturing Audit in the Process of Strategy Formulation", *International Journal of Operations & Production Management*, vol. 10, no. 9, pp. 5-27.

Porter, M. E. 1996, "What is Strategy?", *Harvard Business Review*, vol. 74, no. 6, pp. 61-79.

Prater, E., Biehl, M., & Smith, M. A. 2001, "International supply chain agility - Tradeoffs between flexibility and uncertainty", *International Journal of Operations & Production Management*, vol. 21, no. 5/6, pp. 823-839.

Prigogine, I. 1997, *The End of Certainty - Time, Chaos, and the New Laws of Nature*, First edn, The Free Press, New York, NY.

Rainbird, M. 2004, "Demand and supply chains:the value catalyst", *International Journal of Physical Distribution & Logistics Management*, vol. 34, no. 3, pp. 230-250.

Reaidy, J., Liu, Y., Diep, D., & Massotte, P. 2003, "Intelligent agents for production systems," in *Intelligent agent-based operations management*, S. d'Amours & A. Guinet, eds., Kogan Page Ltd, London, pp. 147-164.

Rice, J. B. & Hoppe, R. M. 2001, "Supply Chain vs. Supply Chain", *Supply Chain Management Review* no. September/Oktober, pp. 47-53.

Richardson, K. A. 2003, "On the Limits of Bottom-Up Computer Simulation: Towards a nonlinear modeling culture", Hawaiian International Conference on System Sciences, Hawaii.

Rigby, C., Day, M., Forrester, P., & Burnett, J. 2000, "Agile supply: rethinking systems thinking, systems practice", *International Journal of Agile Management Systems*, vol. 2, no. 3, pp. 178-186.

Robertson, D. A. 2003, "Agent-Based Models of a Banking Network as an Example of a Turbulent Environment: The Deliberate vs. Emergent Strategy Debate Revisited", *Emergence*, vol. 5, no. 2, pp. 56-71.

Robson, I. 2004, "From process measurement to performance improvement", *Business Process Management Journal*, vol. 10, no. 5, pp. 510-521.

Russell, D. M. & Hoag, A. M. 2004, "People and information technology in the supply chain: Social and organizational influences on adoption", *International Journal of Physical Distribution & Logistics Management*, vol. 34, no. 2, pp. 102-122.

Saghir, M. 2004, *A platform for Packaging Logistics Development - a systems approach*, Doctoral thesis, Department of Design Sciences, Division of Packaging Logistics, Lund University, Lund.

Santos, E., Zhang, F., & Luh, P. B. 2003, "Intra-Organizational Logistics Management Through Multi-Agent Systems", *Electronic Commerce Research*, vol. 3, no. 3-4, pp. 337-364.

Sarv, H. & Landborn, J. 2003, *Den systemiska innovationsstrategin - Inom logistiken och andra systemdicipliner*, Vinnova, Stockholm.

Saunders, M. N., Lewis, P., & Thornhill, A. 1997, *Research Methods for Business Students* Pitman Publishing, London.

Schieritz, N. & Grossler, A. 2003, "Emergent structures in supply chains - a study integrating agent-based and system dynamics modeling", *System Sciences, 2003.Proceedings of the 36th Annual Hawaii International Conference on* pp. 94-102.

Senge, P. M. 1990, *The fifth discipline: the art and practice of the learning organization*, First edn, Doubleday, New York.

Shafer, S. M. & Smunt, T. L. 2004, "Empirical simulation studies in operations management: context, trends, and research opportunities", *Journal of Operations Management*, vol. 22, no. 4, pp. 345-354.

Shankar, V. 2001, "Integrating Demand and Supply Chain Management", *Supply Chain Management Review* no. September/Oktober, pp. 76-81.

Shapiro, J. F. 2001, *Modeling the Supply Chain*, First edn, Duxbury, Pacific Grove.

Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., & Carlsson, C. 2002, "Past, present, and future of decision support technology", *Decision Support Systems*, vol. 33, no. 2, pp. 111-126.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. 2000, *Designing and Managing the Supply Chain Concepts, Strategies, and Case Studies* McGraw-Hill Companies Inc..

Sloan, A. 1963, *My years with General Motors* Doubleday and Co., New York, NY.

Snowden, D. & Stanbridge, P. 2004, "The landscape of management: Creating the context for understanding social complexity", *ECO*, vol. 6, no. 1-2, pp. 140-148.

Souza, R. d., Zice, S., & Chaoyang, L. 2000, "Supply chain dynamics and optimization", *Integrated Manufacturing Systems*, vol. 11, no. 5, pp. 348-364.

Stacey, R. 2002, "Organizations as Complex Responsive Processes of Relating", *Journal of Innovative Management*, vol. 8, no. 2, pp. 27-39.

Stacey, R. 2003, "Learning as an activity of interdependent people", *The Learning Organization*, vol. 10, no. 6, pp. 325-331.

Stacey, R. D. 2001, *Complex Responsive Processes in Organizations - Learning and knowledge creation* Routledege, London.

Stacey, R. D., Griffin, D., & Shaw, P. 2000, *Complexity and management - Fad or radical challenge to systems thinking?* Routledge, London.

Stake, R. E. 2000, "Case Studies," in *Handbook of Qualitative Research*, Second Edition edn, N. K. Denzin & Y. S. Lincoln, eds., Sage Publications, Inc, pp. 435-453.

Sterman, J. 2000, *Business Dynamics Systems Thinking and Modeling for a Complex World* McGraw, New York.

Stock, G. N., Greis, N. P., & Kasarda, J. D. 1999, "Logistics, strategy and structure A conceptual framework", *International Journal of Physical Distribution & Logistics Management*, vol. 29, no. 4, pp. 224-239.

Stock, J. R. 1990, "Logistics Thought and Practice: A Perspective", *International Journal of Physical Distribution & Logistics Management*, vol. 20, no. 1, pp. 3-7.

Stock, J. R. 1997, "Applying theories from other disciplines to logistics", *International Journal of Physical Distribution and Logistics Management*, vol. 27, no. 9/10, pp. 515-539.

Strogatz, S. 1994, *Nonlinear Dynamics and Chaos* Addison-Wesley, USA..

Svensson, G. 2003, "The principle of balance between companies' inventories and disturbances in logistics flows: Empirical illustration and conceptualisation", *International Journal of Physical Distribution & Logistics Management*, vol. 33, no. 9, pp. 765-784.

Swaminathan, J. M., Smith, S. F., & Sadeh, N. M. 1998, "Modeling supply chain dynamics: A multiagent approach", *Decision Sciences*, vol. 29, no. 3, pp. 607-632.

Tan, K. C. 2001, "A framework of supply chain management literature", *European Journal of Purchasing and Supply Management*, vol. 7, no. 1, pp. 39-48.

Tasaka, H. 1999, "Twenty-first-century Management and the Complexity Paradigm", *Emergence*, vol. 1, no. 4, pp. 115-123.

Towill, D. R. 1999, "Simplicity wins: twelve rules for designing effective supply chains", *Control The Institute of Operations Management*, vol. 25, no. 2, pp. 9-13.

Towill, D. R., Childerhouse, P., & Disney, S. M. 2000, "Speeding up the progress curve towards effective supply chain management", *Supply Chain Management: An International Journal*, vol. 5, no. 3, pp. 122-130.

Trim, P. R. J. & Lee, Y. I. 2004, "A reflection on theory building and the development of management knowledge", *Management Decision*, vol. 42, no. 3, pp. 473-480.

Vidal, C. J. & Goetschalckx, M. 2000, "Modeling the effect of uncertainties on global logistics systems", *Journal of Business Logistics*, vol. 21, no. 1, pp. 95-121.

Vollmann, T. E., Cordón, C., & Heikkilä, J. 2000, "Teaching supply chain management to business executives", *Production and Operations Management*, vol. 9, no. 1, pp. 81-90.

von Hayek, F. A. 1989, "The Pretence Of Knowledge", *The American Economic Review*, vol. 79, no. 6, pp. 3-8.

Waidringer, J. 2001, *Complexity in transportation and logistics systems: An integrated approach to modelling and analysis*, Doctoral thesis, Department of Transportation and Logistics, Chalmers University, Göteborg.

Wakeland, W. W., Gallaher, E. J., Macovsky, L. M., & Aktipis, C. A. 2004, "A comparison of system dynamics and agent-based simulation applied to the study of cellular receptor dynamics", *System Sciences, 2004.Proceedings of the 37th Annual Hawaii International Conference on* pp. 86-95.

Walters, D. 2004, "New economy - new business models - new approaches", *International Journal of Physical Distribution & Logistics Management*, vol. 34, no. 3, pp. 219-229.

Weber, M. M. 2002, "Measuring supply chain agility in the virtual organization", *International Journal of Physical Distribution & Logistics Management*, vol. 32, no. 7, pp. 577-590.

Weir, D. 2004, "Sequences of failure in complex socio-technical systems: Some implications of decision and control", *Kybernetes: The International Journal of Systems & Cybernetics*, vol. 33, no. 3, pp. 522-537.

Welford, R. 1995, *Environmental Strategy and Sustainable Development* Biddles Ltd, London, UK.

Wilding, R. 1998a, "Chaos Theory: Implications for Supply Chain Management", *The International Journal of Logistics Management*, vol. 9, no. 1, pp. 43-56.

Wilding, R. 1998b, "The supply chain complexity triangle: Uncertainty generation in the supply chain", *International Journal of Physical Distribution and Logistics Management*, vol. 28, no. 8, pp. 599-616.

Will, J., Bertrand, M., & Fransoo, J. C. 2002, "Operations management research methodologies using quantitative modeling", *International Journal of Operations & Production Management*, vol. 22, no. 2, pp. 241-264.

Williams, T., Maull, R., & Ellis, B. 2002, "Demand chain management theory: constraints and development from global aerospace supply webs", *Journal of Operations Management*, vol. 20, no. 6, pp. 691-706.

Wolfram, S. 2002, *A New Kind of Science* Wolfram Media, Inc., Champaign.

Wooldridge, M. 2002, *An introduction to MultiAgent Systems* John Wiley & Sons, Chichester.

Yin, R. K. 2003, *Case Study Research: Design and Methods*, Third edn, Sage Publications, California.

Yu, Z., Yan, H., & Cheng, T. C. E. 2001, "Benefits of information sharing with supply chain partnerships", *Industrial Management & Data Systems*, vol. 101, no. 3, pp. 114-121.

Zhou, Z. D., Wang, H. H., Chen, Y. P., Ong, S. K., Fuh, J. Y. H., & Nee, A. Y. C. 2003, "A Multi-Agent-Based Agile Scheduling Model for a Virtual Manufacturing Environment", *International Journal of Advanced Manufacturing Technology*, vol. 21, no. 12, pp. 980-984.

Part V

The whole is more than the sum of the parts.

Appended papers

Paper 1

Simplicity vs. complexity in the logistics discipline - a paradigmatic discourse

Presented at the NOFOMA Conference, Linköping, Sweden, June 7-8, 2004. Published in the NOFOMA 2004 proceedings.

Paper 2

Logistics Management from a Complexity Perspective

Published in The ICFAI Journal of Operations Management, vol. 3, No.2, 2004.

Paper 3

Logistics Management in Practice – toward theories of complex logistics

Submitted to the International Journal of Logistics Management.

Paper 4

Combining Case Study and Simulation Methods in Logistics Research

Presented at the 9th International Symposium on Logistics, Bangalore, India, July 14-17, 2002. Published in the ISL proceedings. It is one of the papers that the ISL organizing committee has chosen to invite to be submitted to a Special Issue of The International Journal of Production Economics (IJPE).

Paper 1

Paper 1

Simplicity vs. complexity in the logistics discipline - a paradigmatic discourse

Fredrik Nilsson

Division of Packaging Logistics, Department of Design Sciences, Lund University. Sölvegatan 26, P.O. Box 118, 221 00 Lund, Sweden E-mail: fredrik.nilsson@plog.lth.se, Tel: +46 (0)46 222 91 55; Fax: +46 (0)46 222 80 60

ABSTRACT

Today one could argue that most of the logistics research available has a strong connection to the positivistic paradigm where there is a great emphasis on simplicity in both the research conducted and in the solutions produced. The overall ability to design, plan and control is promoted by the researchers to a great extent. Consequently, firms invest money, time and resources in solutions, based on linear cause and effect relationships, to control and predict logistics activities. As a result, firms' efforts to manage logistics systems and processes often result in frustration and anxiety, not least for the people who are supposed to be in charge.

The purpose of this paper is to provide a paradigmatic discourse in order to move the logistics discipline on the ontological axis towards a less positivistic view i.e. towards considering more complexity in the problematic situations being studied and the solutions provided. A new perspective, the complexity perspective is provided which indicates changes in our epistemological considerations resulting in another, more complex, paradigmatic view, where emphasis on simplicity is set aside and other more complex phenomena such as emergence, non-linearity, heterogeneity and self-organisation are brought into focus.

Key Words: Paradigm, complexity, logistics, emergence, self-organisation.

Another Research Agenda

The quest for developing the logistics discipline, with a more theoretical foundation, is something several authors have emphasised and called for (Arlbjørn & Halldorsson 2002;Dunn & Seaker 1994 ;Garver & Mentzer 1999;Mentzer & Flint 1997;Mentzer & Kahn 1995). Garver and Mentzer (1999 p.33) state, for example, that *"researchers are calling for future logistics research to have a stronger theoretical foundation"*, while Kent Jr. and Flint (1997 p.6) argue in their discussion concerning the future development of logistics that *"another future focus is likely to be theory building."* However, the aim of this theoretical development of the logistics discipline, nevertheless, differs from author to author. There are indications of a striving towards a theory based on positivistic or post-positivistic-oriented epistemology, which Mentzer & Kahn (1995), Mentzer and Flint (1997) and Garver and Mentzer (1999) represent first and foremost. At the same time, authors such as Mears-Young and Jackson (1997) as well as Arlbjørn and Halldorsson (2002) are asking for challenging paradigms for research conducted in the logistics discipline. The positivistic approach means that we will continue to place an emphasis on simplicity in forms of rationality, stability, equilibrium and linearity while the other approach i.e. with challenging paradigms, opens up the logistics field for more complexity to be considered. In other words, as stated by Robertson (2003 p.61); *"if the business world is viewed as being complex, it is inappropriate to consider models developed under paradigms of equilibrium, stability, and linearity to produce an analysis of a turbulent environment."*

Furthermore, the logistics discipline may be regarded as functionalistic[13] (Mears-Young & Jackson 1997). Consequently, since the logistics discipline is first and foremost an applied research area, and most of the research conducted concerns problem-solving methods related to industry, the paradigmatic foundation in logistics has not been challenged to any great extent. Instead, the debate tends to centre around logistics management activities which aim to achieve a predetermined optimum, based on rationally derived set of objectives, often focusing predominantly on cost minimisation. However, as Guba and Lincoln (1998 p.195) state: *"questions of methods are secondary to questions of paradigm."* Morgan (1983 p.14) adds that if the problem contexts are viewed from different paradigms we can *"see and understand how we can research organizations (and any other aspects of social life) in ways that tell us something new about the phenomenon in which we are interested."* In other words the logistics discipline might benefit from a paradigmatic discourse, in order to further develop logistics research approaches and the knowledge that is produced within the discipline.

[13] The term functionalistic is derived from Burrel and Morgan (1979) and is one of the paradigms they use in the analysis of social theory. They (ibid. p.25) state that the functionalist paradigm *"represents a perspective which is firmly rooted in the sociology of regulation and approaches its subject matter from an objectivist point of view."*

This paper deals with how we logisticians perceive the world; simple or complex? More specifically, the focus is on how our assumptions and perceptions of logistics operations affect the choices of methods used and solutions produced. The aim of this paper is to contribute to the debate on challenging paradigms in logistics research and practice. Consequently, this paper represents a proposal aimed at moving the logistics discipline on the ontological axis toward a more nominalistic view or less positivistic view (Burrel and Morgan 1979) i.e. towards considering more complexity in the problem situations under study. The reasons for this are several.

- Firstly, firms have put lot of money, time and resources into methods, models and techniques that are based on assumptions of linear causality and certainty. However, the reality researchers and managers confront is mostly non-linear, uncertain and unstable. One example of a positivistic approach in the logistics practice is the business process re-engineering movement where radical changes of firms, and even supply chains, are seen as designable from a top-management point of view (Davenport 1995; Van Ackere, Larsen, & Morecroft 1993). However, the results of these efforts are not very impressive. Cao, Clarke, & Lehaney (2001) report that 70 per cent of re-engineering efforts result in failure. Another applied method, activity-based costing (ABC) is based on the assumption of *"linking individual products and services to their individual cost drivers"* (Palmer & Parker 2001 p.993) which reflects Taylorist assumptions which are based on Newtonian beliefs of certainty and reductionism principles i.e. perfect rationality and determinism.
- Secondly, control and predictive assumptions are paramount in the usual literature on management (Lissack 1999) where objective reality is taken for granted and linear cause-and-effect relationships are promoted (Macbeth 2002). Consequently, firms' efforts to manage logistics systems and processes have often resulted in frustration and anxiety (Choi, Dooley & Rungtusanathan 2001), not least for the managers who are supposed to be in charge (Stacey, Griffin, & Shaw 2000). Added to this is the fact that when the underlying explanations for firms becoming successful are examined, it is a fact that the reasons are often what we in retro-perspective call by accident or coincidence. Collin and Porras (1997 p.141 in McCarthy 2004) in their study of successful firms conclude; "*In examining the history of visionary companies, we were struck by how often they made some of their best moves not by detailed strategic planning, but rather by experimentation, trial and error, opportunism and quite literally accident. What looks in hindsight like a brilliant strategy was often the residual result of opportunistic experimentation and purposeful accidents."*
- Thirdly, the knowledge produced within the logistics discipline relies heavily on an objective reality i.e. the positivistic paradigm (as discussed above), and as Kuhn (1967) argues, researchers entering a discipline, and thereby a research paradigm, often concur with the common terminology, norms and beliefs provided by people already within the discipline. Consequently, researchers either, consciously or unconsciously, begin accepting these common beliefs and norms, or they change discipline. This means that

researchers who do not believe in the assumptions associated with a positivistic view find it difficult to concur with these, while others researchers accept the assumptions which dominate the discipline, sometimes without even critically reflecting on them. This is the case for logistics managers as well. Consequently, in order to produce new methods, models and techniques to industry and practice other assumptions need to be considered for research conducted and solutions implemented.

- Fourthly, Palmer and Parker (2001 p.997) conclude that "*given the epistemological path taken through the development of alternate management models, there is now, more than ever, a need to re-align the older models with knowledge of uncertainty.*" In the logistics discipline there is and has been a reluctant attitude towards uncertainty. A number of articles have described how to reduce uncertainty (e.g. Childerhouse & Towill 2003) and, of course, this should be done to some extent. However, the pursuit of reducing uncertainty needs to be balanced against epistemological considerations of how to handle uncertainty. This is especially important since efforts focusing solely on reducing uncertainty often produce more uncertainty. As Palmer and Parker (2001 p.992) describe it "*if the current work environment is changing faster than the time taken to develop measurements, then trying to bring about stability through* [e.g.] *documentation is pointless.*"
- Fifthly, increased competition and changing demand are making the marketplace increasingly turbulent i.e. the landscape on which firms operate is not fixed or static and cannot be treated using positivistic principles. Instead, in the words of McCarthy (2004 p.139) *"the size and shape of the landscape, along with the defining environment, is continuously changing."* Consequently, disregarding the dynamics perceived in the world of business by too many simplifications may lead to solutions produced that are too far from reality in order to provide any useful explanations or changes in logistics as well as other business operations.
- Finally, in order to meet increased competition and changing demand companies strive for e.g. agile logistics processes. However, as Prater, Biehl, & Smith (2001 p.827) state *"the introduction of factors that increase supply chain agility may increase supply chain uncertainty and complexity."*

Hence, in this paper it is argued that by considering more complexity, and thereby more uncertainty, in the models constructed and theories developed by researchers as well as managers, our ontological views may change and therefore also the way we communicate our reflections and thoughts i.e. our epistemological considerations. The reminder of this paper is organised as follows. The next section provides a discussion concerning the assumptions found and made in both logistics research and practice. This is in order to draw attention to the underlying assumptions that the logistics discipline relies on at a metatheoretical level. The section following that examines how to transform the logistics discipline from an unchallenged approach of simplification to a more balanced view of complexity and simplicity. It is concluded that the paradigmatic question is the key in order to change the frame of reference of the logistics discipline, which means that another set of assumptions needs to be considered. This set of assumptions is discussed in the subsequent section where assumptions influenced by and derived from the science of complexity are introduced. Finally, the last section provides a concluding discussion and a proposed perspective i.e. the complexity perspective, based on a different set of assumptions which are more connected to real-life events than those generally used today.

Assumptions in Logistics Research and Practice

Today one could argue that most of the research on logistics has a strong connection to the positivistic paradigm (Mentzer & Kahn 1995). In this section positivistic assumptions which in the logistics discipline are given great emphasis on are discussed. These are: command and control, rationality, objective reality, determinism, linear causality, and reductionism. What these assumptions represent are "effective" ways of breaking down descriptions of phenomena of interest which have been the natural way to advance theories for a long time. However as Kauffman (1995) states *"the reduced description does not capture all the features of the phenomenon"* and as we shall discuss in coming sections there are several aspects that cannot be found based on these assumptions, which are highly apparent in all complex systems, not at least logistics.

Command and Control

The overall abilities to design, plan and control are promoted to a great extent in the logistics discipline. For example, in the often-cited definition of logistics management provided by CLM (www.clm1.org[14]), it is stressed that logistics management is about the planning, implementation and control of logistics activities. It seems quite reasonable to interpret the definition in such a way that it implies a positivistic approach to the logistics discipline. Consequently, the definition could be interpreted as one in which an underlying belief of command and control is uppermost, as is the ability of management to plan, implement and control the flow of goods and products, i.e. someone is in the position to control other people and set goals for whole logistics systems and processes. Van Ackere, Larsen & Morecroft (1993 p.413) exemplify the positivistic approach by stating; *"We are all used to the idea that automobiles, ships, aircrafts, office buildings and bridges need careful design to achieve their purpose. But there is much less awareness that business organizations too are 'designable'."*

This observation, that researchers and managers believe they can design and control organisations, is supported by other authors such as Stacey, Griffin and Shaw (2000 p.18), who have observed that *"most managers continue to believe that their role is essentially one of designing an organization and controlling its activities."* However, they (ibid. p.4) also put forward another observation that could be regarded as paradoxical to the belief that managers can design and be in control, because several managers agreed that in their day-to-day operations they were *"the ones in charge but repeatedly finding that they where not in control."* Nonetheless, the common belief of being able to control organisations and, for that matter logistics processes, may not be surprising since management according to a positivistic view brings assumptions and

[14] March 2003

values that are of a mechanical and deterministic character. Axelrod and Cohen (2000 p.29) provide a good explanation for this mechanical approach when they state: "*No doubt, machines and hierarchies provide easier metaphors to use than markets and gene pools. So it is no wonder that most people are still more comfortable thinking about organizations in fixed, mechanical terms rather than in adaptive, decentralized terms.*"

Rationality and Objective Reality

In order to be successful in the planning and control of logistics activities the assumption of rational behaviour is compelling. Rationality implies that each and every constituent part of a system being planned operates rationally i.e. they all have perfect information, the same background, similar beliefs and assumptions, and work towards the same goal (known and designed by someone outside the system). Furthermore, as Allen (2000b) declares, the environment in which the company or department works is stable both before and after the decision has been taken. Additionally, the effects that we do not know can be ignored since they have no effect on the situation in questions. The rationality assumption relies on another element in the positivistic view, namely objectivity. This implies that every phenomenon is perceived in the same way regardless of whoever observes it and that it is value-free, time-free and context independent.

Determinism and Linear causality

Causality relies on sufficient knowledge of prior conditions in order to show future events or impacts, and is the principle behind determinism (Bar-Yam 1997). Since Descartes and Newton, science has been heavily influenced by beliefs of deterministic assumptions. However, as Nobel prize winner Ilia Prigogine (1997 p.6) states, "*Popper and many other philosophers have pointed out that we are faced with an unsolvable problem as long as nature is described solely by a deterministic science.*" In natural science there are at least two major improvements that have destroyed the dream of solely deterministic relationships. These are in quantum physics, where it has been proven that there is fundamental indeterminism at the sub-atomic level (Kauffman 1995), and in mathematics with the field of deterministic chaos, which Baranger (2000 p.8) explains by stating: "*chaos destroys our reductionist dream, the dream that we have absolute power if we only know enough about the details.*"

The use of linear programming, which is widely used in the practice of logistics to e.g. optimise resource allocations in supply chains, is a good example of an applied method based on deterministic and linear causality assumptions. According to Shapiro (2001 p.85), there are five fundamental properties accepted in linear programming. These are: 1) linearity 2) separability and additivity 3) indivisibility and continuity 4) single objective function, and 5) data known with certainty. The great advantage of linear programming is of course the simplicity of using it. However, it might not represent many of the problems and situations we are affected by in the logistics discipline, especially not at present, since there are several non-linear tools on the market.

Reductionism

Some of the prominent assumptions in the logistics discipline are those concerning the possibility of reducing complexity and quantifying it by separating parts or problems into simple elements and sub-problems (McCarthy 2004), which lay as the foundation for the positivistic paradigm (Goodwin 2000). Kauffman (1995 p.VII) states that *"the past three centuries of science have been predominantly reductionist, attempting to break complex systems into simple parts, and those parts, in turn, into simpler parts."* This implies an approach where an identified phenomenon (e.g. a logistics process) is broken down into solvable parts (e.g. inventory, transports, manufacturing and sub-processes of these) and where the parts, after being scrutinised and handled separately, are placed together into a solution in a summative manner. *"Such a deterministic view parallels the physical laws advanced by Isaac Newton, which assume that if the complexity of any system is understood then eventually every known interaction in it can be accurately predicted."* (Zohar, 1990 in Palmer & Parker 2001 p.981) With such an epistemological assumption in mind, *"better management is often seen as simply running the "machine" faster or more efficiently"* (Allen 2000a p.1). In management jargon this epistemological assumption could be regarded as top-down-oriented and, as I have interpreted it, the rule in the logistics discipline. However, while this reductive top-down-oriented process suits various problems where reductionism can be assumed quite confidently (Dent 1999), it may not always benefit the result if the phenomenon under study consists of interdependent parts that are difficult or impossible to unravel, i.e. problem situations where context and phenomenon are complex.

Making these assumptions i.e. determinism, reductionism etc. means that stability and equilibrium represent an optimal state to strive towards and that this is possible, since reduction of uncertainty balances the demand and supply of products. This type of reasoning i.e. a striving towards states of equilibrium and stability, together with reductions of uncertainty, is apparent in the logistics discipline, which Lambert, Stock and Ellram (1998 p. 453) emphasise by declaring that *"an effective organization must exhibit stability and continuity,"* and Lambert and Cooper (2000 p.72) state: *"controlling uncertainty in customer demand, manufacturing processes, and supplier performance are critical to effective supply chain management."* To summarise then; these assumptions and beliefs represent a paradigm that relies on known environments and a predictable future, where someone i.e. managers, has the ability to deliberate design and amend a logistics system towards a chosen goal and this can be done without any thoughts about the history related to the problem. Consequently, we will obtain simple models that are quite easy to understand, however they will certainly not represent many of the problems that are apparent in the logistics discipline, neither for researchers, nor for managers.

Towards more Complexity

In order to challenge the common positivistic assumptions in logistics and develop the logistics discipline, the process of knowledge creation i.e. the epistemological considerations, are central. Arlbjørn & Halldorsson (2002 p.31) address the process of knowledge creation on three different levels (see figure 1.1), the practice level, the discipline level, and the meta level.

The practical level, starting from the bottom, concerns the actual logistical work being accomplished in day-to-day operations. The discipline level is where the majority of the logistics-related research is focused. It is on this level that new logistics methods are developed; either from research with an empirical focus, where best-practice solutions are reported and "glory stories" (New 1996) presented, or as theoretical borrowing from other theories (Stock 1997). The final level, the meta level, is where the ontological and epistemological debates are centred and thereby lie as the foundation for the paradigm the logistics researcher belongs to. Ontological assumptions are assumptions about reality, and, as Guba and Lincoln (1998) argue, the ontological questions concerning our view of reality are the first to be asked when a paradigm is discussed. The next question, suggested by Guba and Lincoln (ibid.) concerns knowledge and, as Burrel and Morgan (1979 p.1) state, is thereby *"about how one might begin to understand the world and communicate this as knowledge to fellow human beings."* According to Burell and Morgan (ibid.) a paradigm consists of

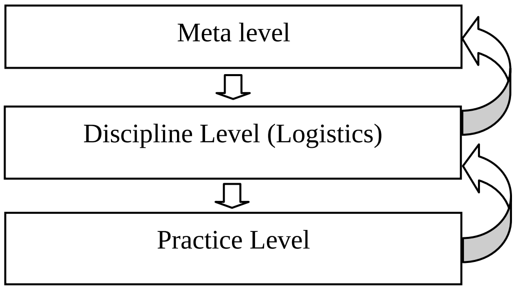


Figure 1. The interplay between the levels of practice, discipline and philosophy of science. Modified from Arlbjørn & Halldorsson (2002 p.31).

meta-theoretical assumptions and these assumptions have direct implications for the methodology and methods used and thereby constrain the basic beliefs taken for granted during the research process. This means that the paradigmatic question is the key, in order to change the frame of reference of the logistics discipline.

A paradigmatic discourse may benefit the logistics discipline by increasing our consciousness of *why* we as researchers do the things we do and *how* we do them. When we enter a research field the common assumptions and beliefs which exist in the community are transferred, in explicit as well as implicit modes, and eventually taken for granted (Kuhn 1996). Kuhn (1996 p.46) states: "*Scientists work from models acquired through education and through subsequent exposure to the literature often without quite knowing or needing to know what characteristics have given these models the status of community paradigm."* This seems to be the case in the logistics discipline, where in a recent review of doctorial dissertations in Scandinavia between 1990 to 2001 by Gubi, Arlbjørn, & Johansen (2003), it was concluded that as much as 45 per cent have not explicitly incorporated methods or theories originating from the philosophy or theory of science.

Mears-Young and Jackson (1997) claim that it might be useful for and beneficial to logistics for researchers to be more self-reflective about what foundations the methods they use and the solutions they provide stand on. Powell (2003 p.286), with relevance to the suggested paradigmatic discourse, states, "*for any empirical discipline, epistemological beliefs have theoretical and methodological consequences,* *and habitual beliefs can lead to dogmatism, illusion, or despair."* And, as Arlbjørn & Halldorsson (2002 p.22) state: *"if we take this* [the positivistic] *view for granted, we may produce a unilateral view of logistics knowledge that only focuses on objective and observable phenomena."* Furthermore, ontological as well as epistemological considerations i.e. changes of paradigmatic views might reveal new approaches and novel results or as Dent (1999 p.12) describes it *"how we see things determines much of what we see."* Moreover, as Lissack (1999) emphasises, the language being used in a discipline or a firm reflects how reality is conceived, and this limits the possibilities available for the members to improve their mutual understanding as well as to improve solutions to various problems both within the discipline and within firms.

The Complexity Perspective

The perception of supply chains and logistics systems as being complex is emphasised by several authors (Bowersox & Closs 1996; Christopher 2000; Cox 1999; Lambert, Cooper, & Pagh 1998; Lumsdén, Hultén, & Waidringer 1998; Tan 2001). However, the complexity is often derived from an interpretation of logistics systems as being difficult to understand since these systems consist of a great number of parts, relationships and flows, i.e. they should be heavily reduced and simplified in order to be dealt with.

As discussed above, in order to move towards less positivistic research and managerial views, there are implications that need consideration when research is being conducted. For example, the concepts of self-organisation and co-evolution are not explicitly dealt with in logistics research and methods and techniques such as systems dynamics, linear programming and other quantitatively oriented approaches cannot comply with these approaches. However, in the emerging science of complexity these concepts and other related ones, such as emergence and adaptability, are of central importance and interest. Complexity theory and its paradigmatic foundations will be introduced here and used as a theoretical foundation towards a paradigm representing assumptions other than those today present in the logistics domain i.e. a complexity perspective.

The ideas and concepts that have appeared in the science of complexity have various applications and points of origin, and these ideas are continually being developed in several areas within natural sciences, as well as in areas related to social sciences. The science of complexity designates an approach in trying to find universal properties among several disciplines and thereby unifies knowledge and perspectives on reality between different theoretical areas. *"The study of complex systems focuses on understanding the relationship between simplicity and complexity."* (Bar-Yam 1997 p.293) In that sense, it may be regarded as a truly interdisciplinary science.

While the characteristics of complexity theory might seem closely connected to the general systems theory (Von Bertalanffy 1969), cybernetics (Ashby 1956; Beer 1959), system dynamics (Forrester 1995) and the systems approach (Checkland 1993), several differences are identified when we examine how the complexity theory has an impact on research approaches and assumptions. One apparent difference is that *"one of the basic premises of complexity theory is that much of the apparently complex aggregate behavior in any system arises from the relatively simple and* *localized activities of its agents. Systems theory, on the other hand, defines complexity as arising from a high number of parts (agents) and interactions."* (Phelan 1999 p.239) Another, difference is the emphasis on time and change in complexity theory which differs from the systems theory (Choi, Dooley, & Rungtusanatham 2001). Furthermore, in systems theory the focus is on structure, and on how essential the structure is in order for the dynamics in a system to be understood. This point is especially stressed by Sterman (2000) and Senge (1990), who argue that *'structure drives behavior'*. From a complexity perspective one would agree with this statement, however, as paradoxical it may be, the complexity researcher would also argue that "behaviour creates structure" and would perhaps emphasise this more. The structure is an emergent outcome of self-organising behaviours. The difference, again, is the question of time. The quotation above i.e. *'structure drives behaviour'*, works well in a static context, however, as proven by Prigogine (1997), since time has a direction structures will change. The reason is that we change structures in our daily operations in whatever we do as well as in what we choose not to do.

Nevertheless, the complexity movement is first and foremost an attempt to move science away from the strong thoughts of reductionism and positivism in the majority of scientific disciplines today. From an ontological view the perceived reality is complex i.e. phenomena, people, artefacts etc. are interwoven and interrelated and the processes perceived are irreversible, all of which denotes the important factors of time and change (Axelrod & Cohen 2000; Bar-Yam 1997; Gell-Mann 1994; Kauffman 1995; Waldrop 1992). The future is mainly viewed as unknown, or, as Prigogine (1997 p.1) states, under *"perpetual construction."* Choi, Dooley, & Rungtusanatham (2001 p.356) declare that *"in a complex system, it is often true that the only way to predict how the system will behave in the future is to wait literally for the future to unfold."* It follows from this that the epistemological assumptions associated with the complexity theory are, to a greater extent, in line with the limitations of handling or even understanding perceived reality. Richardson, Cilliers, and Lissack (2001 p.13) state that *"a principal requirement of a complexity-based epistemology is the exploration of perspectives."*

While the complexity theory consists of several concepts that are treated more or less in each of these disciplines and theories, it is probably best described by some of the central concepts considered in the complexity theory. These are emergence, self-organisation, adaptation and co-evolution, all of which will be briefly described in the next section. These concepts serve as a unifying bridge to the following section where the complexity perspective will be described and other concepts related to a less positivistic view of logistics knowledge and reality.

Emergence and Self-organisation

Emergence could be addressed as the outcome of collective behaviour i.e. self-organisation of several units, elements or human beings i.e. agents[15], performing something individually, or together, that creates some kind of pattern or behaviour that they themselves cannot produce (Bar-Yam 1997;Goodwin 2000;Lissack 1999). Emergence is commonly referred to as the global behaviours that emerge from the

[15] the term agent is commonly used in the complexity theory for the constituent parts of a system

interactions individuals make with each other in a local context. Local context refers to connections in either spatial and/or conceptual space (Bonabeau & Meyer 2001;Gell-Mann 1994;Kauffman 1995). This means that emergent properties are to be found in the collective of constituent agents, since these do not have these properties themselves (Axelrod & Cohen 2000). The concept of the "invisible hand" introduced by Adam Smith in the eighteenth century could be regarded as an emergent phenomenon. Bar-Yam (1997 p.10) provides another example from thermodynamics of two emergent properties, namely pressure and temperature. *"The reason they are emergent is that they do not naturally arise out of the description of an individual particle. We generally describe a particle by specifying its position and velocity. Pressure and temperature become relevant only when we have many particles together."*

It is crucial to consider the phenomena of self-organising and emergent behaviour, which are often observed in every kind of complex system, since these explains several situations where the models or predictions made concerning a certain phenomenon do not provide anything substantial. An understanding of self-organising behaviour is beneficial in order to determine the possibilities to control a particular phenomenon. Stacey, Griffin and Shaw (2000 p.155) state that *"when one succumbs to the powerful drive to reduce complexity to simplicity one loses sight of what is so striking about the possibility of self-organizing interaction producing emergent coherence."*

The concept of emergence and that of self-organisation are what I would argue represent the least-understood features or concepts related to the complexity theory in the logistics context. From a rational perspective, i.e. treating human beings as rational in their behaviour, self-organisation does not exist, since the outcomes of processes and activities are results of design and choices (Stacey, Griffin & Shaw 2000). Nonetheless, global properties as a result of emergence are observable in the logistics area even if their origins and appearance are not addressed to a greater extent. A process is an example of an emergent phenomenon, as it is the result of several parallel and sequential activities or events, i.e. distributed both in space and in time, to produce a coherent outcome. In other words, a process is an emergent phenomenon resulting from the actions of different agents.

By making the assumptions of self-organisation and emergence, we limit the prediction of the system under study to probabilistic patterns of behaviour on different levels of description. The behaviour of individual events is considered, and according to Allen (2000b p.85) this gives *"the system a collective adaptive capacity corresponding to the spontaneous spatial reorganization of its structure."* This means that the agents within the system can and often will change the system structure. The consideration given to the agents in the system distinguishes the self-organising approach from system dynamics. The ability to reconfigure the system from the outside is also probabilistic at this stage, i.e. influences from the outside can affect the system but what outcome it will produce will only be revealed over time. The link to logistics research and practice is hard to make since tools or methods based on only these assumptions are limited. However, the work carried out by Eurobios[16], using

[16] www.eurobios.com

agent-based modelling in the solutions produced, suits this approach (see Nilsson & Darley 2004 for a description). The consideration of emergence and self-organisation is a progression towards a less positivistic approach i.e. more connected to reality, since assumptions of linearity, determinism, rationality and reductionism are disregarded and instead, highly common behaviours found in all type of organisations are considered i.e. emergence, non-linearity, bounded rationality.

Adaptation and Co-evolution

Adaptation in complex systems can be described as the way agents, as well as collections of these, in competitive and co-operative ways act on and react to changes perceived in their environments. What this means is that agents adapt to adaptations by other agents in their local context i.e. they co-evolve. Holland states (in Waldrop 1992 p.146) that *"one of the fundamental mechanisms of adaptation in any given system is this revision and recombination of the building blocks."* This could have a physical as well as conceptual dimension, whereas the former could be the rearrangement of ants in protecting their nest, and the latter could mean thinking in new ways, gaining new perspectives on reality, and thereby adapting to, for example the information revolution. Andersson (1999) adds to this the importance of adaptation as being something that has evolved and has not been planned, especially in environments considered to be far from equilibrium and stable conditions. Another central feature especially required for populations to adapt is variety within the population (Axelrod & Cohen, 2000). This relies on the argument that variety and heterogeneity represent differences between the capabilities of the elements within the population, which brings new and challenging perspectives to certain issues. Allen (2000b p.88) makes the distinction that *"adaptation and evolution result from the fact that knowledge, skills, and routines are never transmitted perfectly between individuals, and individuals already differ."* In other words, thanks to differences, disagreements and conflicts adaptation and co-evolution can take place. Furthermore, as MacIntosh & MacLean (1999) state *"if one accepts the notion that systems not only complex and adaptive, but that their complexity and adaptiveness can itself change, then one can see different implications for the evolution of organizations."*

Conclusions and Discussion

"For 50 years organization science has focused on "controlling uncertainty." For the past 10 years complexity science has focused on how to understand it so as to better "go with the flow" and perhaps to channel that flow." (Lissack 1999 p.120)

One great challenge for logistics researchers and practitioners to reconsider, in developing the logistics discipline, is what the quotation above emphasises i.e. the need to recognise uncertainty and complexity and "go with the flow" instead of trying to remove and control uncertainty. This reconsideration has to start in a paradigmatic discourse, since, as stated previously, the ontological and epistemological assumptions are prerequisites for the methodological and method-related assumptions and choices that are being made.

In this paper the paradigmatic discourse suggests reflecting on the meta-theoretical level as to how complexity concepts e.g. emergence, self-organisation, adaptability etc. will provide an alternative paradigmatic view, that is, another research agenda.

MacIntosh &MacLean (2001 p.1345) state that *"the development of complexity theory, …, is regarded by some as signalling the arrival of a new scientific paradigm in the Kuhnian sense"* which is in line with the proposed complexity perspective in this paper i.e. a perspective where more complexity is considered in the research process and the solutions provided. The focus is placed on reconsidering assumptions normally accepted in the logistics discipline that are of a positivistic character, and on extending these frames by considering other assumptions and perspectives. The complexity perspective is illustrated in figure 2 (see below) where the commonly used assumptions in the positivistic view i.e. linear causality, reductionism, determinism, objective reality, simplicity, independence, and command and control, are extended by factors derived from the paradigmatic view proposed in this paper.

While the positivistic view covers approaches and assumptions that are appropriate to

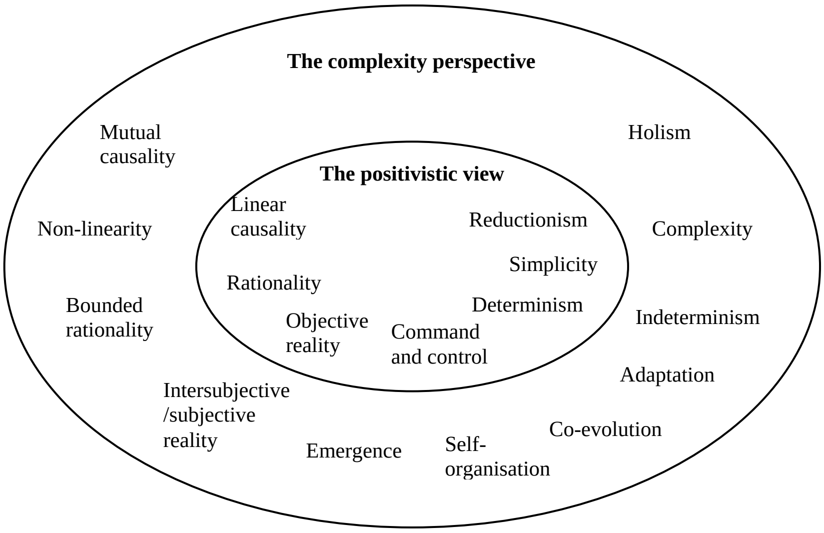


Figure 2. The proposed complexity perspective based on the science of complexity as an extension of the traditional positivistic view, in the logistics discipline. The perspective is here illustrated in a figure derived and modified from Dent (1999 p.9).

some type of problems, the complexity perspective emphasises phenomena and factors highly common and apparent in social contexts i.e. in logistics-related areas. These will be described and compared to the positivistic assumptions underlying the bulk of research in the logistics discipline today.

- ***Mutual causality and non-linearity.*** Instead of linear causality the causes of most problems and issues are of a mutual character since small disturbances can be amplified in non-linear fashions so that there is no interest in finding single factors for complex problems. This Butterfly effect (Palmer & Parker 2001) of small changes in some conditions which sometimes cause huge changes in outcomes and other times no measurable effects makes the Newtonian linearity of cause and effect virtually worthless in the understanding of complex systems which logistics systems typically represent.

- ***Bounded rationality.*** In essence, rational choice and behaviour cannot be found in logistics operations, and even if the people involved could act rationally they are constrained by the impossibility of accurate information and perfect forecasts that rational models impose. Instead, recent research indicates that there are several interesting outcomes when the assumptions of "perfect rationality" are relaxed to some extent (Darley 1999). This relaxation of rationality makes theories, models and solutions more connected to what can be observed in daily logistics operations.

- ***Intersubjective/subjective reality.*** Adaptation is a central feature covered by the complexity perspective and since the agents' actions are the results of perceptions of the reality they feel exposed to, this adaptability is a result of their subjective views of reality. This ontological view differs from the objectivistic approach emphasised in the positivist view.

- ***Emergence.*** In an objective reality it would not be appropriate to mention the concept of emergence since it involves non-reductive patterns which cannot be derived or determined from the agents' autonomous activities. Emergent patterns are, however, still apparent when the collective behaviour these agents create together are examined.

- ***Self-organisation.*** The concept of self-organisation does not fit into the positivistic paradigm since it does not follow any of the assumptions or factors listed above. From a positivistic perspective, self-organszation causes uncertainty, and since it cannot be effectively controlled, planned or designed it should be reduced, or even eliminated. However, in several cases, this process of self-organisation is the reason for novelty, creativity and innovation.

- ***Adaptation and co-evolution.*** The fact that agents, whether they are seen as people or firms, co-evolve causes a number of problems in the positivistic paradigm. Again, co-evolution does not match up with the deterministic assumptions and the linear causality emphasised in the positivistic view, since it involves non-linear feedback mechanisms from parallel activities, distributed both in time and in space, often by a huge number of agents.

- ***Indeterminism.*** In the positivistic view the emphasis on determinism is the rule rather than the exception. Deterministic assumptions underpin the great emphasis for reducing uncertainty and the focus on actions to improve some identified or conceptualised system in order to reach an optimal state. This differs from the indeterministic approach which is emphasised in the complexity perspective. The focus of the complexity perspective is, in contrast, on exploratory analysis aimed at understanding a certain phenomenon, which helps the people involved to live with uncertainty instead of trying to remove it.

- ***Simplicity and reductionism.*** From an epistemological point of view, disregarding simplicity as a means of communication of knowledge and instead considering it as an emphasis on provision of a complex picture, diverges the complexity perspective from more positivistic assumptions in the act of creation of knowledge described. Complexity could be defined as the amount of information needed to describe or understand something (Bar-Yam 1997). This implies that striving towards simplicity through modelling and explaining certain phenomena in a positivistic manner i.e. by adopting a solely reductive approach, might, in many cases, result in too great a disregard for information and data to provide a picture which is sufficiently complete to facilitate comprehension. One example is that the dynamics might not be included in such simplistic descriptions and, as Gillies and McCarthy (2000) hint, the complexity perspective shows that much of our knowledge is focused on static descriptions i.e. on being, rather than on dynamic processes i.e. on becoming.

To summarise; the complexity perspective proposed in this paper is based on insights gained from the science of complexity. As stated in the introduction, the assumptions made concerning how to approach and transfer knowledge attained from our perceived reality govern the choices of methods used when research is conducted and have, of course, great influence on the results obtained and presented from any research process. Adopting a complexity perspective means taking a step away from the common positivistically influenced view, which dominates the logistics discipline, and approaching the phenomena of interest with a different set of assumptions and prerequisites in the research and management process.

References

Allen, P. M. 2000a, "Harnessing Complexity", *The Complexity Society Working Papers Series*.

Allen, P. M. 2000b, "Knowledge, Ignorance and Learning", *Emergence*, vol. 2, no. 4, pp. 78-103.

Arlbjørn, J. S. & Halldorsson, A. 2002, "Logistics knowledge creation: reflections on content, context and processes", *International Journal of Physical Distribution & Logistics Management*, vol. 32, no. 1, pp. 22-40.

Ashby, W. R. 1956, *An introduction to cybernetics*, First edn, Chapman & Hall LTD, London.

Axelrod, R. & Cohen, M. D. 2000, *Harnessing Complexity - Organizational Implications of a Scientific Frontier*, First edn, Basic Books, Perseus Books Group, New York.

Bar-Yam, Y. 1997, *Dynamics of complex systems*, First edn, Perseus Books, Reading, Massachusetts.

Barrenger, T. 2000, Chaos, Complexity, and Entropy - A physics talk for non-physicists, http://www.necsi.org/projects/baranger/cce.html Visited: 2002

Beer, S. 1959, *Cybernetics and management*, First edn, The English Universities Press LTD, London.

Bonabeau, E. & Meyer, C. 2001, "Swarm Intelligence - A Whole New Way to Think About Business", *Harvard Business Review*, vol. 79, no. 5, pp. 106-115.

Bowersox, D. J. & Closs, D. J. 1996, *Logistical Management, the integrated supply chain process*, International edn, McGraw-Hill, New York.

Burrel, G. & Morgan, G. 1979, *Sociological Paradigms and Organizational Analysis; Elements of the Sociology of Corporate Life*, First edn, Heinemann Educational Books Ltd, London.

Cao, G., Clarke, S., & Lehaney, B. 2001, "A critique of BPR from a holistic perspective", *Business Process Management Journal*, vol. 7, no. 4, pp. 332-339.

Checkland, P. 1993, *Systems Thinking, Systems Practice* John Wiley & Sons Ltd, Chichester.

Childerhouse, P. & Towill, D. R. 2003, "Simplified material flow holds the key to supply chain integration", *Omega*, vol. 31, no. 1, pp. 17-27.

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. 2001, "Supply networks and complex adaptive systems: control versus emergence", *Journal of Operations Management*, vol. 19, no. 3, pp. 351-366.

Christopher, M. 2000, "The Agile Supply Chain - Competing in Volatile Markets", *Industrial Marketing Management*, vol. 29, no. 1, pp. 37-44.

Cox, A. 1999, "A research agenda for supply chain and business management thinking", *Supply Chain Management: An International Journal*, vol. 4, no. 4, pp. 209-211.

Darley, V. 1999, *Towards a theory of autonomous, optimising agents*, Doctor of philosophy, The Division of Engineering and Applied Science and the Department of Economics, Harvard University.

Davenport, T. 1995, *Business Process Reengineering: Its Past, Present and Future*, Harvard Business School Publishing, Boston, 9-196-082.

Dent, E. B. 1999, "Complexity Science: a Worldview Shift", *Emergence*, vol. 1,no. 4,pp. 5-19.

Dunn, S. C. & Seaker, R. F. 1994, "Latent variables in business logistics research: Scale development and validation", *Journal of Business Logistics*, vol. 15, no. 2, pp. 145-173.

Forrester, J. W. 1995, "The beginning of system dynamics", *The McKinsey Quarterly* no. 4, pp. 4-16.

Garver, M. S. & Mentzer, J. T. 1999, "Logistics research methods: Employing structural equation modeling to test for construct validity", *Journal of Business Logistics*, vol. 20, no. 1, pp. 33-48.

Gell-Mann, M. 1994, *The Quark and the Jaguar: Adventures in the Simple and the Complex* ABACUS, London.

Gillies, J. M. & McCarthy, I. P. 2000, "Complex Systems Thinking: Key insights for the social sciences, and an industrial application", Warwick University, Coventry, UK.

Goodwin, B. 2000, "Out of Control into Participation", *Emergence*, vol. 2, no. 4, pp. 40-49.

Guba, E. G. & Lincoln, Y. S. 1998, "Competing Paradigms in Qualitative Research," in *The Landscape of Qualitative Research*, N. K. Denzin & Y. S. Lincoln, eds., SAGE Publications, Inc., Thousand Oaks, pp. 195-220.

Gubi, E., Arlbjørn, J. S., & Johansen, J. 2003, "Doctoral dissertations in logistics and supply chain management: A review of Scandinavian contributions from 1990 to 2001", *International Journal of Physical Distribution & Logistics Management*, vol. 33, no. 10, pp. 854-885.

Holland, J. H. 1998, *Emergence from Chaos to Order*, First edn, Perseus Books, Cambridge, Massachusetts.

Kauffman, S. 1995, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* Oxford University Press, New York.

Kent Jr, J. & Flint, D. J. 1997, "Perspectives on the Evolution of Logistics Thought", *Journal of Business Logistics*, vol. 18, no. 2, pp. 15-29.

Kuhn, T. S. 1996, *The Scientific Revolution*, Third edn, The University of Chicago Press, Chicago.

Lambert, D. M., Cooper, M. C., & Pagh, J. D. 1998, "Supply Chain Management: Implementation Issues and Research Opportunities", *The International Journal of Logistics Management*, vol. 9, no. 2, pp. 1-18.

Lissack, M. R. 1999, "Complexity: the Science, its Vocabulary, and its Relation to Organizations", *Emergence*, vol. 1, no. 1, pp. 110-126.

Lumsdén, K., Hultén, L., & Waidringer, J. "Outline for a Conceptual Framework on Complexity in Logistics Systems", A. H. Bask, ed., NOFOMA 98, Finnish Association of Logistics, Helsinki.

Macbeth, D. K. 2002, "Emergent strategy in managing cooperative supply chain change", *International Journal of Operations & Production Management*, vol. 22, no. 7, pp. 728-740.

MacIntosh, R. & MacLean, D. 1999, "Conditioned emergence: a dissipative structures approach to transformation", *Strategic Management Journal*, vol. 20, no. 4, pp. 297-316.

MacIntosh, R. & MacLean, D. 2001, "Conditioned emergence: researching change and changing research", *International Journal of Operations & Production Management*, vol. 21, no. 10, pp. 1343-1357.

McCarthy, I. P. 2004, "Manufacturing strategy: understanding the fitness landscape", *International Journal of Operations & Production Management*, vol. 24, no. 2, pp. 124-150.

Mears-Young, B. & Jackson, M. C. 1997, "Integrated Logistics - Call in the revolutionaries!", *Omega*, vol. 25, no. 6, pp. 605-618.

Mentzer, J. T. & Flint, D. J. 1997, "Validity in Logistics Research", *Journal of Business Logistics*, vol. 18, no. 1, pp. 199-216.

Mentzer, J. T. & Kahn, K. B. 1995, "A framework of logistics research", *Journal of Business Logistics*, vol. 16, no. 1, pp. 231-250.

Morgan, G. 1983, *Beyond Method - Strategies for Social Research*, First edn, SAGE Publications, Inc.

Morgan, G. 1997, *Images of organization*, Second edn, SAGE Publications, Thousand Oaks.

New, S. J. 1996, "A framework for analysing supply chain improvement", *International Journal of Operations & Production Management*, vol. 16, no. 4, pp. 19-34.

Nilsson, F. & Darley, V 2004, Improving decision-making with agent-based modelling - experiences from a packaging company, Working paper.

Palmer, E. & Parker, D. 2001, "Understanding performance measurement systems using physical science uncertainty principles", *International Journal of Operations & Production Management*, vol. 21, no. 7, pp. 981-999.

Phelan, S. E. 1999, "A Note on the Correspondence Between Complexity and Systems Theory", *Systemic Practice and Action Research*, vol. 12, no. 3, pp. 237-246.

Prater, E., Biehl, M., & Smith, M. A. 2001, "International supply chain agility - Tradeoffs between flexibility and uncertainty", *International Journal of Operations & Production Management*, vol. 21, no. 5/6, pp. 823-839.

Prigogine, I. 1997, *The End of Certainty - Time, Chaos, and the New Laws of Nature*, First edn, The Free Press.

Richardson, K. A., Cilliers, P., & Lissack, M. R. 2001, "Complexity Science: A "Gray" Science for the "Stuff in Between"", *Emergence*, vol. 2, no. 3, pp. 6-18.

Robertson, D. A. 2003, "Agent-Based Models of aBanking Network as an Exampleof a Turbulent Environment:The Deliberate vs. EmergentStrategy Debate Revisited", *Emergence*, vol. 5, no. 2, pp. 56-71.

Shapiro, J. F. 2001, *Modeling the Supply Chain*, First edn, Duxbury, Pacific Grove.

Stacey, R. D., Griffin, D., & Shaw, P. 2000, *Complexity and management - Fad or radical challenge to systems thinking?* Routledge, London.

Stock, J. R. 1997, "Applying theories from other disciplines to logistics", *International Journal of Physical Distribution and Logistics Management*, vol. 27, no. 9/10, pp. 515-539.

Tan, K. C. 2001, "A framework of supply chain management literature", *European Journal of Purchasing and Supply Management*, vol. 7, no. 1, pp. 39-48.

Van Ackere, A., Larsen, E. R., & Morecroft, J. d. W. 1993, "Systems Thinking and Business Process Redesign: An Application to the Beer Game", *European Management Journal*, vol. 11, no. 4, pp. 412-423.

Von Bertalanffy, L. 1969, *General Systems Theory - Foundations, Development and Applications*, First revised edn, George Braziller Inc., New York.

Waldrop, M. M. 1992, *Complexity - The emerging science at the edge of order and chaos* Touchstone, New York.

Paper 2

Paper 2

Logistics Management from a Complexity Perspective

Fredrik Nilsson* and Jonas Waidringer**

*Dep. Design Sciences, Div. Packaging Logistics, Lund University, 221 00 Lund, Sweden, Tel: +46 462229155, Fax: +46 462224615, E-mail: fredrik.nilsson@plog.lth.se
** Transek AB, Sweden Tel: +46-31-15 98 70, Fax: +46-31-15 98 11, E-mail: jonas.waidringer@transek.se

Abstract:
The aim of this paper is to discuss the implications a complexity perspective may have on the management of logistics. The CLM definition of logistics management is used as a base to address the implications a complexity perspective has on the logistics discipline. A framework is developed to assess the logistics complexity based on significant properties (structure, dynamics and adaptation) on three levels of resolution (individual/parts, the firm and the network). The identified emphasis of planning and controlling in logistics management are questioned and it is suggested that a change concerning the elements related to the property of adaptation is needed. This means that the process of planning and controlling has to be balanced by considerations to emergent phenomena and the processes of self-organization taking place in the flow of products and information. One conclusion is that a modified version of the definition of logistics management is called for.

Keywords: Complexity, Logistics, Management, Dynamics, Adaptation

Introduction

This paper sets out to discuss complexity in the context of logistics management. The logistics discipline is considered as a complex system given that it involves interdependent actors with a high degree of interactions. The importance of logistics is predicted to increase since the ability to adjust procurement, production, and transportation to customer demands will, together with the management of fast and accurate information flows, become essential in future business environments (Shankar 2001). Logistics management covers the flow of products and information between firms, that is, logistics activities with the fundamental value-adding features of time and place utility (Ballou 1999; Lambert, Stock and Ellram 1998). Lambert, Stock and Ellram (2001 p. 454) refer to a study made of 100 US firms showing that logistics *"typically had responsibility for outbound transportation, intra company transportation, warehousing, inbound transport, materials handling, and inventory control."*

The difficulty in coordinating the logistics activities within and among firms is expected to increase since the dependence among interacting firms intensifies and thereby also the ability to deliver to and supply each other. Axelrod and Cohen (2000 p.26) expect *"systems to exhibit increasingly complex dynamics when changes occur that intensify interactions among the elements"*. Thus, handling the logistics system in the supply network will create new demands on logistics management, which means that new approaches and methods are needed for managers to understand and deal with logistics processes.

What logistics management is really about is how to handle the difficulties and complications that constitute logistical problems. Christopher (1998 p.54) observes that *"the complexity of the logistics task appears to be increasing exponentially."* However, the common approach to handling logistics complexity is based on mechanical assumptions, where the problems are broken down into separate parts that are easy to analyze and solve. With insights from the science of complexity the authors of this paper take another standpoint by questioning the prevailing thoughts about logistics management. The authors' aim in this paper is to discuss the implications a complexity perspective may have on the management of the socio-technical processes that constitute logistics.

Logistics management

Logistics management is defined by the Council of Logistics Management (CLM) as:

> *"The process of planning, implementing and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements."* (*What's it all about?* CLM book - in Lambert, Stock & Ellram 1998 p.3)

Based on this definition one could say that logistics management covers several areas where managerial responsibility is addressed. Those are in this paper addressed as *the structure of and the flow within the logistics system*, *the scope of logistics activities*, and finally *the conformation to customer requirements*.

The structure of and the flow within the logistics system

Logistics systems are often described as a network of nodes and links describing an interconnected web. Wandel and Ruijgrok (1995) establish the basic notion of networks and the correlation between the descriptions of the transport industry as a network. The correlation between the infrastructure, the resources that move on the infrastructure and constitute the transportation network are shown in Figure 1.

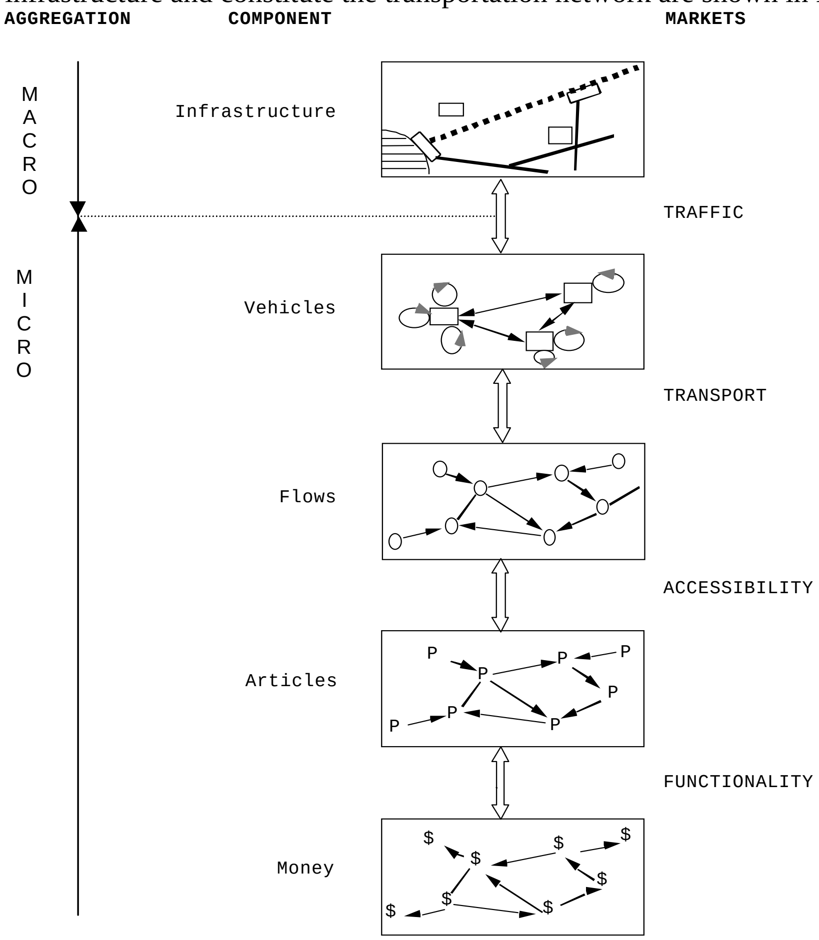


Figure 1

The transport network, resources and infrastructure (Wandel & Ruijgrok 1995), (derived from Waidringer 1999)

The figure describes the correlation between the aggregation level, from macro to micro, the components of the system and the markets. Traffic is regarded as a market for infrastructure services, e.g. the trade of space and time. Transport is the market for the movement of vehicles on the infrastructure. The accessibility market is the market for flows (or slots) made available by the service providers operating on the transport market. Finally there is a market for functionality that is derived from producer and consumer relations. The consumers buy (using money or an equivalent) articles that give the users a functionality. The model could possibly be expanded to include the financial market including the macro economic scale but it was not regarded as useful to expand the model that far in this context.

The scope of logistics activities

The scope, in CLM's definition on page 2, *from point of origin to point of consumption* indicates that logistics management covers several firms. This is supported by Bowersox, Closs and Stank (2000) who claim in their conclusion that it has been estimated that only 20 percent of the scope of logistics activities are within the direct control of a firm's logistics function. One reason for this is the evolutionary change of information and physical flows that have reshaped the logistics context from being a question of a number of detailed but not related material flows to complex supply networks. Of major influence are innovations in information technology, which both have fostered a distinct quickening in information processing as well as reduced, for example, the tonnage handled in physical flow. The value-to-weight ratio of a pound of GDP in the US has gone from $3.64 in 1977 to $6.52 in 1997, a 79 per cent increase (Meyer 1999). Consequently, products are easier and hence less costly to move, which has forced industry to reconsider its logistics flows and usage of performance indicators.

Logistics activities and the term supply chain, introduced by Oliver and Webber (1982), have been discussed at different systems levels, as indicated in figure 2. The three stages also describe the basic evolution into more and more integrative solutions that has been noted over the years. For example, the notion of supply chains have been modified, which (Rice & Hoppe 2001) explain by masking the point that supply network is a better term than supply chain when addressing the networks of companies engaged in the supply relationships of today. In the stages below we also incorporate the transformation of logistics from a cost saver inside a specific organization to logistics as a set of activities that supports the strategic intentions of coordinated organizations, as noted by Bowersox and Closs (1996).

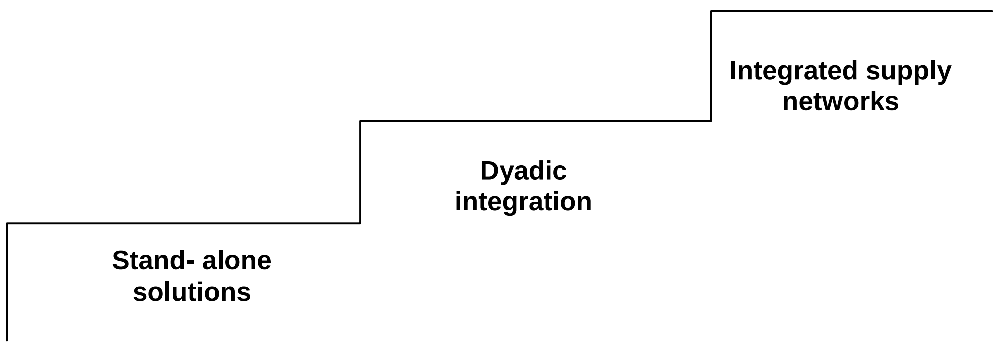


Figure 2

The evolution of logistics solutions (Sjöstedt et al 2001, modified)

In the first stage with stand-alone solutions no actual supply chain can be distinguished and the focus for logistics management is on optimization within the individual firm in order to reach cost savings.

In the second stage with integrated firms in pairs it is possible to talk about an interaction between at least two of the participants in the chain. Cost saving is still an important issue but is supplemented by activities that increase the participants' market shares.

In the last stage, integrated supply networks have been predicted by several researchers to become the dominant organizational form for future competition (Christopher 1998; Cox 1999b; Lambert, Cooper, & Pagh 1998; Durtsche *et al*. 2000; Lee, Padmanabhan, & Whang 1997a). A major reason is greater demands from customers and competitors, which compel firms to focus on delivering greater value to the customers, in less time. In order to satisfy these demands, the ability of suppliers to speed up the innovation process increase. This means that firms are encouraged to cooperate with several other firms and sometimes even transfer several in-house capabilities to suppliers (Rice & Hoppe 2001; Bowersox & Closs 1996a). Consequently, the strategic capabilities for a specific firm will then lie in the relationships it has with other firms in its business context. In other words, the network in which firms are involved will be the source of competitive advantage (Gulati, Nohria, & Zaheer 2000; Kogut 2000).

The conformation of customer requirements

Satisfying the end-customer's requirements is increasingly becoming the key element for success. Traditionally, the value logistics contributed with was lowering the transportation costs for the firms in the supply chain when they pushed products toward the market. Today, the value is created through adding a service dimension that besides the product features required, gives the customer accessibility to the product based on the customer's demand.

The core function of any logistical system is, in figure 3, simply referred to as management of flows. The figure illustrates how the consumption functions**,** as part of marketing or other business activities**,** generate a specification that is transferred through the logistical function to the producer.

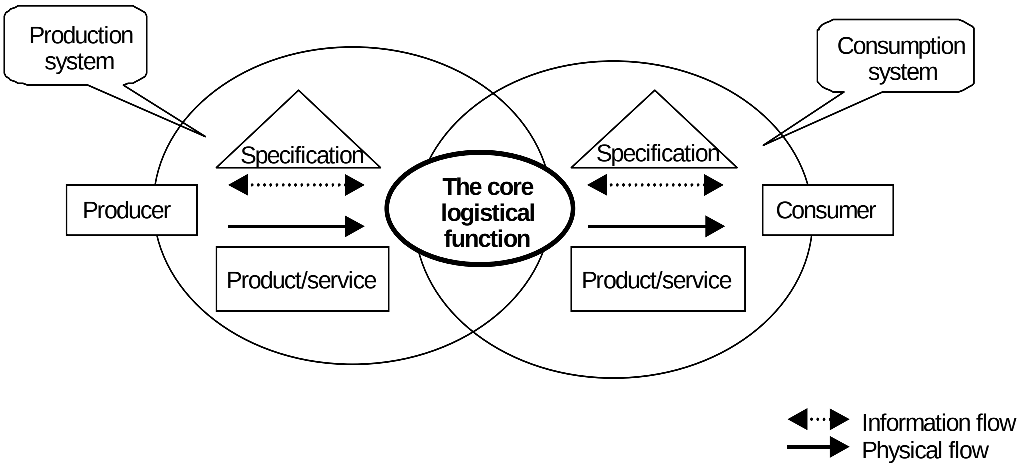


Figure 3

The role of the core logistical function in a Value-Added Industrial System (Sjöstedt et al 2001, modified)

Through the production function the producer materializes the specification into a tangible product or service, which is brought forward to the consumer through the logistical function. The producer has to judge how many resources have to be used in order to meet the specification in a satisfactory way; that is basically a judgment of the market opportunity. The consumer in his or her turn judges how well the product or service correlates with his or her expectations, a process which in this case basically is a utility evaluation.

Complexity in logistics systems

The notion of logistics systems as being complex is not new, which the following citation, given by Manheim as early as in 1979, shows:

> *"Transportation involves the movement of people or goods from one location to another. This requires the expenditure of energy by man, animal or machine., …, In many cases, especially in industrialized countries, transportation is achieved by quite* ***complex processes*** *in which men and machines interact, within institutions that are often large and complex, to deliver transportation services to customers."* (Manheim 1979 p.13)

Although Manheim does not define the concept of complexity or discuss how this complexity arises or can be handled, he observes that the logistics system consists of complex processes. However, describing and understand logistics systems as a class of complex systems is quite recent occurrence.

Even though logistics has been mentioned in articles about complexity before, there are only two articles to the authors' knowledge, that specifically address this issue based on the science of complexity. The first article addresses the complexity as uncertainty involved in supply chains and discusses this from, according to Wilding (1998 p.599), *"three interacting yet independent effects."* These are deterministic chaos, parallel interactions and demand amplification. These effects cause complexity in the logistical processes based on uncertainty in the supply chain. In the second article, Lumsdén, Hultén and Waidringer (1998) also address the uncertainty of causing complexity, the uncertainty of customer demands and time needed for sub-processes are especially noted. Further, three other aspects are addressed regarding the complexity of logistics systems namely; a large number of system states, heterogeneous system, and distributed decision-making. They conclude that there is a need for *"better models of logistical systems… [that] lead to better predictions of the behavior of real systems"*(p.171). In both articles the complexity, which has arisen in the logistics systems, is derived from mainly universal and external aspects that can be objectively viewed, and are global phenomena for these systems. However, the impact the parts within these interconnected and interdependent systems have on each other in creating the global phenomena, are not emphasized to a great extent.

Our paper takes the standpoint that complexity in logistics systems appears when technical systems are put in a social context. The technical systems can in themselves be more or less complex, but when the relationships and interaction between technology and man for a certain class of systems is subject to analysis, each system description is too extensive, since in practice it will be impossible for human actors to handle. The most important factors in such a statement are:

- that there exists a infrastructure or network dimension that is characterized by having properties that change slowly. For example the infrastructure is relatively constant since changes take time i.e. when a new road connection is built or a process-machine is placed within a paper mill. This is a technical dimension once structure elements such as the road network or the placement of machines are set.

- the processes in supply networks are changed faster than the network or infrastructure since the processes use this structure. The use of roads or railways can be changed due to many factors such as cost benefits, regulatory changes or new customers on new locations. The processes can both be technical as well as social at the same time.

- that the infrastructure and the processes are influenced by a large number of decision-makers (actors) that are often spread geographically, with different goal functions and different time horizons for their decisions. This is a social dimension.

A logistics complexity framework

In order to discuss logistics complexity a definition proposed by Waidringer (2001) is used:

> *Transportation and logistics systems' complexity resides in the nature of the structure, dynamics and adaptation. It is a measure of the possibility of modeling these properties and their interaction in a way that allows of implementation of*

control mechanisms, forcing the system under study to meet required service, cost and environmental demands. (Waidringer 2001 p.115)

To address the complexity of logistics activities three properties have been identified within the logistics area that have significant impact for the management of logistics activities. These are *the structure property, the dynamics property*, and *the property of adaptation.* The structure property is related to the infrastructure in the context of logistics, and covers physical as well as information and communicational structures. The dynamic property is related to the processes performed on the network i.e. the flow of goods, money and information within the structure and hence the dynamics in these processes. The property of adaptation is related to the organization and the decision-making i.e. the management and control of the structure and the dynamics, in order to realize the processes on the network.

These properties are in this paper put into three different levels of resolution in the context of logistics and the emergent behaviors or patterns in the transition between the levels are then discussed. It is to be noted that these levels are arbitrary and it is regarded as beneficial to adapt these levels to the problem being studied. The levels chosen are: *the individual/parts, the firm* and, *the network*.

The individual/parts level is where the smallest relevant elements for a logistics systems description are positioned. These elements are the individuals performing different activities but also artefacts that are being used by the individuals. Together, these elements represent the structure. The actual actions by the individuals are addressed as the dynamics. Finally the adaptation is related to how each individual perceives the effects of his/her own actions as well as actions performed by others which affect both the structure and the dynamics.

On the level of the firm the structure is referred to as the infrastructure within each firm in terms of physical structure and intranet, to informal networks emerging from connections among the individuals and/or the parts. The structure of the firm and the perceived boundaries provide the cognitive representation for the individuals of what *"constitutes the object of membership, that is, of identity"* (Kogut 2000 p.408). This makes it the internal perspective where the dynamics constitute of the movement of individuals and the flow of objects, information etc. between the structure elements. The distinction between the individual and the firm level is something Lissack (1999 p.111) addresses by firms "*often experience change as an emergent process."* Still it is the people in the process of sense making that individually and collectively give meaning to the actions (i.e. the adaptation property) that are performed by firms (Lissack 1999).

The network level represents the new organizational form where the structure is referred to the constellation of firms and the infrastructure for both information and physical flow that is being used. The link between the firm structure and the network structure lies in the jointly emergent phenomena embedded in spatially defined networks of labor (Kogut 2000). The dynamics derive from all logistics activities between the firms. Ballou (1997 p.623) states, with relevance to the property of dynamics, that the activities involved on an inter-organizational level are little understood and *"if organizational processes can be developed to deal with logistics matters external to the firm, the firm stands to gain in a way not otherwise possible"*. Concerning the adaptation property of the network, it is considered that both the firm and the supply network are emergent outcomes from interactions of the individuals at the same time as the notion of the firm and the supply network influences the behaviors of the individuals' actions and perpetual constructions. That is to say that they exist at the same time forming each other.

In order to address the implications a complexity perspective may have on logistics management, the three properties (structure, dynamics and adaptation), and the different levels of resolution are used as a framework.

Implications for logistics management

The identified implications a complexity perspective may have for logistics management will here be discussed based on the framework described above. Since logistics management is connected to other kinds of management there are of course similarities in the type of problems that are being treated. However, logistics is by nature a discipline where a mechanistic approach has been successful since the benefits firms exhibit from logistics are time and place utility of products. Time can easily be divided into time intervals and measured quite easily. The spatial dimension is also rather easy to divide into parts because there is a measurable distance from for example Boston to Chicago. Both these measurements are of a technical character and fit well in the property of structure as well as the property of dynamics since distance is related to structure and time is related do dynamics. With a perspective of reality as being objective it is then quite easy to deal with these properties with a mechanical and summative approach. However, as stated in the framework above, the dynamics, taking place in the structure, is being interpreted by logistics managers that by their actions influence the properties of structure and dynamics. The actions are based on the perpetual construction of reality each individual makes. This, being directly related to the property of adaptation has not been greatly emphasized in logistics management.

Planning and Control

As stated in the CLM definition of logistics management, the focus in logistics is on planning and controlling the activities performed. The easiest way to plan and control is in trying to eliminate the complexity involved. Lambert, Stock and Ellram (2001 p. 453) observe that *"an effective organization must exhibit stability and continuity; it must find a unique offering that it can deliver to the market and stick with it to provide customer value."* The emphasis on stability and continuity is expressed in the models used which address transportation and logistics, since these are based on equilibrium assumptions (Allen 2000). In other words, the desirable strategy for logistics managers is to reach equilibrium states that are simple enough to handle by eliminating redundancy and focusing on efficiency and cost reductions. *"Disorder is the price of progress in a dynamic world"* as stated by Quinn (in Coleman 1999 p.38) and this view is also the price for logistics activities.

However, since logistics management covers management of socio-technical processes the dominant approach of planning and control of activities and processes by managers is questioned by the authors. Stacey (2001) describes the view of planning and control as fruitless since the predictability within firms is limited if not impossible and Lissack (1999) argues against this traditional management assumption of control and prediction by stating that with human activity follow emergent outcomes.

The emphasis on planning, and thereby prediction, and control implies a formative and rationalist teleology based on the teleological view Stacey, Griffin and Shaw (2000) describe in their book *Complexity and Management*. A central assumption in logistics management is that the manager has a position outside the system being controlled, which puts him/her in the position of an observer. The manager or the management team has the freedom of choosing the future goals for the logistics system and the capability to design its structure and how and when the flows are determined to take place. This description places logistics management as rationalist teleology since *"the observer has the freedom to choose goals for a system"* and *"even the ability to design it"* (Stacey, Griffin and Shaw 2000 p.72). Added to this is the formative teleology since the manager, in the position of an observer, is able to stand outside the system. Stacey, Griffin and Shaw (2000) especially point out that a formative teleology excludes the interlinked matters of human freedom, the unknown and ethics.

Further, added to the planning and control emphasis, the common approach to handling logistics activities is based on a top-down approach. This means that the actions are planned and decided by the logistics management, which has the ability of viewing the logistics system from "above" i.e. the plan will be based on global logistics phenomena. The planned actions are then properly being distributed to the right places where each action is performed. However, since "*the complex whole may exhibit properties that are not readily explained by understanding the parts"* (Kauffman 1995), the result is that emergent phenomena formed from the bottom-up by local interactions of autonomous individuals and parts, are not being captured. Bonabeau (2002) especially address that emergent phenomena may in several cases be counter intuitive, which make these emergent phenomena impossible for managers to neither plan nor control.

Based on the levels of the resolution described earlier, the individual level is of major importance for logistics management since it is on this level that actions are performed or affected by autonomous individuals. As a result of their actions and the perpetual interpretations of the outcome of other individuals' actions, global phenomenon emerges. Allen (2000 p.83) points out that as a process of sense making: *"there is a complex and changing relationship between latent and revealed preferences, as individuals experience the system and question their own assumptions and goals"*. Bonabeau (2002) address that it is the individuals within firms (and not processes) that make mistakes and causing errors and he goes as far to point to a paradigm shift from spreadsheet and process-oriented approaches to focus on the individuals.

What is required for logistics management in order to move towards robust network constellations is a shift in mind-set. Park (2000 p.61) address this clearly by stating that *"executives must realize that the old top-down, command-and-control structure is ineffective, and in many cases counterproductive."* This approach is in line with the new kind of management Tasaka (1999) describes in his article "Twenty-first-century Management and the Complexity Paradigm." He states that managers should not plan or manage but instead stimulate self-organization. It is through self-organization that the behavior emerges from interactions individuals make with each other (Bonabeau and Meyer 2001).

Consequently, a paradigmatic change from a planning and control approach (top-down) to an emergent and self-organizing approach (bottom-up) would result in changes in the way logistics activities are being managed. Dent (1999 p.12) describes this as *"how we see things determines much of what we see"*. Therefore is it today impossible to describe what we are expected to see when a complexity perspective has influenced how we see for example the activities related to logistics. However, the transformation of mind-set, from a planning, control, to an emergent and self-organization approach, may have consequences for the definitions used in logistics.

The implications a complexity perspective has on logistics management are here illustrated by a discussion of the CLM definition used in this paper. The first part, *"the process of planning, implementing and controlling"* is what logistics management are doing *"for the purpose of conforming to customer requirements."* This is by definition related to the property of adaptation since it demands interpretation by people concerning the customer requirements, and especially for logistics management concerning planning and controlling activities needed for customer fulfillment. Since we are living in an increasingly interconnected world there are several factors that might influence the customer requirements, but certainly also the actual flow and storage of products and information. This leaves logistics management with great interpretation consequences since emergent phenomena are unpredictable and the managers are not in the position of an observer or designer standing outside the logistics system. Still, they are supposed to plan and control the flows of products and information in increasingly interconnected supply networks. What is needed to handle this paradox is a more balanced view of planning and control with considerations to emergence and self-organization.

For logistics management to realize the paradox of control and self-organization, a bottom-up perspective on the logistics activities could give novel insights and act as the balanced view. This could act as a complement to the dominant focus on global phenomena and the associated top-down approach related to this. Possible insights might be that logistics managers will learn that the possibility of breaking network level problems down to actions for individuals is difficult. The effects would be interesting and challenging since global patterns identified in complex systems are not possible to be broken down into the behavior of the individuals/parts (Stacey 1996)

Conclusions and future research

This paper has discussed and analyzed the implications of a complexity perspective on logistics and one conclusion is that a modified version of the definition of logistics management is called for. Based on the discussion earlier in this paper would suggest a change concerning the elements related to the property of adaptation. This means that "the process of planning, implementing and, controlling" has to be balanced by considerations to emergent phenomena and the processes of self-organization taking place in the flow and storage of products and information. This will have to be studied further in order to find a better definition, that is more in line with the environment and conditions that logistics management faces in everything from strategic thinking to everyday work.

In this paper only a short assessment of some of the components that give rise to complexity in logistics systems has been made, although these components are considered some of the main factors. In order to assess the full complexity it is necessary to go deeper in the analysis, but the purpose of this paper was mainly to analyze the concept of complexity in the context of logistics management and to show that it is possible and useful to describe and analyze logistics systems in this context. The underlying purpose of this research is that if the complexity of logistics systems complexity can be modeled and assessed it will give researchers as well as logistics managers a better understanding of these systems and in the future facilitate a more efficient and effective handling of logistics systems.

This paper provides another conceptual model to the research area of logistics that hopefully will give an increased understanding of the problems and systems analyzed and that it in this way will be a part of a further development and enhancement of the research into complex logistics systems. Basically the paper has explored if complexity as a concept and metaphor is useful for describing the shortcomings of logistics systems and it has been proved valid in at least one case.

The future research envisaged is twofold, to analyze complexity in logistics systems *per se* and to study different concepts, models and methods that will help us in understanding and adhering to the requirements of a sustainable society. It is the firm conviction of the authors that there will be an increased demand for more sophisticated solutions to the transport of goods and people which will require more sophisticated approaches, methods and models both to assess these systems properties and to be able to manage and control them in the most efficient way. The concept of complexity is one tool that is possible to use to assess and model logistics systems in order to create a basis for more efficient and effective sustainable logistics solutions.

References

Allen, Peter M. (2000), "Knowledge, Ignorance, and Learning," *Emergence*, 2 (4), 78-103.

Axelrod, Robert and Cohen, Michael D. (2000), *Harnessing Complexity – Organizational Implications of a Scientific Frontier*, New York, Basic Books.

Ballou, Ronald H. (1999), *Business Logistics Management*, International edn, New Jersey: Prentice-Hall Inc.

Bonabeau, Eric. (2002), "Predicting the Unpredictable," *Harvard Business Review*, (March), 109-116.

Bonabeau, Eric. and Meyer, Christopher 2001, "Swarm Intelligence - A Whole New Way to Think About Business," *Harvard Business Review*, (May), 107-114.

Bowersox, Donald J. and Closs, David J. (1996), *Logistical Management, the integrated supply chain process*, International edn, McGraw-Hill.

Bowersox, Donald J. Closs, David J. and Stank, Theodore P. (2000), "Ten Mega-trends that will Revolutionize Supply Chain Logistics," *Journal of Business Logistics*, 21 (2), 1-16.

Christopher, Martin (1998), *Logistics and Supply Chain Management*, UK: Biddles Ltd.

Coleman, Henry J. Jr. (1999), ”What Enables Self-Organizing Behavior in Business, ” *Emergence*, 1 (1), 33-48.

Cox, Andrew. (1999), "Power, value and supply chain management," *Supply chain management, An international journal*, 4 (4), 167-175.

Dent, Eric B. (1999), "Complexity Science: a World Shift," *Emergence*, 1 (4), 5-19.

Durtsche, D. A. Keebler, J. S. Manrodt, K. B. and Ledyard, D. M. (1999), *Keeping score: Measuring the business value of logistics in the supply chain*, Council of Logistics Management, US.

Gulati, Ranjay, Nohria, Nitin and Zaheer, Akbar (2000), "Strategic networks," *Strategic Management Journal*, 21 (3), 203-215.

Kauffman, Stuart (1995), *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*, New York: Oxford University Press.

Kogut, Bruce (2000), "The network as knowledge: generative rules and the emergence of structure," *Strategic Management Journal*, 21 (3), 405-425.

Lambert, Douglas. M., Cooper, Martha C., and Pagh, Janus D. (1998), "Supply Chain Management: Implementation Issues and Research Opportunities," *The International Journal of Logistics Management*, 9 (2), 1-18.

Lambert, Douglas, Stock, James and Ellram, Lisa (1998), *Fundamentals of Logistics Management*, International edn, McGraw-Hill.

Lee, Hau L. Padmanabhan, V. and Whang, Seungjin (1997), "The bullwhip effect in supply chains," *Sloan Management Review*, 38 (3), 93-107.

Lissack, Michael R. (1999), "Complexity: the Science, its Vocabulary, and its Relation to Organizations", *Emergence*, 1 (1), 110-126.

Lumsden, Kenth, Hulthén, Lars and Waidringer, Jonas (1998), "Outline for a Conceptual Framework on Complexity in Logistic Systems" In: *Opening markets for Logistics, the Annual Conference for Nordic Researchers in Logistics - 10th*

NOFOMA 98, (Eds, Bask, A. H. a. V., A.P.J.) Finnish Association of Logistics, Helsinki, Finland.

Meyer, C. (1999), “What’s the matter”, *Business 2.0*, (4), 88-92.

Manheim, Marvin L. (1979), *Fundamentals of Transportation Systems Analysis*, Cambridge: MIT Press.

Park, James (2000), "Evolving Adaptive Organizations," *Perspectives on Business Innovation*, (4), 27-33.

Oliver, R. K. and Webber, M. D. (1982), “Supply Chain Management: Logistics Catches Up with Strategy”In: reprinted in *Logistics: The Strategic Issues*, Christopher, Martin eds., London: Chapman and Hall.

Rice, James B and Hoppe, Richard M. (2001), "Supply Chain vs. Supply Chain; The Hype and the Reality," *Supply Chain Management Review,* (Sept/Oct), 47-53.

Shankar, Venkatesh (2001), “Integrating demand and supply chain management,” *Supply chain management review*, (Sept/Oct), 76-81.

Sjöstedt, Lars (2001), “Transportation vs. logistics”, *work in progress*, Chalmers University of Technology, Göteborg.

Stacey, Ralph (1996), “Management and the science of complexity: If organizational life is non-linear, can business strategies prevail?,” *Research Technology Management*, 39 (3), 8-11.

Stacey, Ralph D., Griffin, Douglas and Shaw, Patricia (2000), *Complexity and management - Fad or radical challenge to systems thinking?,* New York: Routledge.

Stacey, Ralph D. (2001), *Complex Responsive Processes in Organizations - Learning and Knowledge Creation*, New York: Routledge.

Tasaka, Hiroshi (1999), “Twenty-first-century Management and the Complexity Paradigm,” *Emergence*, 1 (4), 115-123.

Waidringer, Jonas (2001), “Complexity in transportation and logistics systems: A conceptual approach to modelling and analysis,” Report 52, Department of Transportation and Logistics, Chalmers University of Technology, Göteborg, Sweden.

Waidringer, Jonas (1999), “Port Logistics from a Network Perspective; A generic model for port terminal optimisation,” Report 41, Department of Transportation and Logistics, Chalmers University of Technology, Göteborg, Sweden.

Wandel, Sten and Ruijgrok, Cees (1995), “Information Technologies for the Development of Transport and Logistics; A Systems Model and Examples,” ATAS Bulletin Information Technology for Development, United Nations, New York, USA.

Wilding, R. (1998), “The supply chain complexity triangle: Uncertainty generation in the supply chain,” *International Journal of Physical Distribution & Logistics Management*, 28 (8), 599-616.

Paper 3

Paper 3

Logistics Management in Practice – toward theories of complex logistics

Fredrik Nilsson

*Dept. Design Sciences, Div. Packaging Logistics, Lund University, 221 00 Lund, Sweden, Tel: +46 462229155, Fax: +46 462224615, E-mail: fredrik.nilsson@plog.lth.se

Abstract:

This article sets out to discuss what logistics managers are doing and facing in their everyday work. The point of departure for this study was to reflect on perceived problems, uncertainties, trends, and solutions in logistics, and how they are handled in the everyday work. The study was exploratory, inspired by grounded theory and aimed at providing grounds for further theory building in the area of *real logistics*. Hence, the purpose of this article is to present findings concerning what logistics managers perceive as being difficult and challenging, and what implications this may have for further advances in the logistics discipline. What came to characterize the findings of this study was related to human, organizational and social aspects i.e. how understanding and sense-making can be accomplished in logistics efforts. Hence, one primary finding of importance for further development of the logistics discipline, and thus of importance for logistics management, is the identification of understanding and sense-making of concepts, techniques and models in logistics. A major outcome from this research endeavor was initial, empirically derived arguments toward theories of complex logistics.

Keywords: grounded theory, logistics uncertainty, complexity, logistics challenges, paradoxes.

Introduction

The perception of supply chains and logistics systems as being complex is emphasized by several authors [1-6]. Furthermore, according to contemporary literature [7;8], the difficulties in controlling and coordinating logistics activities within and among firms are expected to increase, since the interdependence among interacting firms is intensifying. Axelrod and Cohen [9 p.26] expect *"systems to exhibit increasingly complex dynamics when changes occur that intensify interactions among the elements."* Thus, managing logistics in supply networks will create new demands on logistics management. This could imply that new approaches and methods are needed for managers to understand and deal with logistics processes. However, logistics research has not, as yet, developed its thinking and its methods accordingly.

The question for this article is if contemporary logistics models and theories have kept up with the development demands perceived in everyday logistics work and in the number of changes affecting every business situation today. These changes can be related to market changes i.e. increased customer demands, increased competition and globalization; novel strategies i.e. customization, demand chain management, agility and lean concepts; and technological improvements i.e. internet and electronic commerce, enterprise resource systems, and auto-ID technologies. As Prater, Biehl, and Smith [8 p.827] state, *"the introduction of factors that increase supply chain agility may increase supply chain uncertainty and complexity."* Furthermore, Christopher [10 p.259] declares that: *"The challenge to every business is to become a responsive organization in every sense of the word.* However, how is such responsiveness realized in the everyday work of logisticians? Indeed, what aspects are perceived as influencing this overall responsiveness? Furthermore, what do logistics managers perceive to be most challenging and problematic in their daily efforts of making their logistics processes responsive, agile, lean or what ever concept used?

This article sets out to discuss what logistics managers are doing and facing in their everyday work i.e. *real logistics*[17]. The point of departure for this study was to reflect on perceived problems, uncertainties, trends, and solutions in logistics, and how they are handled in the everyday work. This was done through an abductive qualitative method inspired by thoughts and insights from grounded theory [11]. The study was exploratory and aimed at providing grounds for further theory building in the area of *real logistics*. Hence, the purpose of this article is to present findings concerning what logistics managers in their everyday work perceive as being difficult and challenging, and what implications this may have for further advances in the logistics discipline.

As stated at the beginning of this article, there are several authors who claim that logistics processes and phenomena are complex; however, it is not always clear what they mean with by such statements. Milgate [12 p.107], for example, observes that *"complexity should be viewed as a deterministic component more related to the numerousness and variety in the system."* Hence, complexity in logistics is often

[17] The working name of the study has been real logistics.

defined out of quantifiable measures and based on the notion of numerous actors or parts which are interconnected. For clarity, in this article, logistics phenomena are considered complex given that they involve interpreting interdependent actors who are interconnected and in their present situations transform their perception, update their goals, and adapt to the context, both individually and collectively.

The remainder of the article is organized in the following way. First, a presentation of the methodology i.e. a grounded theory-inspired explorative study is provided. Thereafter, major findings of the study are provided, giving the reader a comprehensive picture of the uncertainties logistics managers are perceiving, and the challenges they are facing in their daily work. In the subsequent chapter these challenges are compared with what is provided in logistics literature. This is followed by the presentation of the developments for the logistics discipline suggested from the findings of this study, namely theories of complex logistics. Finally conclusions are provided and further research is discussed.

Methodology

Grounded theory, as initially described by Glaser and Strauss [11], is a qualitative, interpretive, discovery-oriented method which generates theory through field data. This means that grounded theory is inductive in nature and no theoretical propositions or deductively derived hypothesis should be formulated prior to the research endeavor. It has been developed for social science research and as such, it might be interesting for the socio-technical nature which logistics represents. The use of the method in logistics is rare, however Flint and Mentzer [13] report using the method when they examined logisticians' roles when customers desired value changes. They conclude that grounded theory *"offers significant opportunities for future logistics theory development"* (ibid. p.41). Furthermore, Pappu and Mundy [14], in their study of transportation buyer-seller relationships, used a grounded theory approach.

While the grounded theory methodology offers several qualitative approaches for data gathering, the main method in this study was semi-structured interviews based on a number of topic areas, which evolved over time. The majority of the topics were areas to discuss i.e. not specific questions to answer, while a small number were for the responder to fill in and comment on. While Glaser's advice is to neglect literature reviews related to the area under study during the research process so that the researcher's interpretation of the data is not "contaminated", others, such as Walsham [15] and Strauss and Corbin [16], suggest that a certain degree of theoretical sensitivity does not harm the study conducted. Rather, if some literature is studied the research can be helpful in focusing the study, and provides a framework for initial questions and discussion subjects [17]. In this study, theoretical and literature-based thoughts have influenced the creation of topics as well as my perspective of the research phenomenon, making it an abductive research approach rather than a truly inductive one. Theoretical sensitivity has been striven for, and neither propositions nor hypotheses were formulated prior to the study of *real logistics*.

The people chosen for this study were mainly key individuals within large, international, sometimes global, companies (> 500 employees) who had worked with logistics issues on a daily basis. The interviewees have mostly been managers in different positions within the companies chosen, all with responsibility for logistics or supply chain-related issues. Interviewees were represented from inbound and outbound logistics operations and from production, procurement, and marketing departments. All of them had a minimum of four years' experience in logistics, and some up to 40 years. The companies covered several industries ranging from telecommunication and automotive to medical equipment. All companies were beyond the first tier in their supply chains i.e. none of the companies was directly in contact with the consumers; they were suppliers to retailers or industry. In total, 14 people were interviewed in ten companies, and all but one responded positively from the very beginning. Each interview lasted one and half to two hours. The discussions were all recorded on mini-disks (MD) and transcribed in close connection to the discussions. While the number of discussions may seem small, it is sufficient for theory-building purposes since the study goal is to gain in-depth, comprehensive understanding of each individual's perception and experience of logistics. According to Riley [18], it is common to rely on a few informants in this type of research. Furthermore, while the generalizability of the results may be questioned because of the small number of informants, it provides a sufficient platform for further theory-testing research. Furthermore, combined with the literature study, theoretical generalizations can be provided and conclusions for the logistics discipline can thus be drawn from this study.

Most of the participants were found through personal contacts who worked at the companies involved in this study. This made first contact easier and the respondents felt comfortable, since they had been informed and were therefore prepared for me calling them. When no personal contacts were to be found in the organizations, company homepages and people on the switchboard helped out. The next step included a first contact by telephone. Guidelines for telephone interviews were constructed, reviewed and discussed by at least two academics with experience of *"cold calling"*. After this initial discussion a follow-up e-mail was sent and this included a project document (one page) containing a study description and a confirmation of what had been decided. All but one of the participants contacted agreed directly to a meeting, and most of them found it interesting and fun to discuss *real logistics*.

In exploratory qualitative theory-building studies, data analysis and data collection are often interwoven [19] and for grounded theory *"the theory evolves during the research process itself"* [20 p.51]. Thus, initial indications and results guide the further development of the conducted study. This is the principle of theoretical sampling [21]. The companies in this study were chosen based on theoretical sampling principles where the sample size and selection of further study participants were mainly driven by the need for further understanding of the issues involved. The idea behind theoretical sampling is that it continues until theoretical saturation is reached. The first "feeling" of theoretical saturation was gained after eleven discussions and after conducting an additional three, saturation was reached. Since theoretical sampling is intrinsically subjective in nature it was difficult to know when saturation was reached, hence the reason for the additional interviews.

The analysis and synthesis of the data gathered were of an iterative nature, and were performed alongside the data gathering. This process involved several readings of transcripts, listening to the MDs again, organization of data into different topics and categories (coding procedures), from which patterns emerged as streams of thoughts and purposes. From that first interpretation and coding of the data, the next process further explored the categorized data and core categories were made. Major themes emerged from these categorizations, interconnecting the first categories and a comprehensive picture was built up.

In assessing the usefulness of this topical study Partington [22] put forward four criteria (derived from [11]) for theory to be useful. These are: theories should *fit* the real world; they would *work* across range of contexts; they would be *relevant* to people concerned; and they would be readily *modifiable*. These criteria are used in the research valuation. Concerning *fit*, the results presented are contemporary and derived from studies on the field in discussion with logistics managers reflecting on their daily work (*work*). Hence, the suggested theoretical area fits well the empirical situation that has been investigated. Furthermore, the results are emergent concepts related to true issues of the logistics managers interviewed (*relevance*), and the suggested theoretical focus can be constantly *modified* to fit and work with relevance.

Findings

From this study several areas emerged which collectively provide insights into the work of logisticians and the challenges they describe themselves confronting. The presentation here of the results will provide four dimensions of uncertainty factors the logistics managers are facing. From a deeper analysis of the discussions, derived from the final synthesis, three dimensions of challenges the logisticians are facing in their daily work are presented. However, some interesting findings of the logistics managers' impression of their logistics processes and activities are given as an introduction.

One initial finding of interest was that all the participants expressed an overall positive and optimistic view of their logistics operations, declaring that most things work fine. Henrik (all names used are pseudonyms), for example, expressed that *"most of our daily efforts are good even though I believe they can become even better"*, Jenny stated that *"our customers think we are good,"* and Ola expressed the view that *"there is very much that works really well."* Another participant, Mats, who represented a fast-moving consumer goods company, stated that *"none of the FMCG companies can afford to be bad on logistics."* Furthermore, the participants presented a picture showing that logistics is gaining importance in their organizations. Daniel, for example, stated that *"logistics is today not anything one performs in the basement anymore. It is gaining strategic importance,"* and Robert claimed that *"the world is spinning faster, logistics is gaining importance."*

Nonetheless, as the discussions proceeded, several areas of reflection came up and from the analysis concepts emerged. For each concept described and discussed in this article, there are numerous passages, connections, and interpretations gained from various parts of the discussions. For example, the need for a holistic view of the logistics operations was expressed when discussing further developments, when reflecting on events which had been successful as well as events which had resulted in failure and in the initial discussions where the companies' logistics operations were presented.

Logisticians' perceived uncertainty

One of the topic areas discussed was uncertainty factors and in total it can be reported from this study that despite statements about most logistics activities proceeding rather well, all the participants felt that the perceived uncertainty was growing. This growth was due to an overall increased complexity which affected them in their logistics processes and activities. In the analysis these were grouped into four uncertainty dimensions: i) customer demands and expectations, ii) internal processes, iii) human factors and, iv) general trends (see Figure 1).

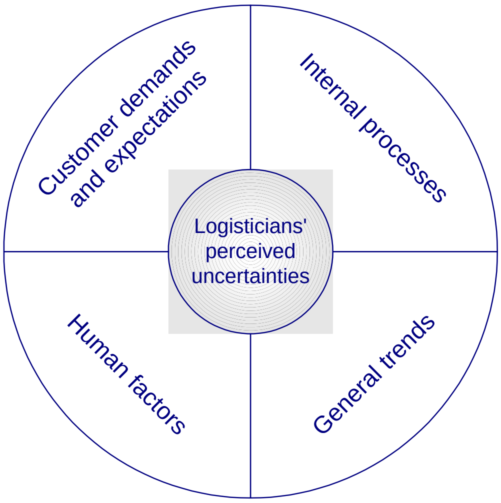


Figure 1. Logisticians' perceived areas of uncertainty

Customer demands and expectations. The first dimension relates to increasing and changing demands from customers, the impacts of which increasingly affect logistics. For all the companies the customer demands on logistics had both increased in scale and in scope i.e. have become more diversified. The participants stated that the scope of the customer demands on logistics had increased and involved several factors such as: shrinking time-windows for deliveries, customized order bookings, increased number of packaging types, customized labeling, variations in number of products per pallet and per order, increased frequency of deliveries, JIT demands, increased product variants, and less volume per order. One participant explained that *"if the time window for a delivery is 14.00-14.30, the truck has to wait if it arrives at 13.00 and generates sometimes complaints because of traffic stocking. And if the truck arrives at 15.00, the customers refuse delivery that day."* Several of the participants recounted similar experiences and believed that these demands on delivery precision were about to increase. The most important aspect of logistics, as expressed by the participants, was that of service levels, measured as on-time-in-full. One participant stated, for example, that *"deliveries are allowed to cost some more as long as service levels are met."* Another participant's opinion, which reflects those of the whole group, was: *"higher service, shorter lead times, those aspects are most important for our prosperity and survival."* However, as they all emphasized in one way or another, those are words which are easy to say but increasingly difficult to accomplish.

In order to meet these increasing demands and thus to keep the important measure of service levels high, one noticeable approach and strategy emerged in the analysis; that of customer involvement. One participant claimed that the customer's awareness of logistics issues had increased and from that, their demands as well, while another explained that *"customer demands are surpassed by everyone."* Some of the participants claimed that the trend they perceived was increased focus on building relationships with customers. They also believed that logistics provided important aspects in relationship-building efforts since trust was gained from confidence on deliveries; as on participant expressed it, *"what customers want they get – on time."* However, the understanding of logistics-related aspects in the relationships of today, despite increased awareness from customers, is perceived as rather small. As one participant expressed it; *"At the customer's procurement departments there are people that love to make good deals with our sales office. These people are often motivated by bonus systems that contradict discussions about expectations and future."* This should be considered together with the observation most participants make, namely, that the marketing and sales forces of their own organizations also lack any greater awareness and understanding of logistics.

A final notion concerning customer demands and expectation is that it interesting to note that only one of the participants mentioned the company's consumers, and no one discussed or reflected on what connections their logistics processes and activities had with the consumers.

Internal processes. Despite numerous texts in the available literature about the importance of functional integration [23-26], and the importance of integration of sales/marketing and logistics [27], several of the participants explained that the internal communication between sales/marketing and logistics is a source of great uncertainty in their daily logistics activities. One participant said that *"sales and marketing have no awareness for how logistics works,"* another statement was; *"the marketing function provides the worst demands possible on us and, of course we can comply, however no one is prepared to take the consequences of higher costs, the need for competence etc."* In addition, the following observation was made by another participant *"front-end have knowledge and competence about customer needs while the knowledge about logistics is often in the back-end."* Thus, the emergent picture in general was that the understanding of logistics in the organizations as a valuable activity was rather limited. The general picture was that logistics processes are supposed to work accurately and efficiently, but without associated costs. For the logisticians this internal factor provides them with unnecessary uncertainty based on the fact that in many cases they are invited into customer arrangements rather late.

Hence, their function becomes one of complying with, rather than providing more effective solutions from the beginning. However, the marketing/sales – logistics interface was not the only area where discrepancy was perceived. One participant pointed to the relationship between IT departments and logistics and argued that IT tools which should benefit and assist logisticians were developed by IT people and best understood by IT people, not logisticians.

Human factors. Human aspects came up in the discussions in all areas discussed. Many felt that the human factor created uncertainty; *"we are not robots, we* ***do*** *make mistakes."* One example was illustrated by the experience of some participants where the importance of meeting the "right" people when visiting customers was vital. However, from the discussions other aspects influencing the perception of human related uncertainty emerged, such as power, hidden truths, and protectionism. The issue of power was declared as an uncertainty factor since it hampered decision processes, and made communication more difficult i.e. was merely an obstacle creating problems in several situations. As one participant expressed it *"people are afraid of making decisions due to internal power structures."* Concerning hidden truths, another participant declared that there are many things we do for the simple reason that we have done them for a very long time. Another recounted that in improvement projects he had received answers such as *"we have done that before, it did not work 24 years ago."*

General trends. The general trends appointed by the participants are related to general developments of technology, ideas, and concepts. The picture provided was of an ever-changing environment where it was continually necessary to check if improvements efforts were right. For example, several of the participants were involved in discussions about RFID (radio frequency identification) technology and about how it could be applied to their businesses. While no one stated that they were working concretely with implementations or pilots, several of them expressed uncertainties about what RFID would mean to their operations, when to start doing something concrete, and concerns about who should pay, how should any cost-sharing policies come about etc were apparent. Others expressed a notion of the increasing amount of ideas and concepts that are provided and made available on the market. Finally, an issue raised by several of the participants in relation to trends was *"how do we prepare our coworkers for future demands and requirements?"* This type of issue involved both a short-term and long-term perspective since efforts were needed relatively fast, while the results were to be gained later on i.e. large investments with risks associated. It was declared by one participant that people was needed that *"could both give gas and brake simultaneously"* in order to meet and lead further developments of logistics.

Based on this discussion concerning perceived uncertainties, it is proposed that:

> **Proposition 1**: *Human factors are both the creators of value and the producers of uncertainty in the logistics context. The more awareness and understanding of human involvement the more leverage is to be gained in improvement efforts*

and the higher levels of integration with customers and internally, can be achieved.

Logisticians' challenges

From this study emerged three challenges logisticians are facing and believe are of importance for keeping up with increasing complexity and further developments of their logistics processes (see Figure 2). These are i) holistic perspective, ii) sensitivity to details and iii) understanding and sense-making.

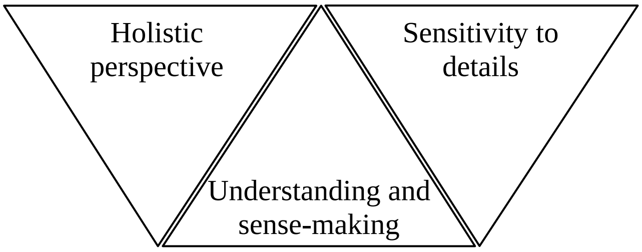


Figure 2. Perceived challenges logisticians are facing.

Holistic perspective. A view which grew from the discussions in the synthesis process was the increasing need for a holistic perspective. All the participants expressed the need for a holistic perspective and that this need was something the whole organization needed not only for logistics operations. It was expressed by one participant that *"the most difficult aspects of his logistics work was gaining a complete picture of the situation."* Another declared that *"we have quite good control of the smaller parts of our business activities,* ***but the big ones…****"* (emphasis added). However, while this need for understanding and awareness by people in the organization for the whole might not be a new issue, the participants reflected that this need was increasing, since the logistics systems had become much more volatile due to improvement efforts, rationalizations, and IT supporting tools. While the participants all had ideas of where improvement efforts could be targeted, they expressed less confidence in how to prioritize what to do. As declared by one participant; *"Since we have a positive flow right now there is no trouble in getting support in different kind of efforts, which makes life easy. However, at the same time it is troublesome how to make priorities, since we cannot be everywhere."* Hence, while the participants were of the opinion that today's common logistics concepts, methods and tools had made it possible to control and monitor a great number of factors within and among firms, they were confronted by the difficulty of understanding and acting when things happen which are of an "unusual" character. This means that priorities are to be made between different improvement efforts and decisions need to be made instantly.

However, at some points in the discussions what was put forward about increased complexity, holism, and understanding of the whole, was interestingly colored by a wish for simplicity in models, solutions, and explanations. For example, one participant first declared that the complexity involved in logistics issues was increasing and that understanding for a comprehensive picture of operations was needed, "*perhaps with better models for control, models based on several parameters.*" However, during the discussion, the desire to find simple models or solutions to deal with logistics issues was voiced. Furthermore, the issues of simple models and simple frameworks were addressed and wished for by other participants as well; participants who during the discussions expressed perceptions of increasing complexity and uncertainty in their work.

> **Proposition 2:** *While the descriptions of holistic complex logistics situations and the wish for simple models and solutions may be regarded as paradoxical, those firms able to find some kind of balance between perceptions of complexity and a wish for simplicity may increase understanding in their organizations, and thus improve internal processes and hence, business performance*.

Sensitivity to details. One participant stated that "*when it comes to accomplishment of customer demands, it is the details that make a difference.*" The general picture, reflected by the statements from participants, was that due to increased interconnectivity and great rationalizations of both internal and external processes i.e. increased delivery precision, decreased time-windows for deliveries, decreased inventory levels, integrated ERP systems etc., the sensitivity to small disturbances could have devastating effects on the overall business performance. One participant expressed it the following way: "*the situation is becoming more complex due to tighter margins, rationalization efforts, and increased cost efficiency demands. At the same time support systems are becoming more complex and since they are highly integrated and detailed it has become more and more difficult to get a holistic view and when something happens it is very difficult to understand what caused it to happen or where the outcome of it will have effects.*" It was also declared by the participants, that in both internal processes as in relation to customers, it was often "hidden" details which made a major difference. This observation of hidden details was often derived from the reflection that even if situations could be perceived with collective clarity and consensus, under the surface there were always factors which made the situations more complicated than they were first thought.

> **Proposition 3:** *As sensitivity to details and small disturbances in logistics operations is perceived to be increasing, those firms able to identify areas where leverage can be found and have the willingness, support, and spirit for accomplishment, are better at conforming to customer requirements than those who do not*.

Understanding and sense-making. Another finding is the identification of understanding and sense-making in logistics. However, this reflection came rather late in the discussions and was often initiated by need for information. Accurate, timely, correct information was initially regarded in the discussions as one of the most important aspects for improving logistics operations. One participant described the need to get information from all parts of the value chain, especially from the end-customer, in order to be able to control the whole system. Another participant declared that with improved information, increased visibility would be accomplished and this was from a global perspective. This was further anticipated by others expressing worldwide system solutions which would be easier to manage with increased visibility since this visibility would ease the information handling among the different parts of the organizations. On remark was that *"people spend lot of time and effort on things that could be displayed on a screen."*

However, as discussions proceeded another reflection emerged; that while information was regarded as important, the real challenge was of a more subtle character, more related to the understanding and sense-making of the information generated and what to do with it. Several of the participants expressed the view that in order to gain real benefits from new technology, new concepts and thinking, the processes of today need to be changed. One participant raised the question *"how can knowledge be transferred to 'John, the truck driver'?"* Another participant pleaded that they needed to *"introduce methods that help to solve problems, not just to fix them for the moment. We are increasing our awareness about this issue, have started to work, … we could become much more effective then."* However, as he continued, a great deal of understanding is needed for this to be accomplished. Others claimed that *"getting the information to people was one thing, however getting understanding of how to use it is much more difficult," "the understanding is rather scarce* [for logistics in our organization]*," "it is difficult to get people to use the logistics concepts and guidelines we provide them with."* In total, the logistics managers expressed that the real difficult aspects of their work were related to rather "soft factors." One participant stated that *"as much as 80 % of the time and effort in improvement projects was related to soft factors"* such as discussions, explanations, persuasion etc. Furthermore, concerning unexpected events, someone else that *"it is one thing is to make the firefighting requirement to meet the customers requests, the difficulties are in understanding what happened; the learning."* And it was declared by several that mind-shift changes were quite difficult in their organizations, sometimes more difficult internally than with customers. A lot of questions were raised by the participants concerning how the awareness and understanding of the individual's activities and actions in relation to the whole could be approached and increased. Furthermore, as expressed by one participant, *"we have models, and there are models to be found, but we lack the conviction"* i.e. the discrepancy between just information, and interpreted and understood information is an apparent problem logisticians are dealing with.

> **Proposition 4:** *Those firms able to focus on the understanding and sense-making aspects in logistics, and possible in the whole organization, and which have the motivation to put efforts into new ways of thinking, acting, informing, communicating both internally and externally, have the potential to achieve both increased efficiency and effectiveness in their operations.*

Uncertainty and challenges in logistics – a theoretical perspective

When relating these findings to literature, there are, of course, several findings which have been identified earlier. For example, the trend in industry is that the requirements and demands from customers are increasing in scope [13;28;29]. Furthermore, the statement made by Stock, Greis and Kasarda [30 p.38] that *"in this new competitive environment, logistics must be accorded a high strategic priority and* *cannot be viewed merely as a cost of doing business,"* was also verified by some participants. However, the overall interpretation was that the identification of logistics as high priority was still in its initial stages. The recognition of logistics as strategically important was rather low, but growing.

Concerning the treatment of uncertainty in logistics, the overall message found in logistics literature is often of reducing uncertainty as much as possible. This type of reasoning i.e. reductions of uncertainty, together with a striving towards states of equilibrium and stability, is apparent in the logistics discipline, which Lambert, Stock and Ellram [4 p.453] emphasize by declaring that *"an effective organization must exhibit stability and continuity,"* and Lambert and Cooper [31 p.72] state: *"controlling uncertainty in customer demand, manufacturing processes, and supplier performance are critical to effective supply chain management."* In addition, the work by Childerhouse and Towill [32] focuses on the concept of seamless supply chains, where simplifications and elimination of uncertainties in processes are argued for. However, other voices are raised concerning the issue of uncertainty, for example Nilsson [33 p.543], who states that *"one great challenge for logistics researchers and practitioners to reconsider, in developing the logistics discipline, is the need to recognize uncertainty and complexity and "go with the flow" instead of solely trying to remove and control uncertainty."*

However, while the logistics literature provides theories, models, and tools for conceptual and technical aspects of logistics i.e. tangible, technical, objective, value-free aspects, it provides little emphasis on soft factors related to human behavior i.e. how concept and techniques should be operationalized. Russel and Hoag [34 p.102], for example, state that *"social and organizational sources of complexity in IT implementations have thus far attracted little research attention from logistics and supply chain scholars."* Furthermore, Johannessen and Solem [35] call for logistics research with a stronger focus on logistics organizational issues and especially for the emphasis on the human and social aspects of logistics to become a central issue. In a definition of logistics provided by Johannessen the following is stated: *"Logistics is complex processes of relations between humans, nature, technology and resources that interact and unpredictably self-organize into emerging paradoxical patterns with value creating potential"* [36 p.87].

The findings of the present study clearly show that the difficult aspects of the logistics managers work were related to soft factors and their integration with concepts, technologies etc. While information was considered an important aspect by the participants, the fundamental issue was expressed as understanding and sense-making by people involved in the logistics activities as well as people in other functions. Thus, the findings from this study point to a complementary area to that of mainstream logistics, where human involvement and organizational aspects are considered i.e. how individuals' and organizations' understanding and sense-making are related to logistical concepts and technical findings. As Kehoe and Boughton [28 p.587] concerning new paradigms in planning and control across manufacturing supply chains, state *"although organizations will need to fundamentally change the way they do business, the barriers lie with the business processes rather than the* *technology."* Hence, the findings of this study point toward a need for the logistics discipline to focus more on complex theories of logistics. The following chapter will provide further arguments why.

Toward theories of complex logistics

The challenges derived from the situations and phenomena logistics managers are perceived as confronting are of a rather complex character. The managers' expressed need for a holistic perspective in order to comprehend their logistics processes can be set contrary to the identified challenge they confront concerning the sensitivity to details that the processes are characterized by. This is a rather paradoxical situation where holism is set against details and the need of having both simultaneously. One traditional solution would be to rely on reductionism, i.e. decomposing the whole into simpler parts, and by doing so assess the details. However, this is not a valid solution since small disturbances can be amplified in non-linear fashions creating surprisingly different outcomes each and every time [37]. Hence, there is no interest in finding single factors for complex problems [33]. Thus, the paradox of holism and sensitivity to details prevails.

Another issue is derived from the expressions of increasing complexity and uncertainty, and the need and wish for simple frameworks and models. Hence, the approach or solution to handle the increasing complexity and uncertainty is to be found in simple models and frameworks!? While simplified models could be regarded as drivers for rationalizations and efficiency improvements, these cause paradoxical situations since not only is the increased perfection of logistics making processes more volatile and vulnerable, it might constrain further developments, as risks of failure may be devastating for the company's operations. This could mean that the logistics innovation potentials might be hampered by the volatility and the sensitivity to details apparent in the interconnected logistics systems of today. Hence, while this volatility of logistics processes may speak for incremental improvements, the increasing market demands may request radical improvement efforts in order to gain competitive advantage. This creates interpretation consequences for logistics managers since they are facing what could be defined as an efficiency/effectiveness paradox i.e. doing things right vs. doing the right things.

Finally, the finding involving information vs. understanding and sense-making is another area making the situation for logisticians a rather complex one. As described earlier the shift from arguing for more information and visibility to putting emphasis on understanding and sense-making reveals another paradoxical situation. This is related to the underlying logic that more information would generate increased understanding and sense-making. The message from the participants was that while technological improvements in providing information contributed to making everyday work easier, they had made life more difficult when something unusual or new happens. And one thing that everybody agreed on was the fact that unusual and new things happened rather often. Hence, the statements in literature about reducing uncertainty by increased information have two dimensions which might produce contrary outcomes. For logistics routine work the increased information might be relevant, however, as the participants explained that they sense an increasing and rapidly changing complexity in their organizations' contexts. It might thus be expected that unusual and unexpected things *will* happen. Consequently, other approaches, perhaps involving greater emphasis on understanding and sense-making of information than solely technical and conceptual related to information, might be relevant.

What the three paradoxical situations, derived form the findings of this study, provide might be arguments for research focused on human and organizational aspects in logistics processes and phenomena. What can be concluded is that the logistics of today is not about keeping to a straight line towards a predetermined goal where deviations and disturbances should be fixed in order for companies to go back to ordinary business. Instead, logistics can be interpreted as a paradox of transformative change processes where the future is filled with possibilities, and the only thing we can certainly know is that the future will not be like the past. At the same time, continuity is kept in the collective; in routines created by humans in the logistics day-by-day activities. Thus, logistics management is about is how to handle the difficulties and complications which constitute logistical problems. Thus, logistics is about people, and people's perceptions about changes. Their perceptions rely on their understanding and sense-making of the logistics activities needed for complying to customer demands and for the exceeding of these, on a daily basis.

Conclusions

This study explored the field of logistics management in practice, with the purpose of presenting findings concerning what logistics managers in their everyday work perceive as being difficult, and what implications this may have for further advances in the logistics discipline.

There were several areas raised which, to some extent, have already been addressed in logistics literature. These would be issues such as increasing demands from customer and the simultaneous overall increase in complexity and uncertainty. Furthermore, the issue of functional barriers, in this study found to be a problem in the relationship between marketing/sales and logistics, was also raised by the participants. However, what came to characterize the findings of this study was related to human, organizational and social aspects i.e. how understanding and sense-making can be accomplished in logistics efforts. Hence, one primary finding of importance for further development of the logistics discipline, and thus of importance for logistics management, is the identification of understanding and sense-making of concepts, techniques, and models in logistics.

A major outcome from this research endeavor was initial, empirically derived arguments toward a theory of complex logistics. As companies are becoming more multifaceted themselves in their relationships with suppliers and customers, and in view of the increased turbulence facing almost all industries, the complexity facing logisticians is a clear fact. The need for theories of complex logistics originates from the challenges logistics managers are facing in their logistics work. These challenges are characterized by novelty (the type of problems are contemporary), and paradoxes which are of an "unsolvable character" and can only be handled by balancing efforts each and every day. This complexity needs consideration when logistics processes and phenomena are approached to ensure increase understanding for people involved and affected, and for the sense-making of logistics phenomena.

Future research

While this exploratory study has provided a reflective picture of logisticians' perceived reality, it is only an initial contribution to the process of developing theories of complex logistics i.e. concerning the paradoxical situations and phenomena logistics managers are confronting in their daily work. The key contribution of this research is that it has taken a step toward increasing understanding of very complex phenomena in a manner that is only possible when using qualitative methods. Further research is encouraged to test the propositions stated to provide deeper understanding of the importance of each of the challenges and their interdependence. Thus, the research challenge is to provide insights and guidance on how rather soft factor can be considered and elaborated by management in logistics situations.

From a methodological standpoint, the provision of a grounded theory-inspired approach to logistics would hopefully encourage more researchers to apply the method and provide further evaluations of its use in logistics. This is especially the case for logistics focusing on human factors and organizational phenomena. Gammelgaard [38 p.479] argues, for example, that "*application of more methodological approaches will strengthen the discipline in terms of new research questions and answers, just as it may have a practical relevance.*" With the grounded theory approach the practical relevance of research is central, and the potential of providing the logistics discipline with new insights is high.

Furthermore, in order to gain even greater understanding of daily logistics, especially of how concepts such as agility and responsiveness are realized in everyday work, action research is suggested. By interviewing an active but reflective participant in everyday logistics, insights into how these concepts are being implemented, executed, and evaluated in practice, could provide the logistics discipline with further developments.

References

[1] Bowersox Donald J., David J. Closs. Logistical Management, The integrated supply chain process. International ed. New York: McGraw-Hill, 1996.

[2] Christopher Martin. "The Agile Supply Chain - Competing in Volatile Markets," Industrial Marketing Management, Vol. 29 No. 1 (2000) pp.37-44.

[3] Cox Andrew. "A research agenda for supply chain and business management thinking," Supply Chain Management: An International Journal, Vol. 4 No. 4 (1999) pp.209-211.

[4] Lambert Douglas M., James R. Stock, Lisa M. Ellram. Fundamentals of Logistics Management. International ed. London: McGraw-Hill Higher Education, 1998.

[5] Lumsdén Kenth, Lars Hultén, Jonas Waidringer. Outline for a Conceptual Framework on Complexity in Logistics Systems. Helsinki: NOFOMA 98, Finnish Association of Logistics, Opening markets for Logistics.

[6] Tan Keah C. "A framework of supply chain management literature," European Journal of Purchasing and Supply Management, Vol. 7 No. 1 (2001) pp.39-48.

[7] Nilsson Fredrik, Jonas Waidringer. "Logistics Management from a Complexity Perspective," The ICFAI Journal of Operations Management, Vol. 3 No. 2 (2004) pp.59-73.

[8] Prater Edmund et al. "International supply chain agility - Tradeoffs between flexibility and uncertainty," International Journal of Operations & Production Management, Vol. 21 No. 5/6 (2001) pp.823-839.

[9] Axelrod Robert, Michael D. Cohen. Harnessing Complexity - Organizational Implications of a Scientific Frontier. First ed. New York: Basic Books, Perseus Books Group, 2000.

[10] Christopher Martin. Logistics and Supply Chain Management. 2nd ed. London: Financial Times, Prentice Hall, 1998.

[11] Glaser Barney G., Anselm L. Strauss. The Discovery of Grounded Theory - Strategies for qualitative research. Chicago: Aldine Publishing Company, 1967.

[12] Milgate Michael. "Supply chain complexity and delivery performance: an international exploratory study," Supply Chain Management: An International Journal, Vol. 6 No. 3 (2001) pp.106-118.

[13] Flint Daniel J., John T. Mentzer. "Logisticians as Marketers: Their role when customers desired value changes," Journal of Business Logistics, Vol. 21 No. 2 (2000) pp.19-41.

[14] Pappu Madhav, Ray A. Mundy. "Understanding strategic transportation buyer-seller relationships from an organizational learning perspective: A grounded theory approach," Transportation Journal, Vol. 41 No. 4 (2002) pp.36-50.

[15] Walsham G. "Interpretive case studies in IS research: Nature and method," European Journal of Information Systems, Vol. 4 No. 2 (1995) pp.74-82.

[16] Strauss Anselm, Juliet M. Corbin. Basics of qualitative research - Techniques and Procedures for Developing Grounded Theory. Second ed. London: Sage Publications, Inc., 1998.

[17] Hansen Hansen Bo, Karlheinz Kautz. Grounded theory applied - studying information systems development methodologies in practise. Hawaii: System Sciences, 2004.Proceedings of the 37th Annual Hawaii International Conference on.

[18] Riley R. "Revealing socially constructed knowledge through quasi-structured interviews and grounded theory analysis," Journal of Travel and Tourism Marketing, Vol. 5 No. 1/2 (1996) pp.21-40.

[19] Eisenhardt Kathleen M. "Building Theories from Case Study Research," Academy of Management Review, Vol. 14 No. 4 (1989) pp.532-550.

[20] Goulding Christina. "Grounded theory: the missing methodology on the interpretivist agenda," Qualitative Market Research: An International Journal, Vol. 1 No. 1 (1998) pp.50-57.

[21] Punch Keith F. Introdution to social research. First ed. London: SAGE Publications Ltd., 2001.

[22] Partington David. "Building Grounded Theories of Management Action," British Journal of Management, Vol. 11 No. 2 (2000) pp.91-102.

[23] Pagell M. "Understanding the factors that enable and inhibit the integration of operations, purchasing and logistics," Journal of Operations Management, Vol. 22 No. 5 (2004) pp.459-487.

[24] Narasimhan Ram, Ajay Das. "The impact of purchasing integration and practices on manufacturing performance," Journal of Operations Management, Vol. 19 No. 5 (2001) pp.593-609.

[25] Berry William L., Terry J. Hill. "Customer-driven manufacturing," International Journal of Operations & Production Management, Vol. 15 No. 3 (1995) pp.4-16.

[26] Hill Terry. Manufacturing Strategy - Text and Cases. First ed. London: MacMillan Press Ltd, 1995.

[27] Mentzer John T. et al. "Toward a unified theory of logistics," International Journal of Physical Distribution & Logistics Management, Vol. 34 No. 8 (2004) pp.606-627.

[28] Kehoe D. F., N. J. Boughton. "New paradigms in planning and control across manufacturing supply chains - The utilisation of Internet technologies," International Journal of Operations & Production Management, Vol. 21 No. 5 (2001) pp.582-593.

[29] Caridi M., R. Cigolini. "Improving materials management effectiveness: A step towards agile enterprise," International Journal of Physical Distribution & Logistics Management, Vol. 32 No. 7 (2002) pp.556-576.

[30] Stock Gregory N. et al. "Logistics, strategy and structure A conceptual framework," International Journal of Physical Distribution & Logistics Management, Vol. 29 No. 4 (1999) pp.224-239.

[31] Lambert Douglas M., Martha C. Cooper. "Issues in Supply Chain Management," Industrial Marketing Management, Vol. 29 No. 1 (2000) pp.65-83.

[32] Childerhouse Paul, Denis R. Towill. "Simplified material flow holds the key to supply chain integration," Omega, Vol. 31 No. 1 (2003) pp.17-27.

[33] Nilsson Fredrik. Simplicity vs. complexity in the logistics discipline - a paradigmatic discourse. 04; Linköping, Sweden: NOFOMA 2004.

[34] Russell Dawn M., Anne M. Hoag. "People and information technology in the supply chain: Social and organizational influences on adoption," International Journal of Physical Distribution & Logistics Management, Vol. 34 No. 2 (2004) pp.102-122.

[35] Johannessen Stig, Olav Solem. "Logistics organizations: Ideologies, principles and practice," International Journal of Logistics Management, Vol. 13 No. 1 (2002) pp.31-42.

[36] Johannessen S. An explorative study of complexity, strategy and change in logistics organizations. Departement of Industrial Economics and Technology Management, Trondheim, 2003.

[37] Kauffman Stuart. At Home in the Universe: The Search for Laws of Self-Organization and Complexity. New York: Oxford University Press, 1995.

[38] Gammelgaard Britta. "Schools in logistics research?: A methodological framework for analysis of the discipline," International Journal of Physical Distribution & Logistics Management, Vol. 34 No. 6 (2004) pp.479-491.

Paper 4

Paper 4

COMBINING CASE STUDY AND SIMULATION METHODS IN LOGISTICS RESEARCH

Daniel Hellström*, Fredrik Nilsson**

Department of Design Sciences, Division of Packaging Logistics, Lund University, Box 118, 221 00 Lund, Sweden, Tel: +46 (0)46 222 72 30*, +46 46 222 91 55**, Fax: +46 46 222 80 60, E mail: daniel.hellstrom@plog.lth.se*, fredrik.nilsson@plog.lth.se**

Abstract

Using case study methods as well as empirical quantitative-based simulation methods are becoming increasingly common in the logistics discipline. However, rare signs of efforts of combining these are to be found in the logistics literature. The aim of this paper is to contribute to the further development of case study and simulation methods in logistics research and practice by presenting and discussing the concept of combining case study and simulation methods. Combining case study and simulation into a multimethod study allows the researcher to harmonise the weaknesses and assess the relative strengths of the various methods. It is concluded in this paper that combining case study and simulation makes it possible to elucidate underlying processes and illustrate a greater depth to the investigation by using the case study method, and at the same time defining and predicting the behaviour and performance of the process or system using simulation. Another valuable benefit is the opportunity for triangulation between the methods and between the different data sets collected in the studies.

Keywords: Case study, Simulation, Research Method, Multimethod, Logistics Research

Introduction

There are several ways of conducting research e.g. experiments, surveys, ethnographic studies, modelling, simulation and case studies to mention but a few. Each method has its strengths and weaknesses and the issue is not that one method is better than the other, rather how well the chosen method helps the researcher solve or clarify his/her purpose or problem. An increasingly common method in the logistics discipline is the case study method. While the method has several strengths, critics often argue that the results are simply anecdotal and that the research itself has not been conducted rigorously enough. Another research method used within the logistics discipline is simulation. Simulation is used in a variety of disciplines and there are numerous books and articles which document its usage and results. However, the majority of the simulation studies deal with idealised axiomatic-based models. While the impact of this method has several strengths, critics argue that the method is too superficial and only solves problems in the computer and not in the real world.

The aim of this paper is to contribute to the further development of case study and simulation methods in logistics research and practice by presenting and discussing the concept of combining case study and simulation methods. This paper will also discuss the possibility of combining case study and simulation methods, since these originate from different methodological assumptions.

This paper focuses on empirical quantitative-based simulation models. More specifically, the types of simulation techniques that will be referred to are discrete-event simulation (DES) (Banks 1998) and agent-based modelling (ABM) (Bonabeau, Dorigo, & Theraulaz 1999; Epstein 1999). Simulation research can be classified into axiomatic or empirical model-based research (Will, Bertrand, & Fransoo 2002). Axiomatic model-based research relies predominantly on idealised problems and deterministic solutions, consequently, as a result "implementing solutions based on these models often turned out to be a tedious process, and also frequently failed" (ibid. p.244). On the contrary, empirical model-based research is primarily driven by empirical findings and forms of measurement and the primary concern of the researcher is to ensure that there is a correlation between reality and the model made of that reality. The remainder of this paper is organised as follows; the following two sections provide a discussion of the case study and the simulation methods. In the subsequent section a methodological perspective is given for these methods since they originate from different research paradigms. This is followed by an introduction of the strengths and weaknesses of the suggested combination of case studies and simulation studies. Finally, a concluding discussion of this combination is provided and further research suggested.

Case study

Case study is a research method with the overall objective of gaining a deep understanding of chosen research phenomena (Stake 2000). The case study method focuses on understanding the dynamics present within single settings (Eisenhardt 1989; Ellram 1996). This means that in case studies the focus is directed towards numerous variables and relationships covering all conceivable aspects which are available i.e. ideographic, whereas in a survey only a few variables in a large population are normally studied i.e. nomothetic. According to Yin (2003) the case study method has a distinct advantage in situations when: “a "how" or "why" question is being asked about a contemporary set of events, over which the investigator has little or no control.”

In the field of logistics the case study method provides an opportunity for collecting empirical data with consideration given to the complexity of the real-life setting. Empirical methods, such as case studies, are receiving increased attention due to the increasing call to incorporate real-world data to improve the relevance of research (Ellram 1996). In logistics, which deals with socio-technical aspects, the understanding of why and how activities are carried out by people is then of prime importance. Research dealing with socio-technical aspects often requires researchers to deal with dynamic and context-dependent variables and relationships. This complexity requires an in-depth study since there may be numerous explanations for the observed outcome.

A major criticism of case study research is the paucity of rigour in the case research process. The criticism is generally directed towards weaknesses such as ambiguous or non-existent discussions of what protocol was used, how cases were selected, how data was collected and analysed and how results were validated. However, to reduce these weaknesses Yin (2003), Meredith (1998), Eisenhardt (1989), Ellram (1996) and Stuart et al. (2002) advocate an analytical approach to conducting case-based research. The approach is generally based on designing, conducting, analysing and reporting case study research in a systematic way, which improves the rigour of the case study process. Another criticism of case study research is its insufficient precision i.e. in quantification of research phenomena (Yin 2003).

Simulation

According to Banks (1998) simulation is an “imitation of the operation of a real-world process or a system over time”. Put in another way, Ball (1996) describes simulation as a method for developing a model of a real or proposed system so that the behaviour of the system may be studied under specific conditions. Simulation studies can have several purposes e.g. prediction, performance, training, education, proof and exploration (Axelrod 1997a). Nonetheless, one common denominator is that of increasing the understanding of the behaviour of a specific phenomenon. Simulation enables the researcher to observe how a system performs and behaves over time when different rules and policies are applied (Shapiro 2001). According to Banks (1998) one of the advantages of simulation is that it allows the researcher to explore different “what-if” scenarios. Another advantage lies in the educational dimension i.e. simulation models can increase the level of understanding for the people involved in a study through e.g. visualisation. In conclusion, this means that simulation studies may assist managers in making decisions in the real world since they can understand the behaviours and results of modelled systems.

In order to capture the real-life behaviour in a simulation the researcher needs to possess a great deal of knowledge about the characteristics of the system under study. Real-life processes are all different, although there may well be similarities, and have different characteristics, which can evolve over time. Dealing with real-life processes i.e. where not everything behaves rationally, is always done in a subjective and situation-dependent way. Consequently, one problematic step in a simulation is to develop an "objective" way to identify and measure relevant parameters. Simulation researchers often develop their own techniques to observe, measure and document data. In simulation this is done in the model conceptualisation phase where the relationships and measurement of the relevant variables are defined. This means that the researcher must know how to identify and measure the relevant characteristics of the system under study.

The interpretation of in-put and out-put data poses a problem in simulation since it requires the researcher to be familiar with the system under study. Will, Bertrand, & Fransoo (2002) state that "One drawback in when conducting simulation research is the lack of methods and techniques in gathering data and interpretations of the phenomenon being studied".

In order to motivate the use of simulation, especially DES and ABM, the phenomenon of research interest requires an appropriate degree of complexity. This complexity can be the result of several interacting and interdependent parts, where these parts are affected by several objectives and constraints, and where the behaviour of the phenomenon cannot be distinguished from the behaviour of the individual parts, but instead in the relationship among these.

Methodological aspects

Logistics is multidisciplinary, attracting researchers from different academic backgrounds such as engineering, business management, organisation etc. Depending on their backgrounds researchers may investigate phenomena from different methodological perspectives. This in turn results in a variety of preferred research methods and perceptions of problem contexts. According to Yin (2003 p.5) the selection of a preferred research method depends on three conditions: (1) The type of research question posed, (2) the extent of control an investigator has over behavioural events, and (3) the degree of focus on contemporary events as opposed to historical ones. We would like to add personal biography and paradigm as elements of a fourth condition for selecting research methods. Every researcher is unique because of her/his particular class, racial, cultural and ethnic perspectives (Denzin & Lincoln 1998). A researcher may have a favourite method or does not possess sufficient knowledge of other possible existing methods.

There are methodological aspects to consider when combining case study and simulation since these methods originate from different research paradigms. According to Burrel & Morgan (1979) a positivist prefers nomothetic and quantitative research methods e.g. simulation, while an anti-positivist prefers ideographic and qualitative research methods e.g. case study. For example, positivistic criticism of the case study method is based on the argument that it relies heavily on the skill and personality of the researcher i.e. lack of objectivity. Furthermore, critics argue that the case study method is unreliable since case studies cannot be replicated, whereas simulations can be replicated at any time. One aspect that should be considered here is time. The context of the case study is continuously changed which may prevent a replicated case study from resulting in the same results. Moreover, a major distinction between case study and simulation is the extent of the investigator's capability to control and access the actual behaviour of the system. The case study method deals with real-life events whereas simulation deals with models which are abstractions of reality. With simulation the researcher can manipulate parameters and relations of interest whereas in a case study the behaviours cannot be manipulated in a controlled manner.

Combining case study and simulation

Combining case study and simulation into a multimethod study allows the researcher to harmonise the weaknesses and assess the relative strengths of the various methods. Combining theses methods facilitates:

- a way to identify and measure relevant characteristics,
- an expanded time horizon,
- further insights into the behaviour and performance of the process or system,
- triangulation between the methods and between the different data sets,
- synergies in the data collection process.

The main strength of combining case study and simulation is that it facilitates a way to identify and measure the relevant characteristics of the system under study through providing a deep understanding of the phenomenon and the context under investigation. When a researcher is trying to represent phenomenon and its context in a computer simulation, extreme demands are placed on him/her in order to replicate the real-life behaviour as well as possible. The researcher needs to possess a great deal of knowledge about the relationships among sub-systems and their components as well as the purpose of a variety of activities and processes going on in these sub-systems, all of which change dynamically. Should this knowledge be lacking the simulation model will not represent what is being examined. These demands make it difficult for methods such as simulation, designed to predict system behaviour, to reflect the variety among systems and their constituent components. Through the in-depth understanding provided by a case study, knowledge about relationships and pattern of behaviour are gained. This means that a simulation combined with case study would help researchers to identify the relevant characteristics and behaviour of a system. Furthermore, a rigorous simulation combined with a case study would help the researcher with the collection of necessary data as it would use various well-documented case data collection methods. This would result in a more rigorous platform for collecting input data for the simulation model and decrease the risk of "Garbage in, Garbage out".

In addition, combining simulation and case study provides the opportunity to expand the time horizon of the study. A case study focuses on understanding a contemporary set of events, whereas simulation could be used to look back in time using historical data and/or look forward in time by running different scenarios. Rather than only focusing on the current situation using case study, a combination of the methods provides the opportunity to look back and/or forward in time using simulation and the chance to create a rigorous platform for the current situation.

Another motive for combining simulation and case study is that the researcher is able to obtain help from the simulation in identifying and gaining insights into the system behaviour and performance by validating and experimenting with the model. Some of the factors influencing the performance and the behaviour of a system may be easy to observe, while others are ambiguous but vital. To produce a reliable simulation, extensive and precise knowledge of real-life behaviour is needed. Furthermore, the combination of several factors might also influence the behaviour and performance of the system. In simulation influential factors could be identified and the insight of the importance of these factors could be gained. In a case study the ability to experiment with influential factors is much more difficult and therefore more difficult to identify.

In addition, another advantage of combining case study and simulation is the opportunity to triangulate between the two methods. Triangulation can be generally considered as a process of using multiple perceptions to clarify meaning and verifying the repeatability of an observation or interpretation (Stake 2000). A strength of triangulating between case study and simulation is the mixing of a qualitative and a quantitative method where the authors agree with Jick (1979) that quantitative and qualitative methods should be viewed as complementary rather than rival methods.

Combining case study and simulation also offers the opportunity to triangulate between the data sets collected in the studies. Different data sets have different strengths and weaknesses concerning the bias of the research. Data sets collected from a simulation perspective might focus more on quantitative data e.g. variances and distributions of events through time, while data collected from a case study perspective might focus more on qualitative data. With two different data sets collected from two different perspectives multiple perceptions are gathered which increase the validity of the research. Furthermore, simulation increases the validity of the research by the validation process of the simulation model. When a simulation model is being validated input data is often questioned and additional data is needed in order for there to be a correlation between the model and the "reality". With a simulation model that does not behave or perform as respondents have explained the researchers are able to identify and eliminate data bias, thus strengthening the validity of the research.

When case study and simulation are combined the different data sets gathered in the studies overlap one another creating synergies in the data collection process. The case study provides simulation with an in-depth description and understanding of activities and processes, facilitating the development of a conceptual model for the simulation model. In addition, the data collected for the simulation provides the case study with an enriched understanding of the dynamics, variances, dependences and relationships between events and activities. Simulation might also provide the case study with additional input data derived from the results of verifying and conducting experiments using the simulation model. The synergies created in the data collection process when case study and simulation are combined is of great importance since it results in fewer resources being needed compared to a situation where separate studies are conducted.

The need for additional skills and resources is one of the weaknesses of combining case and simulation. The researcher does not only need more time to conduct the studies but also has to have access to additional tools. However, the main weakness of combining case and simulation is that it requires the researcher to possess knowledge and skill in both of the methods. Nevertheless, this could be prevented by letting several researchers with different skills carry out the studies. This would also give rise to additional types of synergies, such as multiple investigator perspectives.

Conclusions

Combining case study and simulation into a multimethod study allows the researcher to harmonise the weaknesses and assess the relative strengths of the various methods. Adopting two methodological perspectives means that an extended view of a logistics phenomenon is gained, for example, incorporating soft aspects such as individual subjective interpretations and understanding, and hard aspects that are measured or quantified. Combining case study and simulation makes it possible to elucidate underlying processes and illustrate a greater depth to the investigation by using the case study method, and at the same time defining and predicting the behaviour and performance of the process or system using simulation. Another valuable benefit is the opportunity for triangulation between the methods and between the different data sets collected in the studies. Furthermore, the combination of simulation and case study enables synergies in the data collection process. It is concluded that this multimethod study can be advantageous and may represent a further challenge in the process of doing case study and simulation research.

References

Axelrod, R. 1997, "Advancing the Art of Simulation in the Social Sciences," in Simulating Social Phenomena, R. H. a. P. T. Rosario Conte, ed., Springer, pp. 21-40.

Ball, P. D. "Introduction to Discrete Event Simulation", Algarve, Portugal, pp. 367-376.

Banks, J. 1998, Handbook of Simulation: Principles, Methodology, Advances, Applications and Practice John Wiley & Sons, Inc., New York.

Bonabeau, E., Dorigo, M., & Theraulaz, G. 1999, Swarm Intelligence - From Natural to Artificial Systems, First edn, Oxford University Press, New York.

Burrel, G. & Morgan, G. 1979, Sociological Paradigms and Organizational Analysis; Elements of the Sociology of Corporate Life, First edn, Heinemann Educational Books Ltd, London.

Denzin, N. K. & Lincoln, Y. S. 1998, The Landscape of Qualitative Research Sage Publications.

Eisenhardt, K. M. 1989, "Building Theories from Case Study Research", Academy of Management Review, vol. 14, no. 4, pp. 532-550.

Ellram, L. M. 1996, "The use of case study method in logistic research", Journal of Business Logistics, vol. 17, no. 2, pp. 93-138.

Epstein, J. M. 1999, "Agent-based computational models and generative social science", Complexity, vol. 4, no. 5, pp. 41-60.

Jick, T. D. 1979, "Mixing Qualitative and Quantitative Methods: Triangulation in Action", Administrative Science Quarterly, vol. 24, no. December, pp. 602-611.

Meredith, J. 1998, "Building operations management theory through case and field research", Journal of Operations Management, vol. 16, pp. 441-454.

Shafer, S. M. & Smunt, T. L. 2004, "Empirical simulation studies in operations management: context, trends, and research opportunities", Journal of Operations Management, vol. 22, no. 4, pp. 345-354.

Shapiro, J. F. 2001, Modeling the Supply Chain, First edn, Duxbury, Pacific Grove.

Stake, R. E. 2000, "Case Studies," in Handbook of Qualitative Research, Second Edition edn, N. K. Denzin & Y. S. Lincoln, eds., Sage Publications, Inc, pp. 435-453.

Stuart, I., McCutcheon, D., Handfield, R., McLachlin, R., & Samson, D. 2002, "Effective case research in operations management: a process perspective", Journal of Operations Management, vol. 20, no. 5, pp. 419-433.

Will, J., Bertrand, M., & Fransoo, J. C. 2002, "Operations management research methodologies using quantitative modeling", International Journal of Operations & Production Management, vol. 22, no. 2, pp. 241-264.

Yin, R. K. 2003, Case Study Research: Design and Methods, Third edn, Sage Publications, California.

Appendix

Reflections on research approaches

The aim of this chapter is to provide the reader with a reflection on one of the dominant approaches to logistics research, namely systems approach, and its connection to two paradigmatic approaches identified in complexity literature; complex adaptive systems and complexity thinking. The purpose of such a discussion is to provide the reader with my view of these approaches. Furthermore, for wider appreciation of the complexity framework presented in this thesis, this discussion is valuable and useful.

Systems approach to logistics

To exclude discussion and consideration of systems theory and the systems approach would be foolish when dealing with logistics-related research, *"The systems approach is a critical concept in logistics. Logistics is, in itself, a system; it is a network of related activities with the purpose of managing the orderly flow of material and personnel within the logistics channel"* (Lambert, Stock, & Ellram 1998). As the authors referred to state, the systems approach is critical when considering logistical issues and Bowersox and Closs (1996 p.459) share this view when making the claim that *"a basic understanding of the systems concept is desirable for a full appreciation of integrated logistics."* Furthermore Stock, Greis and Kasarda (1999 p.45) declare that the *"systems approach within the firm has been the underlying premise of much of current logistics management, thought, and practice."* Even more convincing is to use the approach when analyzing the research conducted at my department and at related logistics departments, such as the Engineering Logistics division at Lund Institute of Technology and the Logistics and Transportation division at Chalmers University of Technology (selected from 2000). Out of 15 licentiate theses and doctoral theses presented 13 claimed the systems approach for their research (Andersson 2001; Björklund 2002; Hellström 2004; Holmberg 2000; Knudsen 2003; Lindroth 2001; Modig 2005; Olsson 2002; Persson 2003; Saghir 2002; Saghir 2004; Waidringer 2001; Wallin 2003).

Nevertheless, before I continue my explanation of the above statement it might be beneficial for the reader to know what is meant and taken into consideration when the systems approach and systems theory are addressed (from now on referred as ST). ST derived from at least three foundational theoretical areas which emerged during the 1940's and 1950's. General systems theory (Von Bertalanffy 1969), cybernetics (Ashby 1956; Beer 1959) and system dynamics (Forrester 1968) all deal with the notion that the whole is more than the sum of its parts, and also deal with feed-back processes and relationships between the parts. Later on system sciences split into two branches; hard systems and soft systems approach (Checkland 1993). The former covers the development of cybernetics and system dynamics and is aligned to operational analysis and mathematically oriented approaches, while the latter, as understood by its name has a more qualitative approach and involves attempts to capture a richer context compared to the hard systems approach.

Several definitions of a system exist. Wilson (1993) states that *"a system is a structured set of objects and/or attributes together with the relationships between them in its environment"* while Ackoff (1973 p.664) defines a system as follows: *"a system is more than the sum of its parts; it is an indivisible whole."* Finally, Checkland (1999 p.3) declares that *"the central concept 'system' embodies the idea of a set of elements connected together which form a whole, this showing properties which are properties of the whole, rather than properties of its component parts."* Thus, a system could be regarded as consisting of parts which together make up the whole and where relationships and connections are important, and the whole often is more than the sum of the parts. From this notion of systems can it be said that the systems approach relies on an objective reality (Arbnor & Bjerke 1997) which one can observe holistically.

In accepting the notion of systems comes the issue of boundaries which is another feature of ST. In this context the manager or researcher has the opportunity to choose what will be the system and what will be the environment, *"The system boundaries are the first critical choice a researcher has to make. These boundaries define - and in the same sense - restrict the area of investigation"* (Kramer & DeSmit, 1977 in

Holweg (2001)). Furthermore, following on from this logic comes the ability to created subsystems i.e. a semi-reductionistic approach based on the fact that the overall assumption is holism. Cause-and-effect relationships are not always established within the system but instead, *indicator-effect* (Arbnor & Bjerke 1997). The indicator-effect relationships mean that both equifinality[18] (Von Bertalanffy 1969) and multifinality[19] exist in the systems

However, despite the overwhelming amount of logistics research which uses the ST, there are some aspects which may be reconsidered when research within the logistics discipline is performed, especially if the research object includes or is influenced by people. Such aspects would concern power, conflicts, creativity, novelty, and paradoxes. In this regard Gammelgaard (1997 p.17) declares that "*an objective world view will not be able to bring forward the subjective pictures of the world as those e.g. caused by difference in power between the actors in the system. Consequently the perception of reality becomes insufficient if systems theory is the only approach in logistics.*" This limitation of ST is related to a great extent to the teleological frameworks presented before (see chapter 3.1) and especially concerns the limitations a formative and/or rationalistic teleology represents. The transformative teleology does not fit within ST when it comes to human-related logistics. Stacey, Griffin and Shaw (2000 p.120) state that "*in systems thinking, causality is primarily of the formative type taking a linear form in which the feedback process of the system causes its patterns of behavior, usually in a predictable way, but those patterns do not cause the system dynamics.*" In addition, as Phelan (1999 p.237) states "*a common terminology suggests a high degree of commensurability between the two theories. However, on closer examination, although they share a common worldview, the two theories differ markedly in their research agenda and methodologies.*" However, before any critical examination of ST and comparison with complexity approaches, a description from my view of complex adaptive systems and complexity thinking might be useful.

[18] Equifinality: the same final state may be reached from different initial conditions and in different ways.
[19] Multifinality: that the same indicator can generate several effects.

Complexity approaches

The complexity movement is, as explained by most researchers in the field, first and foremost an attempt to move science away from the strong emphasis of reductionism and positivism in the majority of scientific disciplines today. The argument is that reductionstic and positivistic assumptions restrain further progress and cannot explain empirical phenomena easily found in nature and social life. The ideas and concepts which have appeared in the science of complexity have various applications and points of origin, and these ideas are continually being developed in several areas within natural sciences, as well as in areas related to social sciences. In natural science these areas are, for example; physics (Gell-Mann 1994; Prigogine 1997; Prigogine 2002), biology (Kauffman 1995), mathematics (Casti 1995), computer science (Axelrod 1997; Holland 1998; Wolfram 2002), and in social science; economics (Arthur 1996; Kauffman & Macready 1995), business management and strategy (Axelrod 1999; Beinhocker 1997; Beinhocker 1999; Colbert 2004; Pascale, Millemann, & Gioja 2000; Pascale 1999), organization theory (Morgan 1997; Stacey 1996; Stacey 2000; Stacey 2001), and social networks (Epstein & Axtell 1996; Jin, Girvan, & Newman 2001).

However, when examining complexity theory more deeply it appears that some of its branches diverge into different directions. Again, these branches are derived from the assumptions which are presumed. There are some complexity theories which can be regarded as extensions or parts of ST, since they share the notion of systems, boundaries, formative teleology etc., while other branches clearly set out to present other paradigmatic views, i.e. do not share the assumptions of the first type. Richardson and Cilliers (2001) in their special editors' note indicate that there are different type of complexity theories and complexity thinking. They characterize the options as reductionistic complexity science, soft complexity science, and complexity-based thinking. Stacey, Griffin and Shaw (2000) in their book question whether the complexity movement is a fad or a radical challenge to systems thinking. They also advocate the different use of complexity theory in literature and practice.

For the purpose of this thesis, two branches of complexity theory will be described and discussed in the context of organizations/management/logistics. These are characterized as complex adaptive systems and complexity thinking. This distinction is, in my opinion, important for the reader, especially for those for whom complexity theory is rather new. And hopefully, these comparisons with other paradigmatic views may help the reader orient him/herself. It is important to mention at this stage that this is not a discussion aiming at finding the true or best paradigm or approach for logistics research and practice. Such a discussion would be fruitless and, frankly speaking, foolish for the proposed value lies in gaining knowledge and understanding of what paradigm or approach provides appropriate understanding, and guidance, for the situation or phenomenon present. As it will be further elaborated, my belief is that a multi-paradigm approach will be far more beneficial to any research problem than solely using one; the dilemma is to know when, and under what circumstances to use what. This goes back to the initial statement in this thesis involving effectiveness and efficiency i.e. about doing the right thing vs. doing things right. It does not matter whether you do the research in the right way if it is the wrong thing to do in the first place. However, handling this dilemma is not a simple task and therefore there needs more research, and it will always be a paradox we will have to live with. Nonetheless, ignoring the fact of paradoxes might be devastating for further development of logistics research and practice.

Complex adaptive systems

A complex adaptive system (CAS) can be described as *"a special kind of complex systems since they have the property of adaptation. As the discussion above pointed out, adaptation means that the agents or elements in the system are responsive, flexible, reactive and often proactive regarding inputs from other agents or elements that affect them"* (Nilsson 2003). More generally described, in the words of Choi, Dooley and Rungtusanatham (2001 p.352), complex adaptive systems "*interplay between a system and its environment and the co-evolution of both the system and the environment.*" Waldrop (1992 p.145) gives several examples of what are referred to as complex adaptive systems; "*in the natural world such systems included brains, immune systems, ecologies, cells, developing embryos, and ant colonies. In the human* *world they included cultural and social systems such as political parties or scientific communities."*

CAS consists of several parts, which are commonly referred to as agents, and which act in correlation and interdependence to each other (Bar-Yam 1997). In the context of logistics these agents could be companies, but on a lower level they could also be the people within the organizations and even artifacts like machines and packages. This means that some agents might have greater influence on the system, and some less, but the interesting part is that no one controls the system. Compared to the brain, there is no master neuron controlling what we think (Waldrop 1992). The complexity arises in the adaptive processes among the agents from which perpetual novelty emerges. Attempts to reduce organizational complexity in order to control (i.e. as managers are taught to act) are often counterproductive (Colbert 2004). CAS acts most creatively in states far from equilibrium, often referred as to the edge of chaos, for at the other extreme *"equilibrium is a precursor to death"* (Pascale 1999 p.85).

In complex adaptive systems positivism can still be revealed since there is an underlying belief that identifiable rules of cause-and-effect can be found in the system, i.e. some master rules which have a major influence on the whole system. A commonly referred to example is Craig Reynolds (1987) "boids" program. The program is capable of simulate flocking behavior, similar to birds, by only using three simple rules. These are: a) maintain a minimum distance from other objects and boids in the environment, b) match velocities with other boids in the neighborhood, and c) move towards the perceived center of mass of boids in the neighborhood. Such micro-determinism can be found in the management literature available which adopts CAS theories on management issues. In such literature suggestions and discussions on how organizational authorities' can set these rules, and from that direct global emergent behavior towards predetermined goals, are presented as novel management philosophies.

As described in chapter 2.1 there are a few researchers who have adopted the notion that supply networks and logistics systems are complex adaptive systems. For example, Choi, Dooley and Rungtusanatham (2001 p.352) state that it is *"not enough to recognize a supply network as simply a system – a supply network is a complex adaptive system,"* and Sutherland and van den Heuvel (2002 p.3) state that *"business entities are good examples of complex adaptive systems."* In my licentiate thesis it was also concluded that within the logistics discipline there were several aspects of real-life logistics which was not addressed in the related literature (e.g. self-organization, emergence, adaptability etc.) and for which theories of complex adaptive systems provided explanations.

Complexity thinking

As stated earlier, complexity thinking (CT) differs ontologically, epistemologically and teleologically from both ST and CAS. Ontologically, the underlying belief is that of unorder and subjectivity; epistemologically, of heuristics or anti-positivism; and teleologically, of a transformative nature. Complexity thinking is what I regard as the collection of organizational and social complexity theories such as Stacey et al's (Stacey 2003; Stacey 2000; Stacey 2001; Stacey, Griffin, & Shaw 2000) work on complex responsive processes, Snowden et al's (Snowden 2002b; Snowden & Stanbridge 2004) Cynefin framework, and works by Richardson, Lissack and Cilliers (Lissack 1999; Richardson 2003; Richardson & Cilliers 2001; Richardson, Cilliers, & Lissack 2001). As described earlier (in chapter 2.1) the works of Johanessen and Solem in logistics (Johannessen 2003; Johannessen & Solem 2001; Johannessen & Solem 2002) rely on complexity thinking, more particularly on complex responsive processes.

A major differentiator of complexity thinking in comparison to ST and CAS is that CT is developed for human- and human organizational phenomena, i.e. there are no extrapolations from physical, chemical or biological sciences. This is the consideration Boulding (1956) makes in his taxonomy on the seventh and eight levels (see chapter 3) and in line with his and my own reasoning of "level appropriateness" to theoretical development i.e. theory needs to be developed from and for the type of phenomena and context it will be applied to. These theories applied to management are driven by the empirical observation that the connection of common theoretical management concepts to concrete management practice is rather fuzzy (e.g. strategy and knowledge management). Snowden and Stanbridge (2004) argue that while several schools of thought within knowledge management and organizational strategy exist, the underlying philosophical assumptions remain relatively stable. Furthermore, in complex responsive processes the striving is to *"move away from the notion that human action and interaction is a system or can usefully be thought of as a system, when it comes to understanding change of a transformational kind"* (Stacey, Griffin, & Shaw 2000 p.186). Instead the complex responsive process perspective sets out to explain transformational change as emerging from self-organizing processes which are born out of human interaction.

Based on transformational teleology the future in CT is regarded as mainly unknown, or, as Prigogine (1997) states, under *"perpetual construction"*. It follows from this that epistemological assumptions are in line with the limitations of handling or even understanding of the perceived reality to a greater extent. Focus is on exploratory analysis of the phenomena being studied and these complex phenomena are incompressible from a CT perspective (Richardson, Cilliers, & Lissack 2001 p.8). As Kurtz and Snowden (2003 p.480) point out: *"Conceivability is not the point: preparation for the unexpected is."*

Paradoxes are seen as natural in CT and follow Hegel's logic in that they possess different characteristics and explanations at the same time i.e. phenomena being predictably unpredictable (Stacey 2002), or knowledge characterized as both a substance and a flow, simultaneously (Snowden 2002a). In this way the knowledge "produced" (the substance) in the logistics discipline is still of value and does not contradict a CT perspective but instead complements it since the emphasis is on the transformational change of knowledge (the flow) through human relating and reasoning processes in logistics systems. By this acceptance of paradoxes in organizational contexts the CT perspective involves considerations of central aspects in human life such as conflicts, power, creativity, novelty, joy, and love where these aspects are central to the way human beings relate to each other and these qualities help create meaning in most situations.

In short, what complexity thinking aims to understand is why organizations on a daily basis evolve as they do, why and how meaning is created, how transformational processes of relating through paradoxical changes of identity at the same time as continuity is perceived come about.

A comparative discussion of assumptions

To provide a fruitful discussion and argumentation concerning similarities and differences between the complexity approaches and the systems approach, a categorization of the extended assumptions in figure 3.1 (see chapter 3) will be provided as a starting point. The categories are:

- structural
- behavioral, and
- time-related.

The structural assumptions are **non-linerarity**, **non-equilibrium**, **unorder** and **emergence**, based on the reason that these assumptions relate to beliefs in how structural aspects of logistics phenomena and processes are connected and how they are formed. Assumptions categorized as behavioral are **interdependence**, **subjectivity**, **self-organization**, **coevolution**, and **bounded rationality**, since these all relate to the creatures involved, both individually and collectively, and to how they interact. Finally, the time-related assumptions are **multicausality**, **feed-back**, **indeterminism** and all share the feature that they relate to future states or conditions.

It is important to make the point that this categorization is not a claim to be complete or inclusive since some of the assumptions are related to both time, behavior and structure e.g. coevolution. Instead the purpose is, from a logistics point of view, to bundle them together in such a way that could benefit further development of the logistics discipline. In other words, the reader may and is encouraged to, from his/her subjective view, regard this characterization differently. Thus, the important message is that the reader rethinks the assumptions he/she makes and is driven by. In that process this categorization could be beneficial.

Structural assumptions

When it comes to the structural assumptions one apparent similarity between ST and CAS concerns the fact that both approaches agree on the assumptions of objectivity and from that, a chosen system can be separated from its environment. However, how this is done differs between the two theories. This will be further discussed below.

A second apparent similarity between ST and CAS is the common assumption of system classification in taxonomies and hierarchies. This means that there are some identifiable systems which can be described on a higher level than others, since they consist of other identifiable systems. Furthermore, as the definition above of the system concept provided by Checkland (1997) indicates, there are properties on the systems level forming the whole which are not properties of the constituents' parts. This notion of system properties points to what in CAS is defined as emergent phenomena.

From a CT perspective these notions about systems and of hierarchies and levels are questioned. Johannessen (2003 p.11) states that *"it is firmly a systems theoretical idea to set up boundaries and denote something 'inside' and 'outside'."* Furthermore, Richardson, Cilliers and Lissack (2001 p.9) state *"Given that no hard, enduring boundaries exist in reality, the use of the term "system" can be misleading, as it suggests the existence of completely autonomous entities."*

Another emphasis in systems theory is the focus on structure, and on how essential the structure is in understanding the dynamics in a system. This point is especially stressed by Sterman (2000) and Senge (1990), who argue that "*structure drives behavior*." In this regard Lee, Padmanabhan and Whang (1997 p.548) conclude that companies which aim to get control of the bullwhip effect should attack *"the institutional and inter-organizational infrastructure and related processes."* Another example is provided by Disney, Naim and Towill (1997) in their discussion of causes of the bullwhip effect. They declare that poorly designed order handling systems may cause amplifying behavior through the supply chain and thus, *"it is essential to select the appropriate structure for the production ordering system, and then to set the* *system parameters at their 'best' value"* (ibid. 1997 p.176). It could be interpreted that some hidden order or structure exists, which can be found and in turn helps top management, for instance, to control and direct behavior in lower hierarchies. Johannessen (2003 p.15) states that *"it is assumed that the system is stable for such a time period that analysis can be made … a system should be able to display predictable and stable behavior."*

From a complexity perspective (both CAS and CT) one would agree with the systems theory statement that 'structure drives behavior' (CAS) or at least influences it (CT), however, as paradoxical this agreement may be, the complexity researcher would also argue that "behavior creates structure" or at least, "behavior creates the perception of structure" and emphasizes this more. The "structure" or order in CAS and CT is an emergent outcome of self-organizing behaviors, where those involved might be more or less "powerful", since heterogeneity and variety are facts. Kauffman (1995) calls this self-organizing outcome 'order for free'. Here one explanation for this difference is the question of time. The systems belief works well in a static context, however, as previously discussed, since time has a direction, structures will change (Prigogine 1997). The reason is that in our daily operations we change structures in whatever we do as well as in what we do not do. Gillies and McCarthy (2000) make the point that the complex systems view demonstrates that much of our knowledge is focused on static descriptions i.e. on being, rather than on dynamic processes i.e. on becoming. What CT shares with CAS is the notion of unorder and emergence, and with the soft systems approach, the uniqueness of human phenomena and organizations (Snowden & Stanbridge 2004). Furthermore, as Richardson and Cilliers (2001 p.11) state *"insights from the human sciences on the one hand, and natural science on the other, should not be set against each other, nor should they be assimilated too easily. They should be used to challenge each other."*

Behavioral assumptions

There is a difference between the theories in how complexity arises and how it is treated. In ST the complexity appears in systems as a cause of how many parts and interactions are present, and seen from a holistic perspective, i.e. by viewing the system from above, one could see that many parts are connected and that there are a huge number of parts. All this makes phenomena (i.e. systems) hard to grasp, in other words complicated. In contrast to ST, the overall belief in CAS is that the complexity is the result of interacting agents or parts which follow simple rules. What create the complexity are the self-organizing processes by agents or parts performing different activities. On higher levels of description they create complex as well as simple patterns of coherence and chaos. This means that the heterogeneity of the agents and the variety among them are put forward and not regarded or treated as an average which can be simply viewed at higher levels of aggregation, which is the case in systems dynamics. The uniformity assumption is an instrumental convenience (McKelvey 1997), accepted as *"simplify mathematical analysis rather than because it is true"* (McKelvey 1999 p.299).

The phenomenon of self-organization can be found in all approaches, however, it differs in its meaning and in how it is defined. In ST some elements of a systems behavior are sometimes referred to as being formed by the feed-back loops which are prevalent in e.g. logistics systems. However, there is always a great belief in the engineering capability of the observer (researcher or manager) as being able to control the behavior and direct it toward some predetermined goal. A holistic picture of the situation provides the observer with the chance to see "all" feedback loops and from that he/she rejects those which are deemed less efficient or effective for the overall goal. In CAS the discussion about self-organization is less determinable since there is a belief is that it is far more spontaneous i.e. less engineerable. Kauffman (1995 p.185) states that *"self-organization may be the precondition of evolvability itself. Only those systems that are able to organize themselves spontaneously may be able to evolve further."*

In CAS the notion of system designer is less prevalent and as Fontana and Ballati (in Anderson 1999) argue, self-organization is not a result of individual agents or elements deliberately seeking some kind of order; instead, is it the natural result of non-linear actions. Despite this there is still, in several authors' work on CAS (Beinhocker 1997; Brown & Eisenhardt 1997; Warfield 1999), a belief in designability through simple rules on individual levels. This is especially the case in literature addressing organizations involving humans, where the extrapolation of results identified in physical and natural systems is translated into humanity phenomena with encouragement to managers to find "master rules" in such systems. The result is that several normative management texts implicitly suggest that complexity science opens new doors for control and prediction (see Kupers 2001 for example).

In CT this notion of designability is limited, unpredictable and paradoxical since the firm belief is that a process or phenomenon *"can self-organize into disintegration just as it can into a rigid, repetitive pattern"* (Stacey, Griffin, & Shaw 2000 p.147). Furthermore, in CT a transformative teleology is assumed, meaning that changes do appear spontaneous and unpredictably and, as paradoxical it may seem, emergent continuity is kept simultaneously. This is derived from Hegel's dialectical notion of individual and societal paradoxes being both simultaneous i.e. an individual is both constructing and influenced by the society at the same time (Johannessen 2003) and there are no notions of system levels or hierarchies.

Let us consider another assumption of the extended assumptions, namely coevolution, which can be defined as *"a process of coupled, deforming landscapes where the adaptive moves of each entity alter the landscapes of its neighbors in the ecology or technological economy"* (Kauffman & Macready 1995 p.27). Coevolutionary processes could be seen as combinations of traditional evolutionary thinking and self-organization since evolutionary processes, and especially natural selection, are driven and characterized by competition; the process of self-organization is both cooperative and competitive. In CAS it is explained that through local active and lively behavior global characteristics emerge which then alter the way the agent on lower levels interact (Anderson 1999). This in turn leads to changes in objectives, structures, motivations (Changrui et al. 2002) i.e. coevolution of organizational functions, company networks and of the economy as such.

Furthermore, another behavioral assumption discussed in theory, and experienced by most people in reality is that of subjectivity vs. objectivity. Here again, the theories differ in their treatment of such an issue. While the overall belief in ST is objectivity, or at least an objectively accessible reality, the situation is different in CT. In CT the assumption is of a more interpretive character, where meaning and value are created in the interactions among people in their daily activities i.e. some common view of some characteristics of life is contextually created, and formally or informally agreed on by those involved. However, due to people's multiple identities, paradoxical and time-related aspects might change such agreements, as contexts perpetually change. This is due to the inherent complexity perceived in making long-term commitments to several characteristics and situations simultaneously. In this regard Stacey, Griffin and Shaw (2000 p.61) state that *"systems work, to the extent that they do, because of the informal, freely chosen, ordinary, day-to-day cooperative interactions of an organization's members, and this cannot be controlled."*

This discussion leads us to another assumption which differs widely among the approaches, that of rationality and how bounded it is. Rationality implies that each and every constituent part of a system being planned operates rationally i.e. they all have perfect information, the same background, similar beliefs and assumptions, and work towards the same goal (known and designed by someone outside the system). Furthermore, as Allen (2000) states, the environment in which the company or department works is stable both before and after the decision has been taken. While rationality is more or less rejected by all the approaches (ST, CAS, and CT) it is treated differently by them. In this regard Rigby et al. (2000 p.181) state that *"in practice, open systems theory gives a central role to "management" to maximize bounded rationality (Simon, 1956). This "gatekeeper" role requires management to predict and design appropriate structures and responses and to manipulate resources and connected actors in what is perceived to be a desirable manner."* In other words, based on the assumption of objectivity and the notion of a formative and rational teleology, highly empirically observable aspects, such as conflict, power, and creativity, are disregarded and cannot be satisfactorily explained when a ST is used. Gammelgaard (1997 p.17) concludes, for example, that *"conflicts are simply not on* *the research agenda in that part of reality which systems theory uncovers.“* This is to a great extent the case in CAS as well, however, instead of the great emphasis on avoidance of and reductions in such uncomfortable aspects (e.g. conflict), these are seen as natural and essential for advancements and evolution. Since CT developed for social complexity, the assumption of bounded rationality is the rule, and considerations of subjective pictures of situations, the narratives and contexts are emphasized.

Time-related assumptions

As Phelan (1999) explains, the ST focuses on problem-solving and action to improve some identified or conceptualized system in order to reach an optimal state, i.e. some predetermined objective which represents a stable future situation. Stacey, Griffin and Shaw (2000 p.59) state that "*systems thinking provide powerful ways of thinking about, and designing means of securing, organizational stability and continuity and, in the case of systems thinking, unfolding potential change already enfolded in the system."* This means that a formative and rationalist view is taken for granted. This notion is less emphasized in CAS, for example, Choi, Dooley and Rungtusanatham (2001 p.356) declare that *"in a complex system, it is often true that the only way to predict how the system will behave in the future is to wait literally for the future to unfold."* Holland (in Waldrop 1992 p.147) points out that *"every complex adaptive system is constantly making predictions based on its various internal models of the world – its implicit or explicit assumptions about the way things are out there."* In addition, CAS also has a history which influences both its present actions, and their anticipations and expectations of the future. A consequence of the reliability an agent's history may provide is the fact that history is a limited guide to future behavior. In the process of anticipating the future, agents search for patterns in the past and, as Beinhocker (1999 p.97) declares, *"our drive to see patterns and trends is so strong that we will even see them in perfectly random data."* This makes the connection with a more transformative view for the CAS perspective explicit. Thus, due to multicausality, feed-back and indeterminism, the possibilities for predictions are heavily reduced. However, in the "rule"-based CAS community the wish for prediction is still apparent, often through computer simulations.

The focus in CT is, in contrast, on exploratory analysis where understanding helps the researcher and practitioner to live with uncertainty in stead of trying to remove it. The emphasis is even more on the living present from which we change both the future and the past in the activities we perform and in how we relate to other people.

Final reflections

These research approaches all represent different perspectives on reality, based on different assumptions, and are thus applicable to different contexts, situations, and problems. Knowing each approach's limitations and its underlying assumptions is valuable when using these approaches in any research endeavor. In ST there are certain assumptions which are less beneficial in explaining logistics activities on a daily basis and in creating a meaning for the people involved. ST's provide good objective illustrative descriptions of technical parts of logistics "systems", however, they place less emphasis on the subjective perspectives logistics people have in "reality". The problem with CAS theories applied to human phenomena is similar to that of other approaches discussed earlier in this thesis, in the sense that they are developed and derived from studies of mathematics, physics, chemistry and biology, and not for human and social phenomena. The trend in during the 90's has been to pick out the best parts of new, hyped theories, which in their first intended theoretical and empirical areas have proven to be successful and useful. In other words, replace the atoms or cells with human beings. This temptation to apply novelty is typically human despite the fact, when rethinking the underlying assumptions, that theory does not fit into the context to which it been transferred in its intended form. As a final comment, I would argue that for further developments of logistics, approaching logistics phenomena from several perspectives may achieve best results. The unifying efforts of logistics may provide value since in some situations a common defined terminology may ease communication and consensus. However, based on a belief of an ever-changing reality filled of transformations of identities, a multiperspective approach to logistics may be valuable in making decisions concerning 'the right things to do' i.e. in creating effective logistics.

References

Ackoff, R. L. 1973, "Science in the Systems Age: Beyond IE, OR, and MS", *Operations Research*, vol. 21, no. 3, pp. 661-671.

Allen, P. M. 2000, "Knowledge, Ignorance and Learning", *Emergence*, vol. 2, no. 4, pp. 78-103.

Anderson, P. 1999, "Complexity Theory and Organization Science", *Organization Science*, vol. 10, no. 3, pp. 216-232.

Andersson, J. 2001, *Tools for Improved Performance in the Supply Chain - Experiences from a Software Development Project*, Licentiate thesis, Department of Industrial Management and Logistics, Division of Engineering Logistics, Lund University, Lund.

Arbnor, I. & Bjerke, B. 1997, *Methodology for Creating Business Knowledge*, Second edn, Sage Publications, Inc., Thousand Oaks, CA, USA.

Arthur, W. B. 1996, "Increasing Returns and the New World of Business", *Harvard Business Review*, vol. 74, no. 4, pp. 100-110.

Ashby, W. R. 1956, *An introduction to cybernetics*, First edn, Chapman & Hall LTD, London.

Axelrod, N. N. 1999, "Embracing Technology: The Application of Complexity Theory to Business.", *Strategy & Leadership*, vol. 27, no. 6, pp. 56-59.

Axelrod, R. 1997, *The Complexity of Cooperation - Agent-Based Models of Competition and Collaboration*, First edn, Princeton University Press, Princeton, New Jersey.

Bar-Yam, Y. 1997, *Dynamics of complex systems*, First edn, Perseus Books, Reading, Massachusetts.

Beer, S. 1959, *Cybernetics and management*, First edn, The English Universities Press LTD, London.

Beinhocker, E. D. 1997, "Strategy at the edge of chaos", *The McKinsey Quarterly* no. 1, pp. 24-39.

Beinhocker, E. D. 1999, "Robust Adaptive Strategies", *Sloan Management Review*, vol. 40, no. 3, pp. 95-107.

Björklund, M. 2002, *Environmental Considerations when Selecting Transport Solutions: A contribution to shippers' decision process*, Licentiate thesis, Department of Industrial Management and Logistics, Division of Engineering Logistics, Lund University, Lund.

Boulding, K. E. 1956, "General Systems Theory-The Skeleton of Science", *Management Science*, vol. 2, no. 3, pp. 197-208.

Bowersox, D. J. & Closs, D. J. 1996, *Logistical Management, the integrated supply chain process*, International edn, McGraw-Hill.

Brown, S. L. & Eisenhardt, K. M. 1997, "The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations", *Administrative Science Quarterly*, vol. 42, no. 1, pp. 1-34.

Casti, J. L. 1995, *Complexification: Explaining a Paradoxical World Through the Science of Surprise*, First edn, Harper Perennial, New York.

Changrui, R., Shouju, R., Yueting, C., Yi, L., & Chunhua, T. 2002, "Modeling agile supply chain dynamics: a complex adaptive system perspective", *Systems, Man and Cybernetics, 2002 IEEE International Conference on*, vol. 3, pp. 555-560.

Checkland, P. 1993, *Systems Thinking, Systems Practice* John Wiley & Sons Ltd, Chichester.

Checkland, P. 1999, *Systems Thinking, Systems Practice - includes a 30-year retrospective* John Wiley & Sons Ltd, Chichester.

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. 2001, "Supply networks and complex adaptive systems: control versus emergence", *Journal of Operations Management*, vol. 19, no. 3, pp. 351-366.

Colbert, B. A. 2004, "The Complex Resource-based View: Implications for Theory and Practice in Strategic Human Resource Management", *The Academy of Management Review*, vol. 29, no. 3, pp. 341-358.

Disney, S. M., Naim, M. M., & Towill, D. R. 1997, "Dynamic simulation modelling for lean logistics", *International Journal of Physical Distribution & Logistics Management*, vol. 27, no. 3, pp. 174-196.

Epstein, J. M. & Axtell, R. 1996, *Growing Artificial Societies Social science from the bottom up* The MIT Press, Cambridge.

Forrester, J. W. 1968, "Industrial Dynamics - After the first decade", *Management Science*, vol. 14, no. 7, pp. 398-415.

Gammelgaard, B. 1997, "The Systems Approach in Logistics", Institute for Logistics and Transport, Copenhagen Business School, pp. 9-20.

Gell-Mann, M. 1994, *The Quark and the Jaguar: Adventures in the Simple and the Complex* ABACUS, London.

Gillies, J. M. & McCarthy, I. P. 2000, "Complex Systems Thinking: Key insights for the social sciences, and an industrial application", Warwick University, Coventry, UK.

Hellström, D. 2004, *Exploring the Potential of Radio Frequency Identification Technology in Retail Supply Chains - A Packaging Logistics Perspective,* Licentiate thesis, Department of Design Sciences, Division of Packaging Logistics, Lund University, Lund.

Holland, J. H. 1998, *Emergence from Chaos to Order*, First edn, Perseus Books, Cambridge, Massachusetts.

Holmberg, S. 2000, *Supply Chain Integration through Performance Measurement,* Doctoral thesis, Department of Industrial Management and Logistics, Division of Engineering Logistics, Lund University, Lund.

Holweg, M. 20010, "Systems Methodology in Manufacturing and Logistics Research - A Critical Review", Faculty of Engineering and Faculty of Economics, University of Iceland, Reykjavik.

Jin, E. M., Girvan, M., & Newman, M. E. J. 2001, "The Structure of Growing Social Networks", *Santa Fe Institute working paper, www.santafe.edu.*

Johannessen, S. 2003, *An explorative study of complexity, strategy and change in logistics organizations,* Doctoral thesis, Departement of Industrial Economics and Technology Management, Trondheim.

Johannessen, S. & Solem, O. 2001, "Complexity thinking: A new perspective on strategy and change in logistics organizations", Faculty of Engineering and Faculty of Economics, University of Iceland, Reykjavik.

Johannessen, S. & Solem, O. 2002, "Logistics organizations: Ideologies, principles and practice", *International Journal of Logistics Management*, vol. 13, no. 1, pp. 31-42.

Kauffman, S. 1995, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* Oxford University Press, New York.

Kauffman, S. & Macready, W. 1995, "Technological Evolution and Adaptive Organizations", *Complexity*, vol. 1, no. 1, pp. 26-43.

Knudsen, D. 2003, *Improving Procurement Performance with E-business Mechanisms,* Doctoral Dissertation, Department of Industrial Management and Logistics, Lund Institute of Technology, Lund University.

Kupers, R. 2001, "What Organizational Leaders Should Know about the New Science of Complexity", *Complexity*, vol. 6, no. 1, pp. 14-19.

Kurtz, C. F. & Snowden, D. J. 2003, "The new dynamics of strategy: Sense-making in a complex and complicated world", *IBM Systems Journal*, vol. 42, no. 3, pp. 462-482.

Lambert, D. M., Stock, J. R., & Ellram, L. M. 1998, *Fundamentals of Logistics Management*, International edn, McGraw-Hill Higher Education, London.

Lee, H. L., Padmanabhan, V., & Whang, S. 1997, "Information Distortion in a Supply Chain: The Bullwhip Effect", *Management Science*, vol. 43, no. 4, pp. 546-558.

Lindroth, R. 2001, *Reflections on Process-based Supply Chain Modelling and Analysis - Some Findings based on the ESPRIT Project ISCO,* Licentiate thesis, Department of Industrial Management and Logistics, Division of Engineering Logistics, Lund University, Lund.

Lissack, M. R. 1999, "Complexity: the Science, its Vocabulary, and its Relation to Organizations", *Emergence*, vol. 1, no. 1, pp. 110-126.

McKelvey, B. 1997, "Quasi-Natural Organization Science", *Organization Science*, vol. 8, no. 4, pp. 352-380.

McKelvey, B. 1999, "Avoiding complexity catastrophe in coevolutionary pockets: Strategies for rugged landscapes.", *Organization Science*, vol. 10, no. 3, pp. 294-321.

Modig, N. 2005, *The impact of project characteristics on temporary logistics solutions,* Licentiate thesis, Department of Logistics and Transportation, Chalmers University of Technology, Gothenburg.

Morgan, G. 1997, *Images of organization,* Second edn, SAGE Publications, Thousand Oaks, CA.

Nilsson, F. 2003, *A Complex Adaptive Systems Approach on Logistics*, Licentiate thesis, Department of Design Sciences, Division of Packaging Logistics, Lund University, Lund.

Olsson, A. 2002, *The integration of customer needs in e-business systems,* Licentiate thesis, Department of Design Sciences Division of Packaging Logistics, Lund Univeristy, Lund.

Pascale, R. T., Millemann, M., & Gioja, L. 2000, *Surfing the Edge of Chaos - The Laws of Nature and the New Laws of Business*, Paperback edn, Three River Press, New York.

Pascale, R. T. 1999, "Surfing the Edge of Chaos", *Sloan Management Review*, vol. 40, no. Spring, pp. 83-95.

Persson, P.-O. 2003, *E-business in logistics and transportation - an evaluation of e-business as a tool for efficient logistics*, Licentiate thesis, Department of Logistics and Transportation, Chalmers University of Technology, Gothenburg.

Phelan, S. E. 1999, "A Note on the Correspondence Between Complexity and Systems Theory", *Systemic Practice and Action Research*, vol. 12, no. 3, pp. 237-246.

Prigogine, I. 1997, *The End of Certainty - Time, Chaos, and the New Laws of Nature*, First edn, The Free Press, New York, NY.

Prigogine, I. 2002, "The Future is Not Given, in Society or Nature.", *NPQ: New Perspectives Quarterly*, vol. 17, no. 2, pp. 35-38.

Reynolds, C. W. 1987, "Flocks, Herds, and Schools: A Distributed Behavioral Model", *Computer Graphics*, vol. 21, no. 4, pp. 25-34.

Richardson, K. A. 2003, "On the Limits of Bottom-Up Computer Simulation: Towards a nonlinear modeling culture", Hawaiian International Conference on System Sciences, Hawaii.

Richardson, K. A. & Cilliers, P. 2001, "Special Editor's Note: What Is Complexity Science? A View from Different Directions", *Emergence*, vol. 3, no. 1, pp. 5-22.

Richardson, K. A., Cilliers, P., & Lissack, M. R. 2001, "Complexity Science: A "Gray" Science for the "Stuff in Between"", *Emergence*, vol. 2, no. 3, pp. 6-18.

Rigby, C., Day, M., Forrester, P., & Burnett, J. 2000, "Agile supply: rethinking systems thinking, systems practice", *International Journal of Agile Management Systems*, vol. 2, no. 3, pp. 178-186.

Saghir, M. 2002, *Packaging Logistics Evaluation in the Swedish Retail Supply Chain*, Licentiate thesis, Department of Design Sciences, Division of Packaging Logistics, Lund University, Lund.

Saghir, M. 2004, *A platform for Packaging Logistics Development - a systems approach*, Doctoral thesis, Department of Design Sciences, Division of Packaging Logistics, Lund University, Lund.

Senge, P. M. 1990, *The fifth discipline: the art and practice of the learning organization*, First edn, Doubleday, New York.

Snowden, D. 2002a, "Complex acts of knowing: paradox and descriptive self-awareness", *Journal of Knowledge Management*, vol. 6, no. 2, pp. 100-111.

Snowden, D. 2002b, "Complex acts of knowing: paradox and descriptive self-awareness", *Journal of Knowledge Management*, vol. 6, no. 2, pp. 100-111.

Snowden, D. & Stanbridge, P. 2004, "The landscape of management: Creating the context for understanding social complexity", *ECO*, vol. 6, no. 1-2, pp. 140-148.

Stacey, R. 1996, "Management and the science of complexity: If organizational life is nonlinear, can business prevail", *Research Technology Management*, vol. 39, no. 3, pp. 8-11.

Stacey, R. 2002, "Organizations as Complex Responsive Processes of Relating", *Journal of Innovative Management*, vol. 8, no. 2, pp. 27-39.

Stacey, R. 2003, "Learning as an activity of interdependent people", *The Learning Organization*, vol. 10, no. 6, pp. 325-331.

Stacey, R. D. 2000, "The Emergence of Knowledge in Organizations", *Emergence*, vol. 2, no. 4, pp. 23-39.

Stacey, R. D. 2001, *Complex Responsive Processes in Organizations - Learning and knowledge creation* Routledege, London.

Stacey, R. D., Griffin, D., & Shaw, P. 2000, *Complexity and management - Fad or radical challenge to systems thinking?* Routledge, London.

Sterman, J. 2000, *Business Dynamics Systems Thinking and Modeling for a Complex World* McGraw, New York.

Stock, G. N., Greis, N. P., & Kasarda, J. D. 1999, "Logistics, strategy and structure A conceptual framework", *International Journal of Physical Distribution & Logistics Management*, vol. 29, no. 4, pp. 224-239.

Sutherland, J. & van den Heuvel, W. 2002, "Enterprise application integration encounters complex adaptive systems: a business object perspective", *System Sciences, 2002.HICSS.Proceedings of the 35th Annual Hawaii International Conference on* pp. 3756-3765.

Von Bertalanffy, L. 1969, *General Systems Theory - Foundations, Development and Applications*, First revised edn, George Braziller Inc., New York.

Waidringer, J. 2001, *Complexity in transportation and logistics systems: An integrated approach to modelling and analysis,* Doctoral thesis, Department of Transportation and Logistics, Chalmers University, Göteborg.

Waldrop, M. M. 1992, *Complexity - The emerging science at the edge of order and chaos* Touchstone, New York.

Wallin, C. 2003, *Contract Packaging and its Implications for the Supply Chain - A Case Study of a Contract Packager*, Licentiate, Department of Design Sciences, Division of Packaging Logistics, Lund University, Lund.

Warfield, J. N. 1999, "Twenty laws of complexity: science applicable in organizations", *Systems Research and Behavioral Science*, vol. 16, no. 1, pp. 3-40.

Wilson, B. W. 1993, *Systems: concepts, methodologies and applications*, 2 edn, John Wiley & Sons..

Wolfram, S. 2002, *A New Kind of Science* Wolfram Media, Inc., Champaign.