Chemical Management Services from a Product Service System perspective: Experiences of fluid management services from Volvo Group metalworking plants

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Chemical Management Services from a Product Service System perspective

Experiences of fluid management services from Volvo Group metalworking plants

Martin
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The painting on the cover, "Birches", is an unsigned painting from early 20th century by Nikolaj Triik, the great grandfather of the author.

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I have tried to explain some of the issues in sustainable fluid management in connection to lean production and product service systems. In the course of time I have felt some comfort in looking down at Homer Simpson as an anti-hero.

"Trying is the first step towards failure" *Homer Simpson (Channel 6 Sweden 20070214)*

Martin Kurdve

Lund, November 2009

Executive summary

This thesis analyses fluid management services (FMS) in metalworking industry and determines environmental and economic outcomes of FMS as compared to traditional, in-house, fluid management. Fluid management services, or as it is often called chemical management services (CMS), mean that the suppliers of chemicals are also involved in managing and maintaining the fluids in the use phase. Usually one supplier is responsible for managing all the different fluids on a site, but the management may be restricted to some processes or fluids only.

The services in an FMS comprise outsourced services in manufacturing and fluid management. The environmental gain should mainly come from a common incentive to minimise fluid usage, which in turn could also result in less fluid waste. So far research on FMS has mainly studied the business case for suppliers, even though there have been some case studies presenting economic improvements for customers achieved in outsourcing the fluid management to an FMS supplier (Stoughton and Votta 2003). This research focuses on investigating how the shaping of economic and legal parameters of FMS contracts affects health and environmental outcomes of the fluid management.

The ultimate goal of an environmentally and economically sound FMS, supported in terms of organisational and contractual development, is an industrial system with no waste of fluids, internal recycling of all standard fluids and maximised use of standard fluids that satisfy the needs of a specific production.

This research attempts to answer two questions:

1. What are the main factors influencing the environmental outcome of implementing fluid management services in metalworking industry?
2. How should an environmentally sound and economically feasible model of fluid management services in metalworking be designed?

Fluid management services (FMS) are based on the idea that suppliers of chemicals are also involved in managing and maintaining the fluids in the use phase. An FMS can be a way for fluid users to collaborate with and allocate responsibility for fluid processes to the fluid supplier. If the suppliers then work in a lean way, they will supply the correct function at the correct time with minimal losses. Fluid malfunction, mainly due to quality

failures from metalworking fluids (MWFs) and cleaners can result in the increase of total material use, waste levels and process work. The aims of FMS and lean programs are aligned with aims for improvements in maintenance and material efficiency through continuous improvement work to reduce losses.

Process fluids have influence on several important environmental aspects. Production of chemicals in the fluids consumes scarce resources, fossil oil and energy. At the end-of-life fluids usually generate hazardous waste and emissions to water. Thus the process fluids account for large parts of the total environmental impact of a metalworking (MW) plant. Environmental goals have to be considered in the fluid management control (Ekengren et al. 2002). To manage the fluids efficiently and with continuous progress on environmental performance requires competence and good knowledge of equipment and hardware maintenance, data management and monitoring and control of process fluids.

In an industrial system, a holistic view of the chemicals and fluids is needed (Ekengren et al. 2002). Systematic process fluid management should take a plant-wide point of view on the process fluids used (Asmus 2007). Internal reuse of fluids and chemicals, or closed loop processes, is an aim in most industrial environmental programs and is incorporated in MW as one approach to reduce use of fluids and reduce hazardous waste. In practice, an FMS aiming at reducing usage and reduce waste volumes, requires functioning closed loop processes.

This study of FMS takes a practical approach to sustainable and efficient fluid management and is positioned within Product Service Systems theory. In particular, the research investigates how the shaping of economic and legal parameters of FMS affects health and environmental outcomes of FMS in business relations. The field has been overviewed by literature research on product service system (PSS) publications, FMS application, MW fluids, health and safety problems, environmental aspects and lean manufacturing. The participatory action research approach has been included in a multiple instrumental case study research design where environmental data, economic and maintenance data from the Volvo group have been used together with structured and semi-structured interviews and focus group discussions. Public environmental data has been used to compare performance of different fluid management in this research.

When comparing improvements in environmental performance of fluid management, it is important to determine what performance parameters are used and what influential factors that are changed in the set-up. In this study, Volvo's publicly reported figures – on the use of water, release of VOCs, and generation of hazardous waste – were investigated for ten plants with MW operations, of which five had internal FM and five had different types of outsourced FMS. The VOC data were not useful for the research since only solvents used in the paint shops significantly influence this figure and hazardous waste was difficult to compare due to differences in definitions and procedures.

Both internal management and FMS decrease process water use. FMS has improved this parameter almost a factor two as compared to internal FM. In addition to this, the use of chemicals should be monitored as a multi-dimensional vector. If a scalar indicator is needed, total hydrocarbon use or total costs of chemicals can be used as comparable units for different types of chemicals. Similarly, total cost of hazardous waste can be used for internal comparisons. A useful indicator of fluid management success on system level is the turnover rate or turnover time (TT), that is, *the average time it takes for a system to consume the same amount of chemicals, as it needs in initial fill.* To find the highest potential for improvement an Environmental Loss Model can be used. At most plants health and safety issues associated with fluid use are also monitored. In plants with good management of fluids, there are usually fewer self-reported symptoms, fewer fluid quality problems and fewer production stops.

There are several factors that affect the performance directly and indirectly (Kurdve 2008a). Some factors influence the environmental outcome directly, fluid technology (products and concept), fluid control, equipment design and closed loop solutions. All these can be targeted regardless of the business model. Figure 5-3 visualises a number of direct and indirect parameters influencing the final outcome.

Two main concepts for fluid system compatibility exist in MW: mixable fluids where cleaners and lubricants can be emulsified by the metalworking fluids and non-mixable fluids where the different fluids can be totally separated if mixed. The fluid-concept strategy needs to be included in the fluid management goals.

It has been found to be crucial to develop a list of standard fluids used in purchasing of equipment, which support maintenance and control. The design of fluid systems and equipment is not always optimal (Kurdve and Daghini 2009). Thus there is need for clear guidelines on how to design fluid systems in order to support fluid maintenance. The lifespan of fluids depends largely not only on equipment design, but also monitoring and control system. There is a need for research efforts and increased knowledge in the field of process control for fluids in the MW industry.

Recycling technologies and closed loops of process fluids are fairly well developed and different types of implementation have been seen for most types of fluids. Closing loops gives gains both in lower product usage and in lower waste and emissions. The obstacles are often that fluid suppliers are not involved in end-of-life and thus, in general, fluids are not designed for reconditioning.

The elements in the FMS contract that need to be considered in the set-up are visualised in Figure 5-4: scope (products/services), information and knowledge sharing, financial agreement and responsibility allocation.

To do a good selection of fluids, there is a need for increased knowledge transfer from the use phase of fluids to the development of fluids and back to fluid selection. Usually all cleaners, MWFs, fluid filters and rust protection and sometimes special fluids are included in the product-service scope. The services performed by the supplier should be the ones that the supplier can make more effective than in-house personnel. All fluid handling does not have to be included. Standardisation of fluids should be a goal in the contract. Also, process and fluid monitoring and control needs to be included and feedback to fluid development should be secured.

Small decisions in the production process control can largely influence the fluids. Monitoring data and consumption data should be available and used in controlling the fluids. The FMS supplier should take part in cross-functional fluid system development and work together with maintenance engineers, production engineers and industrial engineers. Fluids should be considered in daily and weekly improvement work for the MW processes. The cost of environmental management within the fluid management needs to be monitored and visualised, e.g., by an environmental loss model. The FMS where waste management is included has shown the largest improvements. This means that it is important to include the entire life cycle of the fluids. The results for different business models are not as clear except that they cannot be volume-based. Finally process, quality and environmental demands (such as recycling, hazardousness etc.) have to be secured in the FMS contract. Supplier cooperation is needed to develop from a process that uses consumable chemicals into a process that uses chemicals as a fluid asset.

The design of equipment needs to be aligned with the fluid concepts, which may be somewhat hindered by an FMS, but monitoring & control and fluid design seem to be equally important as equipment. There may be a need for an innovative business set-up solution to get more influence on equipment design. Also further research in the field of sustainable fluid management on monitoring and control is needed.

The results seem to be generally valid for large companies in the MW industry. Most of the results are probably applicable for other products as well, especially for consumables.

Practitioners working with fluid management and setting up FMS contracts can use the management guidelines developed during the research.

The fluid and service scope should entail all products in the processes outsourced and all services included in the full life cycle of those products. The knowledge and data management organisation has to support common continuous improvements. The business model has to change from a traditional volume-based approach and the responsibility allocation needs to ensure that the supplier takes responsibility for end-of-life and reuse/recycling implementation.

It is important to set up environmental targets and monitor the performance of the FMS contract. There are several factors that directly influence the environmental performance of the fluid processes. The connection between lean manufacturing and fluid management and the effects of introducing lean technologies on the environment could be further investigated, especially in the PSS context where substitution of a product with a service becomes a tool in reducing waste. Recycling technology and conceptual system design are important factors for reducing the environmental impact with a factor X (where X = 2-10) and for changing fluids from being process consumables into process parts that are continuously maintained.

The large group of readers that may benefit from this research is the practitioners of fluid management, purchasing and suppliers of FMS and managers in charge of the environmental and economic outcomes of FMS contracts. Also technical research on fluid management may gain some insights into practice and outcome of the fluid management regardless of the business model, especially in connection to continuous improvement work and collaboration with suppliers within a lean program.

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Paper II: Kurdve, M. (2008a). Chemical Management Services: Safeguarding Environmental Outcome. In S. Schaltegger, M. Bennett, R. Burritt & C. Jasch, *Environmental Management Accounting (EMA) as a Support for Cleaner Production* (209-229). Eco-efficiency in Industry and Science, Volume 24. Springer Science + Business Media B.V.

Paper III: Kurdve, M. & Daghini, L. (2009). Sustainable metalworking fluid systems: Best and common practice for metalworking fluid maintenance and system design in Swedish industry. *International Journal of Sustainable Manufacturing.* (submitted for publishing).

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Abbreviations and definitions

7QC	Seven Quality Control tools, a toolbox for statistical process control.
Chemical Leasing	A PSS where ownership of the fluid is not transferred to the user
CI	Continuous Improvements as defined in EMS, QMS and Lean system standards.
CMS	Chemical Management Services – A PSS where the products are chemicals
CO_2	Carbon dioxide, a gas released from combustion of hydrocarbons, gives global warming
CPS	Chemical Product Services – A PSS where the products are chemicals
CPU	Cost per unit, a financial model where the payment is based on the users' production index, usually number of produced parts.
EMAS	Eco Management and Audit Scheme, a standardised system for environmental management certification within the European Union.
EMS	Environmental Management System – A system for control of environmental risks and hazards
FM	Fluid management, handling and control of process fluids
FMEA	Frequency Mode Effect Analysis, a method for evaluation and prioritisation of risks.
FMS	Fluid management services – A PSS where the products are process fluids
HC	Hydrocarbons, organic substances that are often hazardous for environment and health
JIT	Just-in-time, Lean concept, "only the right amount at the right time" no more no less.
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
Loss	Unnecessary use of money, resources or time or unnecessary emission or generation of waste
Lubes	Lubricants – Oils or fats that help lubrication of moving parts
MRO	Maintenance Repair and Operations
MW	Metalworking – A process that forms or cuts metal into a desired shape
MWF	Metalworking Fluid – A process fluid aiding the MW process
NAP	Non-Automotive Purchasing, The Volvo Groups purchasing organisation for products and services that does not end up on the end-product.
PAR	Participatory Action Research

PSS	Product Service Systems – A system of a product and the service it fulfils for a customer/user
PVC	Processvätskecentrum, Swedish process fluid centre, a Swedish expert network for fluids used in metalworking industry
QMS	Quality Management System – A system for controlling quality risks and performance
Recycling	Reuse of the materials from a discarded product into new raw materials
Reduce	Reduction of amount of product needed
Reuse	Reuse of discarded product possibly after some reconditioning/refurbishing
S	Sulphur, acidifies when released into the environment.
SDS	Safety Data Sheet, compulsory information for safe handling of chemicals.
Six-sigma	Methodology and toolbox for securing and improving process performance
TPM	Total Productive Maintenance – Program for lean and efficient maintenance.
TT	Turnover time, the average time it takes for a system to use as much chemicals as is required in an initial fill
TW	Total Waste, the total amount of waste in weight (kg) from a plant or an operation.
VAC	Volvo Aero Corporations – produces components for the Aero industry
Waste	Physical rest material/products that do not fulfil desired function/quality anymore.
VCE	Volvo Construction Equipment – production of construction equipment vehicles
VOC	Volatile organic compounds, HCs that are easily emitted to air.
Volvo Group	A corporation producing heavy vehicles and machinery
VPS	Volvo Production System – A framework for Lean management in Volvo
VPT	Volvo Powertrain – Produces engines, transmissions and drive trains
VSM	Value Stream Map, analysis of a product along the main material streams.
VTEC	Volvo Technology – Volvo Group's development branch.

CHAPTER

ONE

1. Introduction

1.1 Problematisation

Modern societies to an increasing extent rely on production and use of chemicals. Together with useful outcomes, use of chemicals leads to continuous exploitation of resources and negative impacts on the environment. Chemical substances are often more scarce, more fossil-based and more hazardous than other materials used in the society. However chemicals play an important role in everyday life and provide daily services that are seen as essential for living.

Since the industrial revolution the number of different chemical products has exploded. Chemicals of some kind are needed in almost every industrial process. This situation has led to that users do not always know about the impacts of the chemicals, while producers may be partially unaware about how their chemicals are used. Product service systems (PSS) is a business model aiming to bridge this gap, suggesting producers to get involved in the use phase and increase awareness of the services provided by their chemical products.

Fluid management services (FMS) is a form of product service systems for chemicals. This thesis analyses FMS in metalworking industry and compares environmental and economic outcomes of fluid management (FM) run as FMS with traditionally in-house run FM. Important factors influencing the environmental outcome of FMS are investigated and lifted up to strategic PSS level. A product service system or, as it is also described, a functional contracting of products means that the payment is based on the provided service or function of the product rather than the number of products or volume of products purchased. This business design is aimed at taking away driving forces toward over-consumption and thus has a potential to lower material use and waste volumes. There are several terms for PSS for chemicals. Terms that are used in business and research include chemical management services (CMS) (Mont et al. 2006, Stoughton and Votta 2003), chemical product services (CPS) (Arslan et al. 2005), fluid management services (FMS) (Singhal 2003), functional contracting and chemical leasing (Jakl et al. 2004).

In this thesis the term fluid management service (FMS) will be used since it relates best to the scope of products and services that are used within the Volvo group, the researched company. The scope at Volvo usually includes specific fluids with particular functions that are outsourced to the FMS suppliers, while other chemicals (used in smaller volumes) may be managed in regular business models.

The service part of FMS is comprised of outsourcing services in manufacturing and FM. Since the set-up aims towards a more sustainable and environmentally adapted outcome, sustainable fluid management practice has been a major part of this research.

With environmental care as a corporate value, Volvo wants to ensure the environmental benefits from its outsourcing of FMS. Continuous Improvements (CI) in fluid management are expected not only in the FMS contracts, but also for non-FMS plants. This study analyses FM experiences and compares obstacles and benefits between in-house management and outsourced FMS within the Volvo Group.

Theoretically, the *alignment of economic incentives* together with the involvement of the producer in the use phase should give large environmental benefits from outsourcing fluid management in *functional contracts* or *PSS*, where payment is based on the function of the product rather than on ownership or consumed volume of the product (Reiskin et al. 2000). The gain should mainly come from a common incentive to minimise fluid usage, which in turn also results in less fluid waste. In some respect there may also be an incentive to reduce the hazardousness of products since the supplier personnel also has to handle the chemicals in the use phase and end-of-life phase.

So far research on FMS has mainly studied the business case for suppliers, even though there have been some case studies presenting economic improvements for customers achieved in outsourcing the fluid management to an FMS supplier (Stoughton and Votta 2003). However, there is a lack of case studies investigating and comparing cases where FMS has been implemented with cases where no such implementation was done. There is also a need to evaluate FMS from both an economic and environmental point of view in research of the actual outcome from function-based contracts compared to traditional volume-based contracts.

This research addresses the gap between the supplier's effort of providing FMS and the industrial user's need for such services. The focus is on investigating factors that influence the environmental outcome of chemical management and how these are taken care of in an FMS contract, especially how the shaping of economic and legal parameters affects environmental outcomes of the fluid management. The research assumption is that several important economic and legal parameters influence the business relation and that these have to be considered in FMS contracting.

1.2 Research questions

The desired outcome of this research is to be able to answer the question on how an environmentally and economically sound FMS can be supported in terms of organisational and contractual development.

Based on the problem with managing chemicals outlined above, the following research questions were formulated and investigated in this thesis:

1. What are the main factors influencing the environmental outcome of implementing fluid management services in metalworking industry?
2. How should an environmentally sound and economically feasible model of fluid management services in metalworking be designed?

The first research question goes beyond the general PSS theory and looks into the system of specific technical factors that will affect the environmental outcome of an FMS implementation in metalworking (MW) industry in order to see how the overarching physical, economic and sociological factors in turn will act on this system.

The second research question addresses practical issues that aim to aid professionals with how a successful FMS contract could be to set up and designed and which functions/fluids to select and include in an FMS; what services and responsibilities have to be included in an FMS and during what parts of the fluids life cycle etc.; how should process and quality demands, environmental demands (such as recycling, hazardousness etc.) and health and safety be secured in an FMS?

1.3 Scope of the study

FMS may be applied to several processes either where the chemicals are a part of the end-product, as in painting or gluing, or where the fluid is used in the production process. This study, however, looks mainly at fluid management of the fluids used in metalworking (MW) operations that are not intended to form a part of the final products but are rather used to supply a certain function in the MW process. In this study we concentrate on processing of cast raw material of iron, steel or aluminium, mainly by cutting, turning, milling, boring and grinding. The focus is mainly metalworking fluids (MWFs), cleaners and lubricants, in the metalworking part of Volvo, excluding surface treatment fluids or paint. The fluids are to a large extent reusable and do not have to be released to air or water.

The limitations to the research design are mainly the limited number of plants included in the study and, at some of these, the limited depth of the study. Of the ten plants included only five had FMS contracts and of these, two were only investigated in a comprehensive contract review. Also the research is limited to the years 2000-2008 when there was a general upturn of business in the MW industry. Implications to the result due to the limitations in research design are discussed in Chapter 6.2.

1.4 Intended audience

The intended readers of this thesis are mainly in two groups: researchers and practitioners. Researchers in the field of PSS may gain knowledge from real case comparisons with internal fluid management and, ultimately, input to further questions that need to be researched. Also technical research on fluid management may gain some insight in practice and outcome of the fluid management regardless of business model, especially in connection to continuous improvement work and collaboration with suppliers within a lean program.

The large group of readers that may benefit from this research is the practitioners of fluid management, purchasing and suppliers of FMS and managers in charge of the environmental and long-term economic outcome of FMS contracts.

1.5 Layout of the thesis

After the introduction, there is a theory chapter introducing the concepts of product service systems and specifically fluid management services. Subsequently, Chapter 3 describes briefly the different process fluids used in the metalworking industry and how fluid management in MW industry affects the environment. Finally conclusions from case studies on FMS from literature are summarised.

In Chapter 4 on materials and methods, the scientific paradigm and methodology used for the research are explained, the methods are listed and the researched company, Volvo, and the case studies at Volvo are introduced.

In the analysis of findings (Chapter 5), the research findings are structured in three sets of groups. First, performance monitoring of FM is analysed, the available general environmental performance indices are studied and more specific FM performance indicators are presented. Then, issues or factors affecting FM sustainability are analysed, and gaps and needs in current FM practice are addressed. Finally, the elements that may control these factors and environmental performance in an FMS contract are presented with some reported experiences from Volvo.

The analysis and results are discussed briefly in Chapter 6 together with the validity of the findings and possible generalisations to other areas. Finally, the main conclusions and suggestions for further research are outlined in Chapter 7.

CHAPTER

TWO

2. Product Service Systems

2.1 General theory around PSS

Product service systems (PSS) is put forward as one of the major ingredients in decoupling consumption of goods from economic development. While the consumer still receives the full service of the good, the producer retains ownership and can thus re-sell the service without having to produce additional product.

A "Product-Service System consists of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customers' needs" (Tukker and Tischner 2004, p. 18). To be sustainable and provide environmental performance benefits it should also be a system that is designed to strive "to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models" (Mont 2004, p. 77 and p. 116).

In addition, the set of responsibilities to secure quality, delivery etc. of the functionality and a model for the financial agreement including each of the products and services in the scope needs to be defined in each PSS (Toffel 2002). The PSS consists of a set of products and services with a set of responsibilities and financial models for each part. The combination of the elements may differ for different products, services and responsibilities within the same contract. This is further elaborated in Section 5.3.

When transforming traditional business to a PSS, sustainability may be gained through better efficiency in the life cycle of the product (Mont 2004, White et al. 1999). This eco-efficiency means lower exploitation of non-renewable materials, and lower amount of waste and emissions. Some literature sources expect PSS to add a factor of 2-3 improvement, which together with processes and product changes, as well as consumption changes, would result in factor 10 improvement of environmental performance. For a PSS comprising technology change in process, product and function this could give a long-term factor ten improvement potential on resource depletion as shown in Figure 2-1.

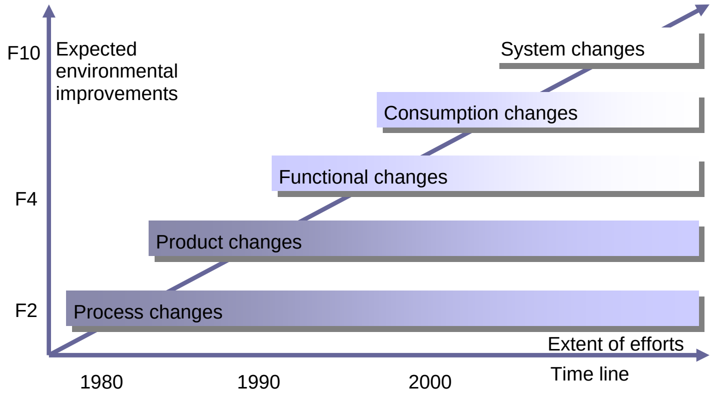

Figure 2-1 Eco-efficiency and sufficiency development steps[1]

If the PSS business model is based on functional results, there may be a factor X improvement potential for PSS (where X = 1-10), but then the PSS must include radical technology change (Tukker and Tischner 2004). If this is not the case, a PSS may give at most factor two and often only marginal improvement or even worsening.

In general, a PSS may deliver better knowledge of how the product should be used in the use phase (Toffel 2002, Votta 2003). Efficiency is assumed to increase due to a strong incentive shift when changing from selling per litre to selling a function and due to a knowledge gain by involving the supplier more in the use phase. The supplier is expected to have better expertise in how to optimally use the product (Toffel 2002). This should help the supplier to decouple profit from resource use. Since drivers to increase chemical use are overcome and knowledge is shared between supplier and user in a better way than in a traditional partnership, the product usage and environmental load should decrease (Votta 2003).

To achieve the efficiency gain, two assumptions have to be valid. The first assumption is that the incentive shift has to be strong enough. The second is that the supplier should have better expertise of the use phase than the user

[1] Elaborated from Brezet, Bijma et al. (2001)

(Toffel 2002). The latter can often be the case when the customer is a normal consumer with low use and maintenance knowledge or when the product-service use is not part of the customer's core business, but also if the product-service package includes special expertise or knowledge. A functional contracting type of PSS has the capability to increase efficiency by a strong incentive shift when use or disposal costs can be internalised to the supplier and when the products have significant reuse/recycling value in the end-of-life phase (White et al. 1999).

In some typical product-based cases, when lifetime of the product is greater than the average customer use period or when the product has a low utilisation rate (White et al. 1999), there is a potential efficiency gain by better utilisation of the product in a PSS than if ownership is transferred to the user. This is the case in carpools, pram leasing etc. When it comes to consumable goods, which are depleted continuously, the gain rather comes from overcoming overuse and minimise waste and emissions. In the best cases, there may be a technology shift turning the product into not being a consumable good anymore.

When designing the scope in a PSS to minimise environmental impact, one has to consider the full life cycle view – production phase, use phase and disposal phase (Mont 2004). In most products' life, the end-of-life is crucial and, particularly whether the products are reused, materials recycled, combusted with energy recovery or disposed to landfill. However, the biggest gain is achieved by the opportunity to use less and thus create less waste that is, to dispose less, especially for hazardous material.

2.2 Fluid Management Services

2.2.1 FMS – in the MW industry

Fluid Management Services (FMS) or as it is often called chemical management services (CMS) means that the suppliers of chemicals are also involved in managing and maintaining the fluids in the use phase. Sometimes, the end-of-life phase with wastewater management is also an integrated part of the FMS (Jakl et al. 2004). Usually one supplier is responsible for managing all the different fluids on a site, but the management may be restricted to some processes or fluids only.

The business models for FMS may be as traditional product and service purchasing, that is, the fluids are paid for according to the amount of chemicals used and services are paid for by man-hour. To be a PSS as it is described in this research the compensation should be decoupled from product volume (Mont 2004). The most common models in metalworking (MW) industry are fixed fee contracts or payment per produced unit in the MW operations. Often the models may be a combination of fixed fee, payment per produced unit, payment per hour or volume for extraordinary events and gratifications for savings. In some models the fixed fee is based on wastewater treatment costs rather than on chemical purchasing costs.

In normal producer-consumer relationships, the supplier tries to sell as much as possible, while the user in this case wants to use as little as possible. By changing the profit base, the supplier gets an incentive to work together with the user to decrease volumes.

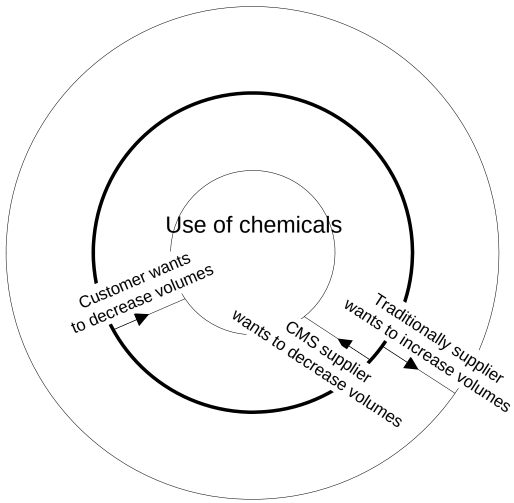

Figure 2-2 Aligning incentives with a CMS contract (Kurdve 2008a)

According to Joas and Schott (2004), consumables with high value (high tie up of capital) that can be reprocessed after use and are not diluted in emission/waste streams are suitable for FMS or "chemical leasing". This means that chemicals most appropriate for FMS are the chemicals that are not "consumed" either by evaporation, emission to wastewater or ending up as part of the final products; they should rather be possible to reuse and/or recycle and have a high value on the market. In spite of this, a chemical management approach is often applied in paint shops, where the chemicals are consumed onto the end-product. This is the case in Volvo, as well as, in other automotive or metalworking industry. Such cases are, however, out of the scope of this research.

It is clear from the theory that a total life cycle perspective is preferred if the environmental gains with FMS should take effect (Mont 2004, Jakl et al. 2004). As explained in the next section, one of the main environmental outcome parameters from FM is generation of wastewater and hazardous waste. Windsperger (2004) highlighted the importance of including the disposal phase in the business case around the service. The best ecological results were achieved by using either "Total care" where recycling of fluids is done on-site by the supplier, or "Client Operation" where the user recycles the fluids even though they are owned by the supplier. But also "Client Care", where the fluids are owned by the user, who recycles them without particular aid from the supplier, gives equivalent short-term ecological benefits, but not as much cooperation between supplier and user.

The gain of introducing FMS comes from overcoming overuse and minimising waste and emissions, but efficiency can also be gained by providing better maintenance, repair and recycling/remanufacturing of the products. This depends on whether the supplier has the capability to provide the fluid functions cheaper or more efficiently than the user company itself (Arslan et al. 2005). If the supplier can focus on the service the fluid delivers to the process better than the user can, then there is a potential gain.

2.2.2 Links to lean manufacturing

There are some important links between FM and lean manufacturing and Total Productive Maintenance (TPM) programs. Lean manufacturing programs aim at minimising unnecessary use of material, labour, equipment etc. mainly by focusing on shortening lead-time and thus identify losses in the processes (EPA 2003). Lean manufacturing programs are usually introduced internally in the manufacturing companies and then suppliers may be involved in due course. It is important to have a process view of the operative tasks and to acknowledge the needs of the internal and external customers. In a sense, lean manufacturing can make internal FM work almost like an outsourced FMS due to the focus on delivery from the fluid processes (lubrication, cooling, transport, cleaning, rust protection etc.) to the MW operations. An example of this is shown in Figure 2-3 where the MWF process with the delivery of MWF functionality to the main MW process is demonstrated.

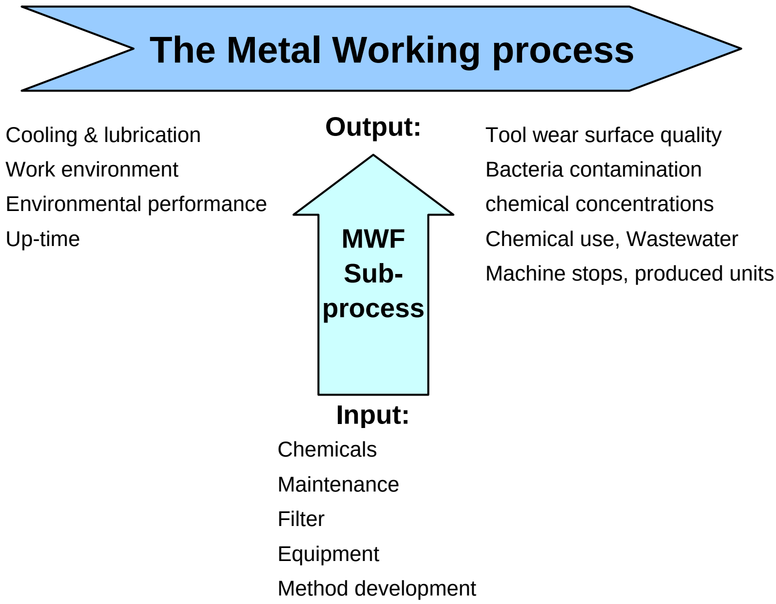

Figure 2-3 Example of fluid-service seen as process, MWF

Lean manufacturing aims to minimise the tie-up of capital in just-in-time (JIT) by supplying just the right amount at just the right time with minimum losses. In order to stabilise the core production, JIT applies the line-back principle where "problems" and non-value adding work are pushed as far from the main production line as possible. To do this efficiently, the suppliers have to be involved in "lean enterprise supply chain activities" (EPA 2003). An FMS can be a way to collaborate with, and push responsibility over fluid processes to, the supplier. If the suppliers then work in a lean way, they will supply the correct function at the correct time with minimal losses.

Both TPM and Lean programs aim for improvement gains in maintenance and material efficiency through continuous improvement (CI) programs or Kaizen programs. Six-sigma and statistical process control are toolboxes to help with the improvement work and stabilise the processes (Hines et al. 2008). These are widely used in automotive and MW industry. However no reported evidence of common use for FM in MW processes has been found in the literature. The aim of FMS and a lean program to reduce unnecessary use and unnecessary emissions are thus aligned and should go well together.

*Loss is **"anything other than the minimum amount of equipment, materials, parts, space, and worker's time which are absolutely necessary to add value to the product."***

- Shoichiro Toyoda, President, Toyota

2.2.3 Examples of FMS case studies in literature

The results from the FMS concept have been studied on several occasions. Reiskin et al. (2000) at the Tellus Institute have studied "servizising in the chemical supply chain" in automotive and electronics industries. They conclude that the most important reasons for un-optimal chemical management are due to "lack of management focus; lack of internal expertise; and conflicting buyer-supplier incentives". One way to overcome these is by externalising the chemicals in the process and to buy them as a service or function from an FMS supplier. Environmental accounting and chemical management statistics are used to design the FMS program at three sites in the electronics industry showing some positive development for lowering VOC and costs. The Tellus Institute also looked into GM's (General Motor) FMS program resulting in less diversity of chemicals and lower cost (Votta 2003). Most customers report short-term product cost savings and long-term management cost savings as well as lowering chemical volumes. The main barriers seem to be the cost accounting and chemical information management (Stoughton and Votta 2003).

There is a small body of literature that presents outcomes of real life cases and best practise in CMS. One of the sources of good case studies is the work of Chemical Strategies Partnership (CSP), an American consultancy company supporting and promoting CMS in the USA. CSP reports, for example, about a case of PPG Industries and Ford Motor Company that since 1988 has shown reduction in VOC (57%) and wastewater sludge (27%) per produced vehicle in a total fluid management partnership based on fixed cost per produced vehicle (CSP 2000a). Another contract from 1987 between Castrol and Navistar engines metalworking plant in Illinois shows a 90% reduction of wastewater and more than 50% reduction of chemical consumption in a fixed fee contract based on historic chemical consumption (CSP 2000b). Yet one contract between Cummings and Castrol reports the success from the Jamestown engine plant with lowered biocide use and improved work environment, as well as 50% economic savings in five years. These results were mainly due to the common cross-functional improvement work and the supplier involvement in Six-sigma activities (CSP 2007).

It is, however, important to recognise that the Tellus Institute and CSP do not report what non-FMS customers may achieve by organising the chemical management, with management focus securing internal expertise and information management, but without outsourcing the management to the chemical supplier.

In spite of the advantages with the FMS model and the favourable economic arguments to move to an FMS relationship with a supplier, at least two main barriers have been identified; *trust of the supplier* – users have been worried about losing control over processes and service functions, felt anxious over safety standards or have had difficulties in relying on only one supplier, and *poor cost allocation* – there have been cases where difficulties to unravel all costs in the FM have made it impossible to do changes in the business relations (Reiskin et al. 2000, Toffel 2002). Thus gains by introducing FMS have often been impossible to calculate.

The question to ask when considering these barriers is what set-up is needed to get the desired factor X improvement through "radical technology change" and turn the fluids from consumables into "liquid tools" or "liquid assets" (Tukker and Tischner 2004).

CHAPTER

THREE

3. Sustainable Fluid Management

3.1 Fluids used in Metalworking

Metalworking (MW) industry comprises different types of operations, such as a foundry or steel mill, plate rolling and sheet stamping, parts manufacturing, paint shops and assembly lines. The parts manufacturing or MW processes require large volumes of chemicals for washing, cooling and lubrication. Incoming metal parts often require initial and intermediate washing due to incompatibility of fluids in subsequent processes or due to inspections, intermediate assembly or other manual handling of metal parts. As other heavy industries, MW industry uses large amounts of lubricants, greases and oils mainly for hydraulic systems and lubrication of machinery. However, the largest volume of chemicals and hazardous materials stems from large amount of metalworking fluids (MWFs) that are used in metalworking operations.

In addition to the above-mentioned fluids, there may be several other fluids, such as quenching agents, coolants, rust-protectants, phosphating baths etc. used in a MW plant. These all have their specific service and management needs, but there are also big similarities in components of the fluids, necessary management knowledge and equipment used for maintenance.

Several chemical components are of the same kind in different fluids. Common components are oil, surfactants, biocides, rust protectants and pH-buffering agents. They all have some adverse effects on the environment. It has to be considered how these fluids mix and affect each other during use and end-of-life phases. The components are often hazardous to the environment, as well as to human health. They also require energy in the chemical production process and in many cases they are based on components originating from mineral oil (Skleros et al. 2008). The complexity of each fluid, and the fact that the fluids will affect each other, means that it is important to consider the industrial system as a whole, rather than to consider each operation and its fluid as a separate entity. In addition to this, the fluids will affect the energy use, machine breakdowns and quality output of the MW process. Energy demand factors, such as torque for engines/tools, temperature of washing, cooling demand etc. are affected to a large extent by the fluid systems. Fluid malfunction, mainly quality failures from MWFs and cleaners in their processes, can cause rejects and thus increase total material use and process work. Failing lubes can destroy equipment and be the reason for production stops.

3.2 Environmental aspects in fluid management

As mentioned earlier, the use of fluids within metalworking (MW) industry creates adverse impacts on the environment and human health. All operations and activities have their significant environmental aspects that in turn give an effect that may be monitored in environmental key performance indicators (KPIs). In the production of chemicals, scarce resources (e.g. mineral oil) and energy are depleted. The use phase creates risks of leakage into soil and water and gives rise to air emissions. Fluid aerosols significantly and adversely affect the health of operators as has been found in the Volvo case as well as elsewhere in the MW industry (Lillienberg 2008, Kurdve 2009). There are environmental risks of emissions to soil and ground water associated with storage piping and tanks. These are, for instance, addressed in Volvos environmental requirements for production plants. At the end-of-life, most of the fluids used in MW within Volvo as well as other MW industry in Sweden and worldwide are considered hazardous waste and have to be handled with care (Kurdve 2008b). Suitable methods for such handling have been discussed in the Swedish PVC (Processvätskecentrum) network workshops. Often, combustion in combination with special landfill is used as a last resort (Kurdve 2008b). Thus the process fluids account for large parts of several of the environmental KPIs monitored at MW plants. Some of the most important KPIs connected to FM are use of chemicals, process water use, VOC emission, energy use, health and environmental hazards and generation of hazardous waste and wastewater.

Environmental goals have to be considered in the fluid management control since the fluids account for large parts of the total environmental impact of a MW plant. Minimising fluid consumption is usually beneficial from both an environmental and economic point of view for the user. Regarding the shift to less emitting processes with less hazardous substances, this link is not always as clear. However, if all costs of environmental control measures and risk minimisation are taken into account it is easier to show economic benefits (Munkøe et al. 2006) than to prove environmental gains. Minimising environmental impacts from daily operations is usually economically beneficial if end-of-pipe solutions are avoided and lean pollution prevention strategies are implemented (EPA 2003).

Fluid consumption should be minimised, and the most important means to achieve this is by prolonging fluid bath lifespan (Skleros et al. 2008). Large improvements of both environmental and economic performance of the processes have been demonstrated trough better control (Ekengren et al. 2002). When bath changes are finally necessary, there may be opportunities for internal reuse after separation of contaminants and addition of consumed components. This requires a good specification of parameters to secure fluid quality. There may also exist opportunities for recycling of expensive components.

Environmental management and cleaner production systems usually include closed loop systems (Ekengren et al. 2002). Closed loop systems can be defined as a system where some or all of the output is used as input to the system. With this definition, closed loops are applicable both for internal and external reuse of fluids. Closing loops results both in less product usage and in lower waste and emissions.

The equipment and handling should be designed so that risks of leakage to soil and groundwater is minimised. The risk issues should be managed with continuously updated risk analyses/FMEA work. With standardisation of equipment and material both risk management and substitution are easier to perform.

In general, for all types of products, avoidance of waste generation and reuse of products is preferred. In addition to this, minimisation of toxicity of the products and their waste residues should be the aim. If waste is generated, material recycling is preferred before energy recovery disposal processes, while landfilling (or dumping in sea) should be a last resort option only (RREUSE 2006). In Figure 3-1 this is visualised as a stairway where the aim should be to go as high as possible.

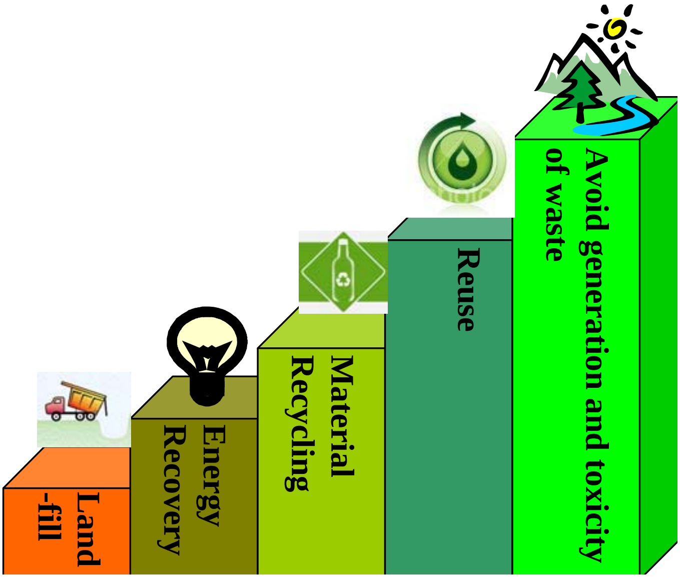

Figure 3-1 The five step stairway for waste management

Hazardous waste, the most important environmental aspect of fluids (Ekengren et al. 2002), is minimised by the same means as above, but also disposal techniques have to be considered. Landfill of metal swarfs with up to 25% fluid has to be avoided (Ekengren et al. 2002). The incineration of fluids and sludge give release of CO_2, other global warming gases and, sometimes, other emissions. Some common fluid components, like mineral oils or rust protectants that will give a large negative environmental impact if they are incinerated or disposed of in landfills need to be avoided.

Components that are too hazardous or that do not fit well with the rest of the fluid systems should be substituted with less hazardous and more compatible components (Helman 2007). This is a long-term development and should be part of the CI work with process fluids. Such work requires active collaboration with suppliers. Components that contribute to VOC and HC emissions through aerosols can be minimised by substitution with less volatile components.

To manage the fluids efficiently and with continuous progress on environmental performance requires competence and good knowledge of equipment and hardware maintenance, data management and monitoring and control of process fluids. In addition to taking the end-of-life aspects into consideration, knowledge of wastewater treatment processes is also needed.

3.3 System view of fluids and fluid concepts

In an industrial system a holistic view of the chemicals and fluids is needed (Ekengren et al. 2002). Large companies usually standardise requirements on chemicals and quality demands on the MW processes, prompting a need for standardising both fluids and their handling instructions. Some practice standards for fluid maintenance and selection of compatible fluids in MW can be found for example in the Institute of Advanced Manufacturing Science (IAMS), *Shop Guide to reduce the waste of MWFs,* as well as Society of Tribologists and Lubrication Engineers (STLE) standards or in German Technische Regeln für Gefahrstoffe (TRGS) and Verein Deutscher Ingenieure (VDI) standards (IAMS 1995a, IAMS 1995b, VDI 3397-2).

Economies of scale usually make it cost effective to standardise process demands so that the same type of fluid can be used in various operations of the same kind (Ekengren et al. 2002). Often, different cutting operations may use the same MWF emulsion and even be connected into a common fluid distribution system with distribution tanks and filters. Even when the fluid systems are not connected, the supply chain is more effective with fewer products.

Systematic process fluid management should take a plant-wide holistic point of view on the process fluids used (Asmus 2007). To lower costs, risks, contamination, emissions and waste while keeping functionality, it is important to see process fluids as a process – with ownership, continuous improvement etc. (Helman 2007).

Internal reuse of fluids and chemicals or closed loop processes is an aim in most industrial environmental programs. Closed loop processes are incorporated in MW as one approach to reduce use of fluids and reduce hazardous waste. Since this is the general aim of PSS for chemicals, it becomes a requirement for environmentally adapted FMS.

At a general level, a FMS in accordance with the PSS definition means aligning incentives to reduce usage and reduce waste volumes. In practice for process fluid management this means functioning closed loop processes (Ekengren et al. 2002).

CHAPTER

FOUR

4. Materials and Methods

This research investigates factors that influence environmental outcome of a fluid management system (FMS). In particular; the research investigates how the shaping of economic and legal parameters of FMS affects environmental outcomes of FMS in business relations. The different views of the supplier, providing chemical management services, and the industrial user, in need of these services, are addressed. The research assumption is that several important economic and legal parameters influence the outcome of the business relation and that they have to be considered in FMS contracting. The research investigates whether FMS works, how it works and why it works or not. It also addresses, on a more practical level how to set incentives for improved environmental (and financial) outcome, including what key performance indicators should be followed and what control parameters/ factors should be used to steer the FMS business to success.

4.1 Research design and paradigm

The research work includes both qualitative and quantitative approaches and aims to reach practical conclusions. The research has been aiming at solving a specific problem of a client, which makes it of applied nature (Easterby-Smith, Thorpe, & Lowe 1991). A main research output will be a practical framework and description of new organisational and contractual methods for development and implementation of fluid management service (FMS) contracts. The development of recommendations to customers and suppliers on how to overcome obstacles hindering a win-win relationship for managing process fluids has been supported by a case study. The important factors and key indicators to maintain a long-term contract ensuring sustainable process fluids management will be listed.

This study of FMS takes a practical approach to sustainable and efficient fluid management and is positioned within Product Service Systems theory. The research thus contributes to two different fields and helps fill the gap between them (Figure 4-1).

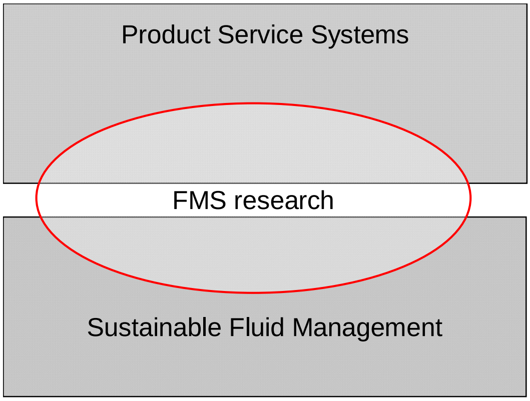

Figure 4-1 The FMS research field

An important element in this research has been participatory action research (PAR). The action research means an experimental approach where full-scale trials are made. In this case, this means that the researcher is part of the studied organisation and takes an active role in changing the reality that he/she studies. The changes have been in which parameters to monitor, as well as trial of different business models and managerial organisation.

Action research may give theoretical insight, but new theory formation is often hard. The road into PAR may be from research or from practice; in this case the researcher has practiced the field first and then started to research with literature reviews and theory studies before commencing with case studies and evaluation of trials.

The drawback of PAR is that the full scale experiments may negatively influence the researched company and thus not all possible actions will be tried out, only the one believed to be beneficial. There is a risk of non-objectivity built in stemming from studying phenomena and changing it at the same time; however cautiously used this may still give useful research results.

Research where the studied organisation is part of the research may be questioned in general. However since research goals and company goals are in line in this case – that is, to find the influential parameters and factors in FMS – it is not a real limitation in this research design.

The PAR approach has been included in a multiple instrumental case study research design where environmental data, economic and maintenance data have been used together with structured and semi-structured interviews and focus group discussions. The instrumental case study, which is within the realism scientific paradigm, was employed since the research deals with complex phenomena ("how" and "why" problems), and the audience and participants have multiple perceptions (Heally and Perry 2000), such as practitioners and colleagues in the researched field (Yin 1994). A case study research is particularly appropriate if the aim is to retain holistic and meaningful characteristics of events from real life (Yin 1994). Some of the results have further been discussed in industrial workshops within the Swedish process fluid centre in order to triangulate the results from literature research and the case studies as described further in Section 4.2.2.

To use a PAR methodology, that is taking part of and in some cases leading the development work, reduces some limitations of the traditional case study research; such as issues of confidentiality and lack of time and interest from the studied company. However, it also means that the research may become subjective in details and there is a need for some objective quantifiers, such as quantified data from environmental reporting etc.

In addition to quantitative data from reporting and databases, qualitative data from interviews and workshops with industry professionals have been used. Clarke and Dawson (1999, p. 55) point out: "While quantitative approaches at their best can show the attainment of the outcome, they rarely touch upon why and how the outcome occurs". On the other hand, the qualitative approach is inductive in its logic, where the researcher attempts to make sense of a situation without imposing pre-existing expectations on the setting (Clarke and Dawson 1999). The qualitative nature of large parts of the investigations has made it important to understand cultural context, avoid polarised explanations and in many cases take a multidimensional point of view in explanations (Silverman 1993). This may in some parts of this thesis be perceived as repetition. Although the basic common ground in these fields are natural science based knowledge, and much data thus has been of quantitative nature, the conclusions have been drawn in a mainly social science field and a qualitative approach has been needed to analyse the results and draw conclusions.

The pertinent factors have been researched in literature, as well as by interviewing environmental and chemical managers at automotive metalworking plants. There has been a discussion with different users of chemical management services, as well as with non-users (normal customers to chemical suppliers) to confirm the important factors influencing sustainable chemical management. Some of these factors have been implemented in FMS-contracts at Volvo resulting in a deeper analysis and ranking of the factors. A comparison between different contracting concepts was used to determine the outcome of business options at four Volvo plants worldwide. Finally different contracting concepts and their outcome at Volvo were investigated to find the do's and don'ts in FMS contracting.

4.2 Data collection methods and sources

4.2.1 Literature analysis

The field has been studied through a literature research on PSS publications, FMS application, metalworking (MW) fluids, Health and safety problems, Environmental aspects and Lean manufacturing. In addition, internal Volvo reports and research summaries have been used.

Environmental reporting figures are collected in two ways. Centrally decided parameters are collected from all plants in the Volvo group and reported to Volvo Group Headquarters for the annual report. Many of these parameters are published in *Volvo Group Environmental data*, published every year. These data are selected to describe the most important environmental aspects, as well as, based on reliability and comparability of the data. For example data on energy use, water use, air emissions and hazardous waste are published. In addition to these, most plants make their own local public environmental report containing additional data. These reports are more specific and contain, for example, volumes of different chemicals used and volumes of different fractions of waste and hazardous waste produced.

Volvo's global chemical purchasing team gathers supplier reports from key suppliers and from all FMS suppliers. The data contains volumes of chemicals per fluid type and supplier, number of different products and improvement suggestions for standardisation, performance improvements and process cost savings. These data are used for confidential evaluations of supplier performance on every site. In addition, user satisfaction is often measured. The evaluation is not done every year but rather every third year. The overall results of these evaluations are used in the research. Specific data is only available after signing a confidentiality agreement.

In the in-depth part of the case study, such as for the FMS pilot plant, additional data on volumes, cost and labour have been gathered from purchasing systems, maintenance systems, and lab reports on fluid measurements. This has been used in order to follow the performance of the plant with FMS pilot projects.

4.2.2 Collaboration with academia and research programs

Some of the studies contributing to the overall results have been performed by Masters students working in close cooperation with Volvo Technology (VTEC) and supervised by the author. These have all resulted in public M.Sc. theses and were selected to be completed by students in order to avoid personal relations with the researcher or due to geographical location. In addition to this, there have been contributions to research programs and expert networks as is explained hereafter.

Cleaning processes and their environmental impacts: how to standardise and recycle cleaners and lower energy use in cleaning were studied in a development study where in-house fluid management (FM) was used to see the environmental improvement potential. The input was partly from the overall FMS comparison where concepts used in FMS plants in France were combined and applied at a plant in Sweden. The study was conducted by Roya Asmus and is published in Asmus (2007).

In one case, a M.Sc. thesis was designed to investigate and evaluate the factors in the partnership between Volvo and the FMS supplier that lead to increased continuous improvement. Issues like trust, cooperation and the organisational needs were investigated for all the actors, including VTEC. Due to the nature of the investigated issues, it was preferable to have an outside student investigating and interviewing the actors who were employed at different levels within Volvo and at the FMS supplier. The study was conducted by Douglas Helman and is published in Helman (2007).

The third M.Sc. thesis was made in collaboration with a research program on "Green Production Systems" and has been used to develop and investigate a model of how to select environmental parameters and visualise the potential improvements in connection to Lean manufacturing. This entailed interviewing several environmental and lean experts within Volvo, including VTEC; which made it suitable to use outside investigators. The proposed model was tried in a case study at a MW plant on an assembly line. This research was made by Qui Xiaojin and Chen Xiaoxia and reported in Qui and Chen (2009). A future study will try it out also for a machining line.

VTEC has studied potential adverse effects of process fluids used within MW in collaboration with the Department of Occupational and Environmental Health at the University of Gothenburg; a wider group of people have been involved in this. Reported issues and effects of the actions at four Volvo MW plants in Sweden were included. The main results were presented at the Metal Cutting Research and Development Centre (MCR) yearly seminar 2009 (Kurdve 2009).

Important parts of the sustainable fluid management research have been done within a research project funded by the Swedish government in collaboration with PVC (**P**rocess**v**ätske**c**entrum), a Swedish expert network for fluids used in metalworking industry. There have been a number of different workshops and benchmark visits within the PVC network. The research has covered common industrial practice on management.

4.2.3 Interviews

A major source of information has been interviews and meetings with different actors within and outside the Volvo Group. The interviewees have been selected by purposeful sampling rather than random sampling, in order to get a sample "rich in information" with expertise in the area. Most interviews have been semi-structured, i.e. an open-ended questionnaire has been used, but the discussion has been allowed to stray away from the exact questions.

People involved in development activities regarding process fluids within the Volvo group were the interviewees. In addition to these, external people involved with development of Volvo process fluids (from suppliers and research institutes etc.) have been interviewed.

Initial interviews for the first paper included 6 internal interviewees working with FM at different plants and 6 supplier employees working with FM at Volvo plants or being in charge of FMS programs in the supplier company. The interviews were prepared by handing out an extensive survey with written open-ended questions. The interviews were conducted over telephone or during in-situ meetings. Additional open-ended telephone interviews with responsible persons of FMS suppliers and with the persons responsible for contracting in user organisations were done at all FMS sites during the contract evaluations that are conducted every 3 years.

Suppliers have been interviewed and participated in focus group discussions around recycling of fluids in the first student thesis project. Five open-ended interviews were conducted with the suppliers (Asmus 2007). Another student conducted interviews with different key actors at the plant and at the supplier to that plant. Semi-structured expert interviews were performed with 14 people, mainly from Volvo group companies. These interviewees were chosen due to their expertise within their field of activity; production, quality, management, environment, maintenance etc. (Helman 2007). Finally, in the third M.Sc. thesis, ten environment experts and six lean experts were interviewed in semi-structured telephone interviews with open-ended questions being sent to the interviewees in advance (Qiu and Chen 2009).

In addition to the deeper interviews, the results have been compared to other companies with similar operations within Sweden and to some extent Germany. Seminars and conferences with process fluid networks have been used as discussion forums for the issues raised.

In addition to the industrial workshops, there have been a number of different project meetings, steering committee meetings, follow-up/revision meetings and email and telephone interaction with the professionals in Volvo and at suppliers.

4.2.4 Focus group discussions and industrial workshops

Focus group discussions (FGD) and industrial workshops have been held internally, for plants and their suppliers, and within larger industrial expert networks. A focus group is a form of group interview where several participants discuss a well-defined topic guided by a moderator. This set-up allows the researcher to probe questions to a group of individuals and thus collectively construct a meaning around a real-life phenomenon (Healy and Perry 2000). Some of such discussions have been structured as focus groups; others have been more of regular meetings or industrial workshops.

Some of the interviews mentioned above regarding recycling of fluids turned out to become almost FGDs rather than interviews since they were semi-structured and the supplier had more than one expert in the topic participating in the interviews.

The researcher participated also in an industrial workshop at VKIS (Verbraucherkreis Industrieschmierstoffe) working group for recycling of fluids in metalworking with experts from eight MW companies in Germany in 2008.

One M.Sc. thesis involved formal focus group discussions regarding continuous improvement (CI) organisation around an FMS contract. The focus group including seven experts from within Volvo was used to conclude whether the proposed organisational change was applicable within the Volvo Group. Two other focus group meetings were held after the thesis was finalised: one with six purchasers in order to extend the applicability to other areas than chemicals and fluids and one together with the local FMS actors from Volvo and the supplier in order to specify the details around the organisation of CI in a supplier-user partnership.

Within PVC (Processvätskecentrum), there have been a number of different workshops within a research program funded by the Swedish government. One workshop with participants from five MW companies, two equipment suppliers and six fluid suppliers included a focus group discussion around end-of-life and recycling of fluids. At two other workshops monitoring and control and equipment design were discussed.

In addition to these workshops there have been annual fluid development meetings with each of the suppliers, with experts from Volvo discussing fluid development issues.

4.2.5 Case study: Volvo's organisation and VTEC's research role

The Volvo Group is a manufacturer of parts, engines, heavy vehicles and construction equipment. With over 60 plants in total, ten metalworking plants worldwide have been evaluated in this study. Further evaluation of the experience within four of the Swedish plants and other MW companies in Sweden has been performed together with PVC. One Swedish plant has been used as a pilot within Volvo to test and evaluate FMS models. The experiences are compared to FMS within Volvo in Brazil, the U.S., and France.

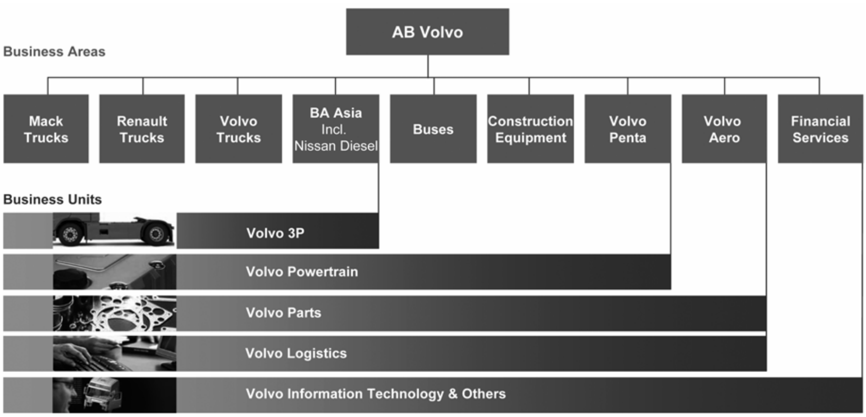

Figure 4-2 Organisational chart of the Volvo Group (Volvo 2009)

Volvo Technology (VTEC) is a research and development company within the Volvo Group (VTEC belongs to "others" in Figure 4-2). VTEC employs around 450 people, of whom 10-20% work with production process development in cross-functional groups. The Environment and Chemistry department comprises around 20 employees with expertise in health and safety assessment, life cycle assessment (LCA), process fluid development, chemical technology, simulation, sustainable production processes, environmental reporting, statistics, quality requirements monitoring & control etc.

The author is a member of one team working with ***sustainable and efficient production processes,*** and the research on FMS and development of process fluids in MW is reported to this team. Within this work, process fluid development for metalworking processes has been an important task including environmental, technical, economic and health & safety aspects of using process fluids.

VTEC collaborates with central purchasing, local environmental experts, local process development and suppliers. Global chemical purchasing within Non-Automotive Purchasing (NAP) is a centralised team belonging to Maintenance repair and operations (MRO) purchasing organisation organised under Volvo Business Services. Each plant belongs to a Business Area or Business Unit (BA/BU) who has its environmental organisation with environmental managers and environmental coordinators. This is described for one plant in Figure 4-3.

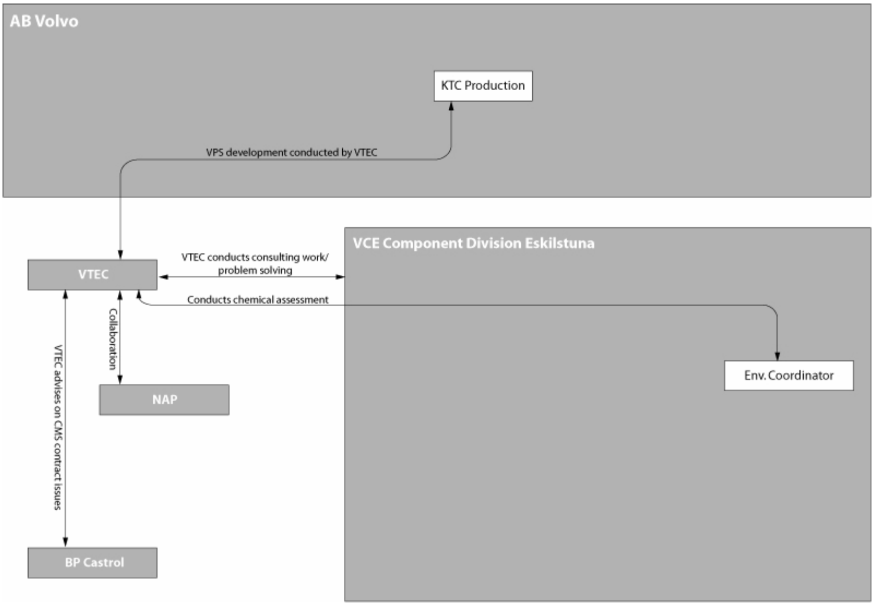

Figure 4-3 Example of organisational relationship for a plant (Helman 2007)

All Volvo group production units are required to achieve ISO14001 or EMAS (the European eco management and audit scheme) certification and maintain the certificate. This certification guarantees, to some extent, the quality of the environmental data used in this research. Every year all plants have to contribute with standardised environmental data to the corporate environmental reporting. This public data has been used to compare performance of different fluid management in this research.

Chemicals used within the Volvo group production plants have to be assessed and approved by central or local specialists with regards to health and safety as well as environmental risks. The baseline is a thorough health and environmental chemical risk assessment. The assessment is based on the suppliers' Safety Data Sheet (SDS), complemented with complete chemical composition information. Reference lists of chemical substances that may not be used (Volvo Black List) or should be avoided (Volvo Grey List) support the assessment process. For all Swedish plants personnel at VTEC Environment and Chemistry assesses the chemicals centrally.

All production facilities report a standardised set of environmental (and other) parameters to Volvo Group Headquarters yearly. The parameters are used to construct a common set of key performance indices used in the environmental reporting. With knowledge of the plants' chemical management there are possibilities to conduct plant comparisons on the standardised set of KPIs (Kurdve 2008a).

The performance of all outsourced contracts is reviewed by Volvo NAP's global chemical team (the group in charge of chemical purchasing) when contracts are revised, usually every 3 or 4 years. The same group also reviews the chemical companies' performance in traditional contracts. The author has worked together with NAP in these reviews.

The CMS/FMS Pilot

One Volvo plant in Sweden has been used as a pilot to continuously test the findings of the research. Thus this plant has been studied in detail when introducing function-based contracting and continuous improvement teams. The environmental and economic performance has been evaluated on a process level, together with the identified connections between different factors that will influence the outcome of the performance indicators.

Qualitative comparative investigations have been done when possible with other plants for different concepts. Student projects have been used for MWF studies, and one M.Sc. thesis was written on the cleaning process at a plant. Three internal Volvo projects have reported on the set-up of the FMS, on the outcome after three years and on comparisons with other FMS contracts. Key personnel have been interviewed in different parts of the studies and have participated in focus group workshops.

CHAPTER

FIVE

5. Analysis of Findings

5.1 Monitoring environmental performance of FM

The environmental aspects of metalworking (MW) and fluid management (FM) can be monitored by different means as discussed earlier in Section 3.2. Table 5-1 lists some of the measurements investigated.

Table 5-1 Main environmental aspects in MW

	processes & *subprocesses*									
Main aspects	Foundry	Machining	Cleaning of parts	*Fluid management*	Assembly	Paintshop	Inspection/test*	dimensions	**KPI**	**alternative KPI**
Energy	X	x	X	x	x	X	x	1	kWh/unit	kWh renew/kWh total
Waste	X	X	x		X	x		n	kg/unit	% kg/kg-produced
Haz. Waste	X	X	x	X		X		n	kg/unit	% kg/kg-produced
Water	X	x	X	X		X	x	1	m3/unit	
Waste water emmision	x	X	X	X		X		n	m3/unit	Turnover time
chemicals	X	X	x	X		X	x	n	kg/unit	kg HC/ unit
VOC	X			x		X	X	1	kg/unit	
Air emission	X					X	X	1	kg/unit	
Noise	X	X				x	x	1	dB	
Soil (risk)	X	X		x		X		n	# issues	
Effect on human health	X	X	x	X		X		1	lost days/ 1M work hour	
	x	**Significant aspects for process**								
	X	**Major significant aspects for process**								
		Scope of research								

Many of the adverse environmental impacts are monitored and reported in Volvo's environmental reporting. Volvo follows, and publicly reports, on the use of water, process water and energy, release of VOC, and generation of hazardous waste. These parameters, used in regular environmental reporting, are also subject to limitations in production permits etc. and are thus considered relevant as indicators of environmental results. Three of these parameters were investigated for ten plants with MW operations, of which five had internal FM and five had different types of outsourced FM (Kurdve 2008a). There were some obstacles for the analysis. For example, most plants had other fluid-using operations than MW such as assembly, welding and paint shops with different business models than for the process fluids used in MW. Reported VOC, for example, mainly originates from paint shops at plants with such operations. VOC trends may show some results, but in practice only solvents used in the paint shops significantly influence this figure. Thus, the VOC figure needed for the scope of this research was found to be undistinguishable from other VOC sources.

Hazardous waste generation is usually directly proportional to the use of hazardous material and should also be positively affected by substitution to less hazardous material; therefore it can be a suitable key performance indicator (KPI) for FM. Still there are difficulties in comparing absolute amounts of hazardous waste due to large differences in definitions of hazardous waste between plants across the world. The reporting of this figure has been found to change over time in the researched plants since the hazardous materials are diluted differently in the processes and, in general, more types of waste are classified as hazardous over time. It was shown that trends in hazardous waste volumes are often unclear due to legal re-definition of the hazardousness of waste (Kurdve 2006, Kurdve 2008a, Kurdve 2008b), but improvement trends from one year to another may still be useful.

The use of process water is commonly used as a relevant environmental performance indicator. It is affected by the use of water-miscible process fluids and is thus relevant to the environmental performance of the FM. It is easier to define and is thus easier to compare than hazardous waste. In most cases, decreased use of process water has been found to correlate well with good maintenance and long life of fluids.

Figure 5-1 below, as well as Figure 4 in Chapter 4 in Kurdve (2008a), shows the improvement rates for plants with FMS and internal FM. Since plants have different total number of operations, the plant level KPIs were indexed with the base year 2001 and graphs show improvement rate, rather than the absolute value. This allowed overcoming differences between plants in definitions and operations. Large improvements before 2001 cannot be seen in this way, but the year-to-year improvement rate for each parameter can be presented.

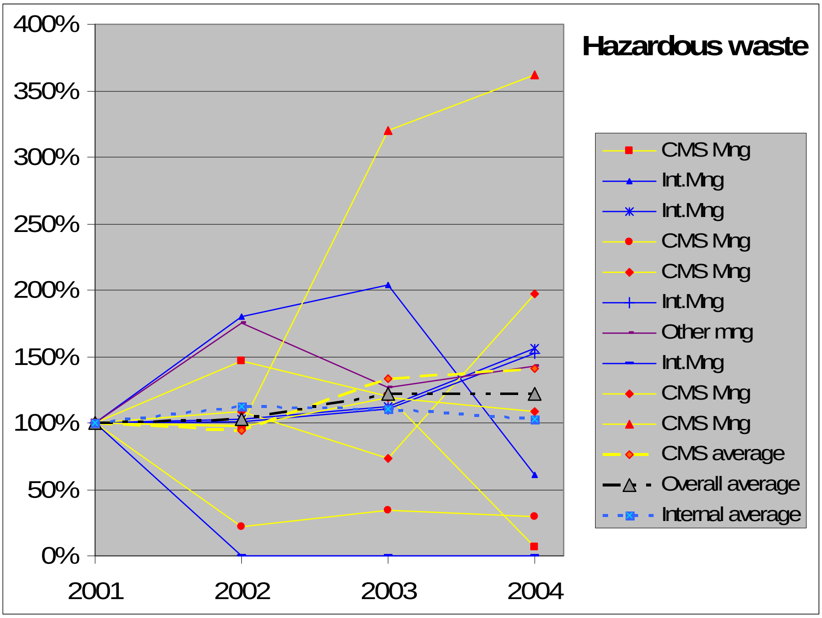

Figure 5-1 Hazardous waste performance (adapted from Kurdve and Mont, 2006)

As mentioned above, the results regarding the use of hazardous waste are unclear and improvements cannot be shown, since dilution and different definitions of hazardous waste increase the values. It is also clear from Figure 5-1 that variations for plants from one year to another are magnitudes larger than the difference between averages.

When looking at process water use, trends are clearer. This is shown in Figure 4 in Chapter 4 in Kurdve (2008a). Both internal management and FMS decrease process water use over the period 2001-2004. FMS has improved almost a factor two over internal FM. Water use will be further discussed in Section 5.3.4. Using publicly-reported figures on plant level provides weak numerical proof of success for the FMS business model. Although there are some limitations to comparing reported figures on plant level, the same parameters can be used for monitoring the follow-up activities, if they are monitored on process level. If **hazardous waste, process water use and emissions of VOC** are monitored separately **for the MW processes** in a plant, these indicators will be useful for showing performance of the FM.

In addition to aforementioned indicators, the amounts of wastewater, regular waste, and **use of chemicals** should be monitored. When it comes to amount of chemicals, this cannot be measured with a single figure; it is rather a **multi-dimensional vector** for each hazardous component. An example of how fluid volumes are used to monitor FMS performance is shown in Figure 5-2 for the fluid consumption per production unit for different types of fluids in the FMS pilot. MWFs and cleaners show a positive development, while cutting oils increase significantly. However, depending on the environmental goals, there may be some single components, such as some specific biocides or rust protecting agents that may be targeted and monitored as shown in Figure 5-2b, where biocide use was measured. The target substances triazin has been phased out, which has increased the morfoline use correspondingly and iodine butyl carbamate has decreased slightly during three years, when production increased. Hazardous waste can be monitored in a similar way for different types of waste. Some targeted types can be monitored in order to see improvements. Neither chemical use, nor waste by fraction is monitored in central environmental reporting, but in most of the investigated plants these figures have been available in local environmental reporting.

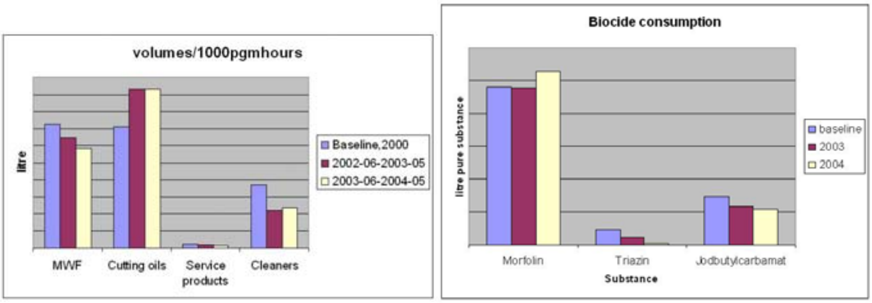

Figure 5-2 a) Monitoring fluid use and b) substance consumption

There are, however, some limitations if each fluid type is monitored only on overall plant level, since there are many different processes and some may demonstrate improvement, while others may show regress. It may therefore be difficult sometimes to use this data unless it is broken down to process and operation level. An additional problem is often that chemical concentration differs when changing products. Thus, this figure is only useful for comparisons between years and not when products have been changed.

One suggested parameter to be used as a more general KPI for chemical use is **total hydrocarbon** (HC). This parameter, commonly used in Ford Motor Company, accounts for the total volume of organic compounds used and, in practice, a figure of the total chemical volume used minus water content in each chemical is sufficient. One difficulty, however, is that although the numbers for calculation of chemical volumes and water content are available, they are recorded in different databases, making it difficult to manage this KPI efficiently. Also, this KPI does not differentiate between hazardous and non-hazardous organic compounds and if numbers are summed up to plant level, worsening and improvement in different operations and processes will be mixed up. However, if used for a single process and calculated for each change, this KPI can be used for monitoring the progress.

Total cost of chemicals is, and should be, followed and evaluated in every FM, whether it is outsourced or not. This economic parameter is often relevant also for environmental impact, since scarce and hazardous materials are usually more expensive, than common non-hazardous materials. Thus, **total costs of chemicals** often increase depending on scarceness and/or hazardousness. Therefore, costs may be a functioning indicator of environmental success. Similarly, the total cost of hazardous waste may be a functioning indicator comprising the different hazardous fractions that may be found in hazardous waste.

A useful indicator of fluid management success on system level is the turnover rate or **turnover time** (TT), i.e. *the average time it takes for a system to consume the same amount of chemicals as it needs in initial fill.* This gives an indication of how well the system is managed (and designed). This indicator should correlate with both process water use and chemical use. TT should be calculated as the total installed fluid system volume divided by consumption volume per year and this gives the turnover time in years (usually below 1). The consumption volume should include both top-ups, i.e. fluid that replaces drag-out fluid sticking to components or evaporation, as well as the entire change of fluid baths.

Most of the KPIs should be **monitored on a per-produced-unit** basis, since use and emissions should decrease if production decreases, in order to keep total environmental efficiency constant or improving. This is especially important when it comes to waste, since the weight of waste can be translated into material efficiency if one uses figures on number of produced units and weight of produced units as the index base (Kurdve 2008a). The material efficiency will be different for different types of operations, but if used as a KPI for each process or operation it can be used to trigger improvements and reduction of material waste.

Similarly, hazardous waste figures per produced mass unit can indicate improvement in reduction of use of hazardous materials. The latter may be somewhat difficult to use over time for fluid waste or wastewater, since dilution will affect the weight of fluid hazardous waste, but not the use of hazardous compounds. As mentioned, the **cost of hazardous waste** per produced unit is a recommended targeted KPI for FM. Also, for FMS some goals and targeted KPIs for waste have been suggested (Kurdve 2008b). Reduction of total waste (TW) and hazardous waste, reduction of waste to landfill and reduction of fossil-based material for incineration are all influenced by substitution and reduction of chemical consumption. Increase of material recycling and reduction of amount of material use not related to the product (TW/total material use) are more dependent on the system and maintenance.

It has been found difficult to compare different plants based on overall plant figures, since they contain different types of fluids and different operations. If figures are **broken down to operation level,** similar operations with similar equipment may be compared. When comparing figures on operation level it is important to acknowledge the differences in metal material in the produced product. Most components produced in the analysed plants are made of steel, cast iron or aluminium. It may be difficult to compare similar operations that are conducted for different materials. For example, it is usually much harder to clean fluids used with cast iron due to the graphite content, than fluids working with steel. The difficulty of comparing values for different plants may be overcome, if an indexing of the KPI is done with a start year and then the improvement of each parameter is measured year by year.

To evaluate the improvement potential, the research has also looked into connections between improvement work in environmental management in connection to continuous improvement (CI) in Lean Production program. An **Environmental Loss Model** can be used in order to evaluate different environmental impacts and the potential to improve the operations with regards to these impacts. The model takes up the performance of the significant aspects of a process in a value stream map (VSM) of the current situation, then a loss analysis is performed, a possible future state VSM is constructed and the performance of the aspects are calculated (Qiu and Chen 2009). To **evaluate the different aspects** shown in the loss model into one figure, LCA is used to weight them together. The performance of the full process and its potential improvements can be visualised in an easy way. After implementation, the real improvements are measured and a new current state is constructed. Even though the environmental loss model gives a good visualisation, the method needs further development in simplifying the identification of what aspects to include and simplification of how to resolve the identified environmental losses.

At most plants health and safety issues associated with fluids use are monitored. Lost days per million work hours and number of workers health cases are usually monitored and these numbers should be checked for all operators who are exposed to fluids and aerosols from fluids. Also annual surveys of operators' self-reported health issues have often been used within Volvo as an indicator to monitor the number of employees who experience lighter health symptoms. The **lighter health symptoms** were found to **correlate well with poor management of fluids** in Volvo. This is also an important indicator of productivity level (Kurdve 2009). In plants with good management of fluids, there are usually fewer self-reported symptoms, fewer fluid quality problems and fewer production stops. Although the surveys are not primarily made to evaluate the FM, they have been included in the FMS reviews and are a useful indicator for the overall performance. It is important to note that internally managed areas also greatly contribute to the work environment; ventilation, general work place order and adherence to safety instructions are equally or more important than the FM. However, these issues are also managed better at plants with a functioning structure for the FM with good communication at appropriate levels, well-functioning data management, ongoing continuous improvements, etc.

A concluding remark is that there are several performance indices to use for monitoring continuous improvement and comparisons of plants. These should be followed on process level and sometimes on fluid system level rather than on plant level. The following parameters have been researched:

<u>Multi-dimensional KPIs:</u>

- Waste & hazardous waste – Volumes of waste for each type
- Chemical use – Volumes used for each type of chemical
- Environmental loss analysis – Impact of each environmental aspect identified

<u>Single dimension KPIs:</u>

- Waste and Hazardous waste – Total cost of hazardous waste and waste respectively.
- Chemical use – Total HC and total cost of chemicals
- Process water use – Volume of process water used for the fluids

- Turnover time – Time of fluid use corresponding to initial fill volume. Correlates to chemical efficiency.
- Work environment – total number of complaints (usually /*million work hr* rather than /*produced unit*)

All of these are usually divided with the production index in order to get an environmental efficiency KPI per produced unit instead of environmental outcome KPI.

5.2 Influencing factors

When the performance parameters have been established, it is important to know what factors may influence this performance and what actions may be taken to support improvements. There are several factors that affect the performance directly and indirectly (Kurdve 2008a). Firstly, choice of fluids and fluid technology concept will of course greatly influence all factors. Recycling technology and equipment and system design will influence use, emissions and waste, as well as energy losses. Monitoring and control practice and maintenance will affect life span of the fluids and their functional effectiveness. All these factors can be targeted regardless of the business model.

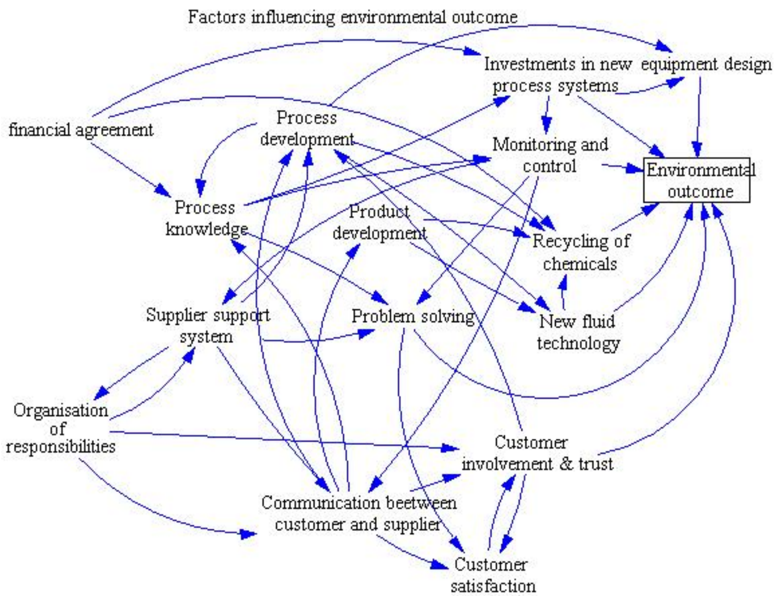

Figure 5-3 Factors influencing the environmental outcome (Kurdve 2008a)

Figure 5-3 visualises a number of direct and indirect parameters influencing the final outcome of the process as well as direct or indirect interactions. Several factors influence the environmental (and economic) outcome directly, fluid technology (products and concept), fluid control, equipment design and recycling/closed loop solutions. These have to be targeted with goals in the FMS partnership with secondary parameters – the factors we can control in the FMS set-up.

A radical technological change, needed in order to contribute to factor X improvements, may stem either from going towards dry machining or going towards a process, where fluids are not consumed and not emitted (Skleros et al. 2008). To achieve the latter, demands should be made at least to include closed loop and reuse of fluids, as well as to improve monitoring and control methods drastically. Fluids need to be designed for long life and reuse. In order to do this properly the equipment in which fluids are used needs to be considered. Cleaner technology for example should be chosen on the basis of fluids that are easy to filter and MWFs should be designed to fit the central system flows.

5.2.1 Fluid technology: products and concepts

The choice of fluid is a balance between not using persistent hazardous chemicals that may be emitted and the aim of getting a long life of fluids in use (Ekengren et al. 2002). When it comes to fossil-based oil, the development and also the price of mineral oil versus bio-based oil tend to push towards using more vegetable oils and less fossil products (Skleros et al. 2008). However, the life cycle impact of the additives also needs to be considered. As a secondary impact, the recyclability of the compounds, their volatility and tendency to be emitted, and their performance in incineration and landfill treatments have to be considered.

The study of standardisation and systematic process fluid management shows that two main concepts for fluid system compatibility exist:

1. **Mixable fluids**: lubricants, MWFs and cleaners are standardised and mixable with each other. The lubricants can be a concentrated form of MWF or the oil phase of the MWF. The cleaner can be either the same as MWF or the water-based phase of the MWF. This concept works best in cases where there is a large drag-over between fluids and large leakage of lubricants.

2. **Non-mixable fluids**: lubricants, MWFs and cleaners are standardised and are easy to separate in case of drag-over. The lubricants do not emulsify in the MWFs and cleaners are a different type of emulsifier system (if any), than MWFs. This concept works when leakages and drag-over is limited.

In reality we have both of these concepts side by side in the factory. Some cleaning may be done by MWFs while other cleaning operations use a very different type of cleaner. Some lubricants (that leak a lot) are compatible with the MWF oil phase, while others are totally non-emulsifiable.

To succeed with overall environmental goals, this research has found that inclusion of strategic fluid concepts in the fluid management is necessary. If FM is outsourced to an FMS supplier, the standardisation targets and concept strategies should be agreed on in advance.

Decrease of the number of different chemicals on each site has been targeted by purchasing in the FMS researched. Decreasing the number of chemicals facilitates follow-up on volume decrease and results in less risk of mistakes and thus lower risks for the environment and human health. Also, costs for handling risks decrease if fluids are the same or of similar type of hazardousness. Thus standardisation in concepts, as well as in different products within a plant, is advantageous and it decreases overall management cost, since each product needs to be included, and updated, in purchasing, maintenance, chemical management, health and safety programs, environmental management and quality systems.

Standardisation of fluids is needed not only to keep these concepts as clean as possible, but also to reduce the risks for the environment and health, since used chemicals are less complex, and less mixing of different components takes place. It also makes monitoring and control and logistics easier. Good knowledge of operations and equipment performance is needed in order to manage a functioning standardisation. It has been found that it is usually possible to give a specification of the fluid function or properties, rather than specify a brand or a particular fluid for each operation. Then, when all operations have been specified, one or two fluids of each type (cleaner, MWF, lube etc.) are chosen that satisfy the range of functions in all operations. Standardisation has been shown to cut handling costs and reduce human errors, and in the long-term lower equipment purchasing costs in Volvo. It has been crucial to use the list of standard fluids when purchasing equipment in order to keep fluid management in control. The new equipment has to function with the standard fluids. The standardisation is also a prerequisite for success in internal reuse.

Volvo has experiences from standardisation of lubricants and process fluids. These show possible monetary savings of 10-30% in chemical costs. In addition, savings in chemical assessment and risk management are essential. An opportunity to provide all fluids has been the driver for the supplier to standardise, while the users' main driving force has been to improve the effectiveness of maintenance. The economies of scale aided Volvo global chemical purchasing team, and environmental targets have been supported with increased recycling opportunities. Some counter forces have also been identified. For example, the supplier may want to market a certain product or try out a new product outside what is prescribed in the standard. On the other hand, the user may have special operational needs, and the machine design may not support any of the standard fluids. Often, the latter has its cause in poor specification and lack of knowledge of the user and the equipment supplier.

There are several factors that directly impact the economic and environmental effectiveness of fluid use in MW. Lifespan of fluids depends largely on equipment design, as well as monitoring and control (Kurdve and Daghini 2009). The lifespan affects waste amounts and chemical consumption. These factors also largely affect human health (Kurdve and Daghini 2009).

5.2.2 Monitoring and control

This study has also shown that the knowledge of control practice needs to be improved (Kurdve and Daghini 2009). Fluid monitoring and control using regular control theory has been found to be seldom used in MW industry. Implementation of statistical process control and use of control charts and variation trends are low in most MW FM. Even though 7QC tools and Six-sigma technology[2] are widely used in the automotive and MW industry, the implementation in fluid management has been low. FMS suppliers do not use statistical control, Six-sigma or variance control to any larger extent. However, in internally managed FM these tools are not used

[2] Six-sigma is a process quality control program including several tools to improve a process, 7QC tools are also process quality control tools that are commonly used in industry (Bergman and Klevsjö 2001).

very often either. Single attempts of using Six-sigma methods have been carried out within Volvo Group plants in Sweden and also at Volvo Cars in Sweden (Kurdve and Daghini 2009). The barriers for wider implementation are lack of knowledge among Six-sigma champions in chemistry and non-linear systems and the unclear economic saving potential of improving monitoring and control (Kurdve and Daghini 2009). Other companies (such as Ford Motor Company) report similar experiences (Kurdve and Daghini 2009). Control methods using trend curves are used in large systems in some automotive plants, but seldom in smaller systems (Kurdve and Daghini 2009). There is a need for research efforts in the field of multivariate process control for fluids in MW industry and **increased knowledge** of measuring, monitoring and control of fluids within the MW fluid management.

5.2.3 Equipment design

The design of fluid systems and equipment is not always optimal for extending fluid life (Kurdve and Daghini 2009). Thus there is need for clear **guidelines to equipment manufacturers** and internal industrial engineers on how to design fluid systems in order to support fluid maintenance. The equipment design in general practice in the researched companies has not adequately considered how to maintain long life of fluids.

If fluids are chosen conceptually to fit the machines in the process, internal reuse can be built into the infrastructure. Quality parameters should be specified in order to understand whether a fluid is fit to perform the function as needed. This may be difficult and usually a close collaboration with the supplier has been needed in the successful cases.

5.2.4 Recycling technology

The main way to improve the cost and environmental efficiency of FM is to close loops and prolong fluid life in those loops, i.e. to extend the chemicals' life in the systems (Kurdve 2008a, Kurdve and Daghini 2009, IAMS 1995, Skleros et al. 2008). This will cut costs of purchasing logistics, waste and even downtime. Closing loops gives gains both in lower product usage and in lower waste and emissions (Ekengren et al. 2002), but has to be designed into the FMS when setting the limits for what products, services and responsibilities are included and how the business model that pays out the efficiency gain is set up.

Within Volvo there have been successful examples of internal reuse of MWF oils and emulsions, cleaners and lubricants. The key to success has been standardisation of fluids, choice of fluids that are suitable for filtering and quality control, building up of a relation with the supplier and a simple infrastructure for collection and distribution of the fluid.

Recycling technology of the process fluids is fairly well developed and different types of implementation have been seen for most types of fluids. Some examples within Volvo are presented in Section 5.3.4. However, despite multiple examples, internal reuse is not the default choice when designing a fluid system or choosing fluid concepts. Closed loop systems are used for larger systems, but when the fluid fails, it is discarded, rather than reconditioned. The obstacles are often that fluid suppliers are not involved in end-of-life and thus, in general, fluids are not designed for reconditioning. There is a need to **increase involvement** and responsibility of the fluid suppliers for end-of-life stages.

Finally, there is a need for further implementation of reuse and component recycling technologies by giving responsibility and economic incentives to implement closed loops that reach into the suppliers' operations. Also, further solutions on how to succeed in knowledge transfer and solutions to how financial investments should take place need to be developed. This is further presented in Section 5.3.

5.3 The design of an environmentally sound and economically feasible model of FMS

An environmentally sound and economically feasible FMS ensures an industrial system with no waste fluids, internal recycling of all standard fluids and maximised use of standard fluids that satisfy the needs of a specific production. The standard fluids should be compatible with each other and contain as little hazardous material as possible. Therefore, there will be need for both substitution of new compounds as well as labour and processes for cleaning and renewing old chemicals. With the primary influencing factors summarised in Section 5.2 the next step is to explain the research results on the secondary factors, which influence the primary factors. Some important elements in the supplier-user partnership that have to be considered in the contract were introduced in Chapter 2: scope (products/services), information and knowledge sharing, financial agreement and responsibility allocation. These are visualised in Figure 5-4.

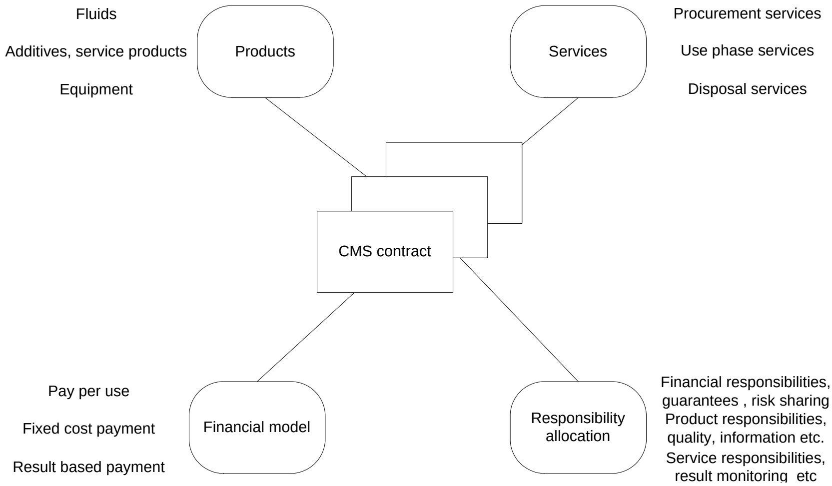

Figure 5-4 An FMS *set-up including scope, responsibility and financial model (Kurdve 2008a)*

5.3.1 Selection of scope of fluids and services

Firstly, to do a good selection of fluids, there is a need for increased knowledge transfer from the use phase of fluids to the development of fluids and back from the existing machines and equipment to fluid selection.

As mentioned above, it is important to have the right scope of the FMS contract. Within Volvo, the best result regarding the environmental performance has been when the FMS supplier takes care of the full life cycle, including wastewater management. Usually all cleaners, MWFs, fluid filters and rust protection fluids are included in the scope. Lubricants can be included for standardisation, conceptualisation and procurement; however, the actual lubrication work may often be hard to separate from regular professional maintenance. Any work included in an operator-driven "autonomous maintenance" should not be outsourced, since it increases operator knowledge about the process. If special fluids/processes (phosphating/quenching) are included, a higher knowledge about the processes is needed from the FMS supplier.

The services performed by the supplier should be (as in all outsourcing) the ones that the supplier can make more effective or could perform better than in-house personnel. All fluid handling does not have to be included. For example, it has been proven to be better to use production personnel for annual cleaning and regular filter cleaning, since it gives the operators a better understanding of the fluid system and how the production process affects it. However, since cleaning of systems is crucial (Kurdve and Daghini 2009) inspection and control of the cleaning before filling up fluid should be left to FMS supplier personnel. In a similar matter, all types of actions need to be listed and specified with regards to who performs them and who takes responsibility for monitoring.

An improvement potential that has been found in all plants in the study is that a systematic set-up of the fluid system concept has to be made by the user and FMS supplier together. When selecting the scope, all fluids that will affect each other should be included, other fluids that function separately can also possibly be included if this fits with the responsibility and function scope. The experience shows that there often is lack of a fluid strategy. For example, lubricants are often not matched with the MWFs, which they eventually will leak into. There is often a mismatch between the surfactant in the cleaners and in MWFs. In the industrial infrastructure the different fluids' design and how they affect each other should be planned and taken into account in equipment and machinery set-up as well. Standardisation of fluids should also be a goal in the contract. Odd products can successfully be replaced with fluids designed for long life and reuse in the industrial infrastructure. This has been found to be a common situation in all MW industry.

To succeed with a scope including closed loop systems requires the supplier to be able to specify separation and filtering equipment. Also, process and fluid monitoring and control is needed. Most plants aim to be proactive and regulate the process before the fluid is out of specification and has to be disposed of. To do this, they need to ask for development of trend analysis, control charts and multivariate analysis (as mentioned in Section 5.2) in the specification of the monitoring and control service. Quality specifications need to be set for the fluids and the responsibility for failures has to be clearly allocated. There should be two types of business mechanisms that manage the risks and the efficiency gain. The first model for managing the risks has to assign responsibility costs. The business model for managing the risks due to responsibility allocation has to be documented in the FMS-contract when setting the limits for what products, services and responsibilities are included. The second model for sharing efficiency gains has to be set up and documented in order to distribute costs for improvements and assign the economical gain.

To be efficient from an economic and environmental point of view, FMS needs to include end-of-life in the scope. As pointed out by Windsperger (2004), the biggest potential is if the FMS includes waste management. The results from Volvo, presented in Section 5.3.4 below, also point out that wastewater management is essential for the environmental success of an FMS contract.

Finally the scope of the contract needs to be set up to fit the main elements of the agreement: products, services, responsibilities, and finances. The various contracts researched sometimes include logical gaps and misunderstandings. The FMS design has to consider each of the functions delivered by every fluid, the services and responsibilities that need to be included, as well as what parts of the fluids' life cycles that need to be in focus.

5.3.2 Organising knowledge and information sharing

It is important to involve chemical product development in the full life cycle of chemicals and to **demand knowledge transfer** from the users and the disposal companies to the designers of fluids. To achieve the needed knowledge transfer, there is a need for user expertise to have time allocated to work with fluid specification, design and substitution work. It is also crucial that the supplier organisation is set up in a way so that the feedback is easily received by fluid developers and that in-practice experiences are used together with laboratory performance. Entering an FMS partnership should positively influence this knowledge transfer, but the exchange is not automatic; rather it has to be designed into the management and organisation of the FMS.

In long-term relations with a knowledgeable fluid supplier, feedback to fluid development should be secured. Closed loop and recycling concepts should be discussed with development engineers in both supplier and user companies. It is important that the FMS supplier has a process development department where these issues can be brought up. However, this is not always the case. The user company should also involve the process development department within the FMS supplier company in purchasing of new equipment.

The responsibility for system design and equipment design usually stays with the MW plant even when an FMS is implemented. The feedback from FM to equipment specification is usually slightly easier with an internal management of fluids than when another party, the FMS supplier, is involved. However, the specification of fluid systems when ordering equipment is often forgotten or disregarded also in internal FM. Thus, there is a need to establish cross-functional improvement teams on different levels. It is important to keep some fluid system expertise in-house, even when FM is outsourced and it is important to involve fluid expertise from the suppliers early in the specification process. In order to influence the system hardware design, there is a need for an organisational design in order to facilitate the communication between the FMS organisation and the responsible for industrial design from the user side.

The knowledge of how to monitor and control fluid parameters in FM has to increase in general in the MW industry according to the research. This expertise with knowledge of statistical process control and non-linear systems is hard to find and there is no easy answer as to whether suppliers or users are better at supplying this expertise. Thus, it is not possible to generalise about whether external or internal FMS is better in this respect, even though best practice on monitoring and control within Volvo has been found in internal FM. However, the monitoring and control and the data management for fluids need to be secured. It is important to not only monitor and store health and safety related fluid data, but also general fluid parameters that can be used for predictive control of the fluid and proactive actions. The experience is that this may often be poorly understood by both suppliers and user representatives and therefore forgotten or neglected in contracting.

It is also important to have clear communication of KPIs and influencing factors of the fluid management to production managers. Small decisions in production process control can largely influence the fluids. Information between the two parties needs to be open and clear. Also, problems with fluids can make a whole plant hazardous to work in and may affect production severely. Data on fluid state, production plan, maintenance plan and labour schedule should be readily available for both/all parties. Data management has proven to be crucial for building trust and establishing close cooperation, as well as for the continuous development work. Monitoring data and consumption data should be available and used in controlling the fluids. It is also important to secure the knowledge and expertise of the FMS personnel to make sure that they are capable of improving the operations under safe and sound conditions and of building trust between supplier and customer. Knowledge management should be included in the organisational set-up of a partnership.

Making sure that the entire cross communication will work, sets certain demands on trust between the partners. Trust is nothing that can be decided on, it is largely dependent on the individuals involved and on their relationship. However, there are certain facilitators for building trust. An **open information system** with all data that may be necessary for follow-up of the FMS performance and future planning should be in use. Also regular opportunities to **meet and communicate** in daily production meetings, improvement meetings and cross-functional development meetings are important (as demonstrated in this study). Finally, the **responsibility allocation and economic incentives have to be clearly stated** and communicated to everyone involved in the FM. If there exists issues open for individual interpretation or that are stated in contracts, but not communicated, trust will be jeopardised.

The above-mentioned factors will influence the environmental outcome of all types of fluid management. Some become easier to control in an FMS type agreement and others require somewhat more energy to obtain with an external party involved. To get benefits of the FMS partnership, there is a need to ensure participation by the supplier in improvement work within Lean programs (Helman 2007). The FMS supplier should take part in cross-functional fluid system development work together with maintenance engineers, production engineers and industrial engineers. Fluids should be considered in daily and weekly improvement work for the MW processes.

5.3.3 Responsibility allocation and economic incentives

To promote cooperation and trust, responsibility allocation has to be absolutely clear. The level of trust should be agreed upon, and trust needs to be stronger than in traditional businesses. Even small issues have been the cause of loss of trust and stagnation of continuous improvements in some FMS contracts in the Volvo case study. The responsibility of each implementation or investment should be connected to the resulting economic gain from that change and to the party performing the actual operation. Every single task is usually listed and the responsibility set. The list of responsibilities often changes during the course of an FMS contract and how this process works has been specified in the set-up of the contracts in this study. The aim of the responsibility allocation is to give the parties the correct span of control.

As stated, clear **responsibility allocation and economic incentives** are both important in order to build trust between the partners. If there are issues open for individual interpretation or that are stated in contracts, but not communicated, trust will go down. It will also distract energy and focus away from the improvement work.

Since the continuous improvement work relies on a close contact between the user and supplier company the organisational set-up of the participation in cross-functional teams need to be clearly stated and described in the FMS contract. In practice it has been proven that each function that takes part in FMS improvement work should have cross-functional meeting participation in their personal job description and the responsibility to send a substitute if needed. The cross-functional teams need to have access to performance data and tools for improvement work.

The business models used need to be specified and understood. It is seldom the case that only one business model is used. In most cases, fluids or services that fall out of the scope are purchased with traditional business models, based on price per litre of chemical and per hour of labour. Volvo has experience of FMS contracts with partly fixed prices, payment per produced unit and fixed price based on waste costs. Functional contracts where the fluids' actual function is paid for have not been tested, since the fluids have multiple functions that are hard to specify. Per-unit based payment is the closest to functional contracting. Often there is a fixed monthly price for labour, which is close to the pay per hour type of payment or is comparable to internal employment.

The cost of environmental management within the fluid management needs to be monitored and visualised e.g. by an environmental loss model. The value of environmental results should be included in the cost per unit or at least as a baseline demand similar to quality demands.

The responsibility for the end-of-life of the fluids should be allocated to the supplier. When aiming to go up the five step stair of waste management as shown in Figure 3-1, it is important to have incentives not only for lowering chemical cost, but also incentives for lowering waste costs (Kurdve 2008b). To avoid some types of hazardous material that are not wanted in recycling loops, substitution should be economically promoted (Kurdve 2008b). The process re-design may need substantial efforts. One way to reach a feasible economic and environmental solution may be to contract the supplier of chemicals to take part of the design and quality guarantee of the "regeneration process". It was also shown in this research that avoidance of combustion of fossil-based material is important (Kurdve 2008b).

5.3.4 Practical FMS contracting experiences

The most important success factor for environmental, as well as, long-term economic performance has in the Volvo case been to let responsibility for the whole life cycle be under the control of one actor. This seems to be more important than the CPU-based financial model. To be able to compare plant improvement trends over time, figures for water use per produced unit was indexed with the baseline in 2001 in Figures 5-5 to 5-7. When looking at process water use, the trends are clear: while internal management shows approximately constant water use per produced unit (Figure 5-5 and trend for internal FM in Figure 5-7), FMS demonstrates decrease of around 50% (Figure 5-6 and trend for FMS in Figure 5-7). FMS has improved almost a factor of two compared to internal FM (Figure 5-7). The FMS where waste management is included shows the largest reductions of water use (trend for FMS-WM in Figure 5-7). However, cost-per-unit based FMS does not show better performance than other FMS (trend for FMS-CPU in Figure 5-7).

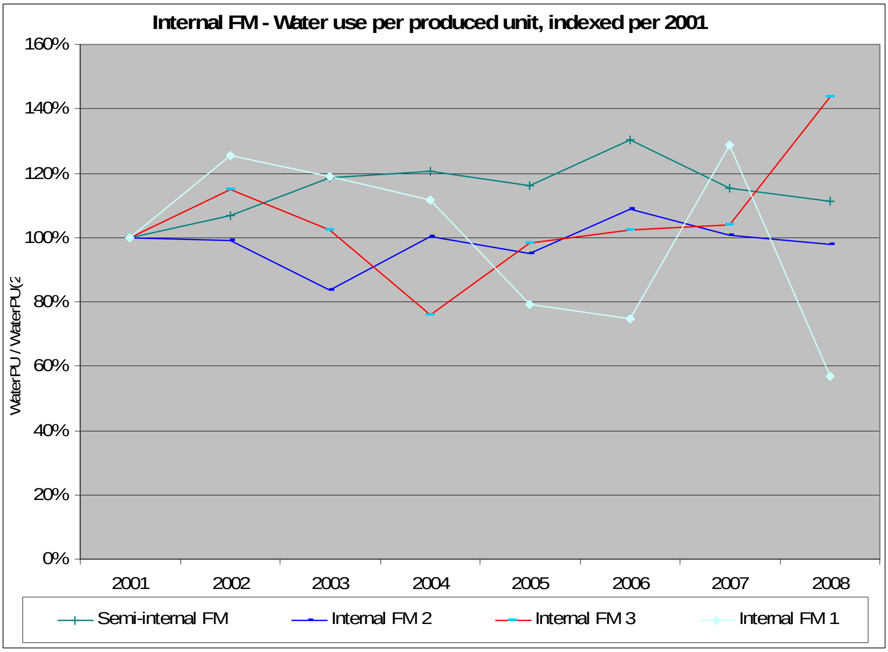

Figure 5-5 Water use at four plants with internal FM 2001-2008

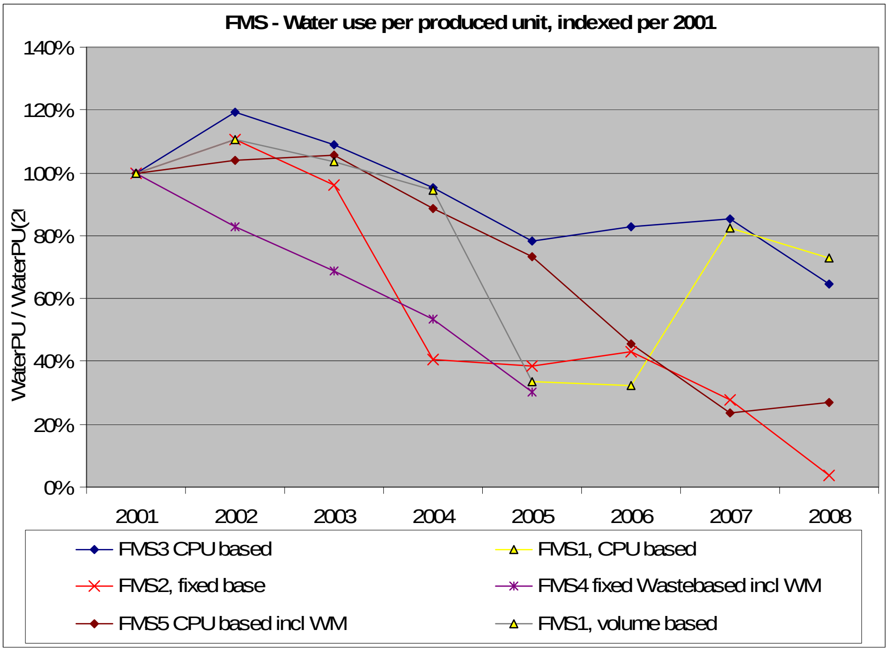

Figure 5-6 Water use at five plants with FMS 2001-2008

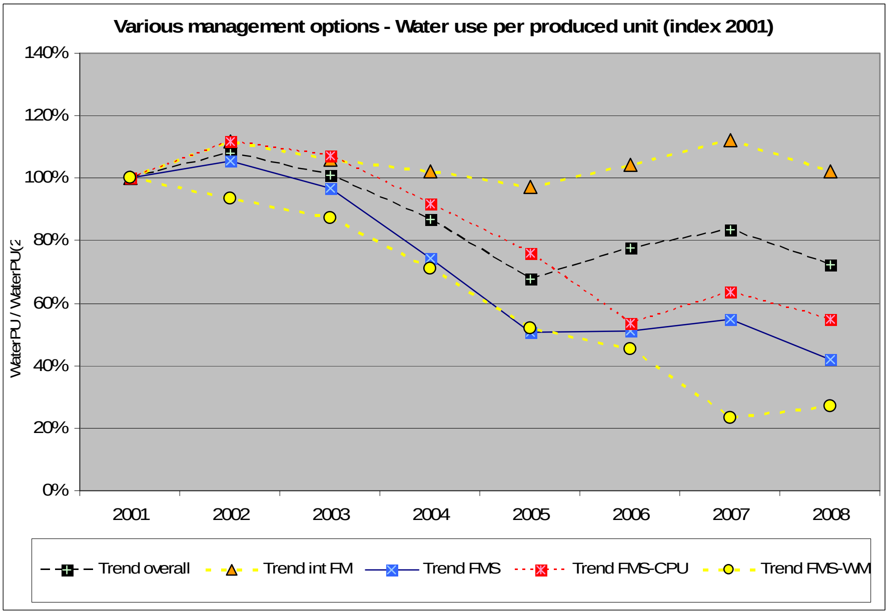

Figure 5-7 Water use related to management options main trends 2001-2008

In two of the five FMS contracts (FMS 4 and 5 in Figure 5-6), wastewater management is fully included. The proofs are weak considering that there are only few plants included in the study, which means low statistical significance. However, interviews with managers show higher satisfaction with the FMS supplier and the partnership if wastewater management is included. Also, holistic system understanding by supplier seems to benefit from this; internal reuse and external recycling solutions are a natural part of the FM operation in these plants. The detailed results shown by suppliers are good, even though the overall waste figures including all different operations in a plant are hard to evaluate. With common KPIs that can be broken down to each process the evaluation would have been easier. In Figure 5-8, an example from one of the plants (FMS 4 in Figure 5-6) shows the broken down waste figures for the MW process from the start in 1995 until 2004 giving a much clearer picture than the overall plant figure.

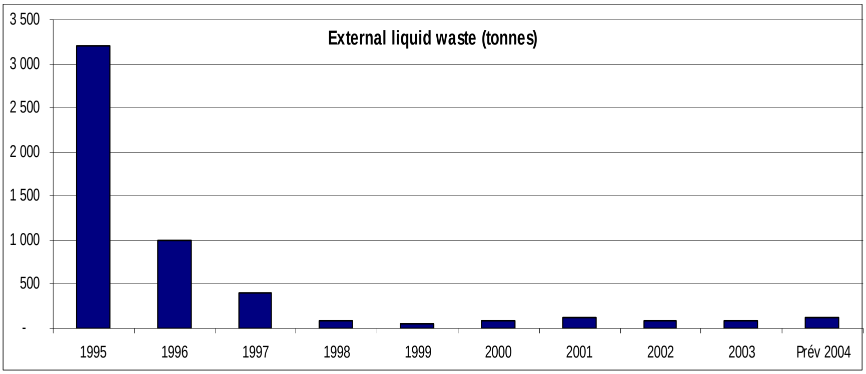

Figure 5-8 Liquid hazardous waste volumes in an FMS contract from 1995

It may be important to point out that this performance is not dependent on the supplier; the two FMS including waste management are contracted with different partners, both of which are involved in other contracts in the study.

The other experience is that a cost per litre contract in combination with outsourcing FM showed the worst performance of the FMS (FMS1 Figure 5-6) and customer satisfaction was low. Figure 5-9 shows that the volumes per produced unit for all fluid categories except cleaners increased from 2001 to 2004. In 2005 the contract was renegotiated with a cost per unit set-up instead.

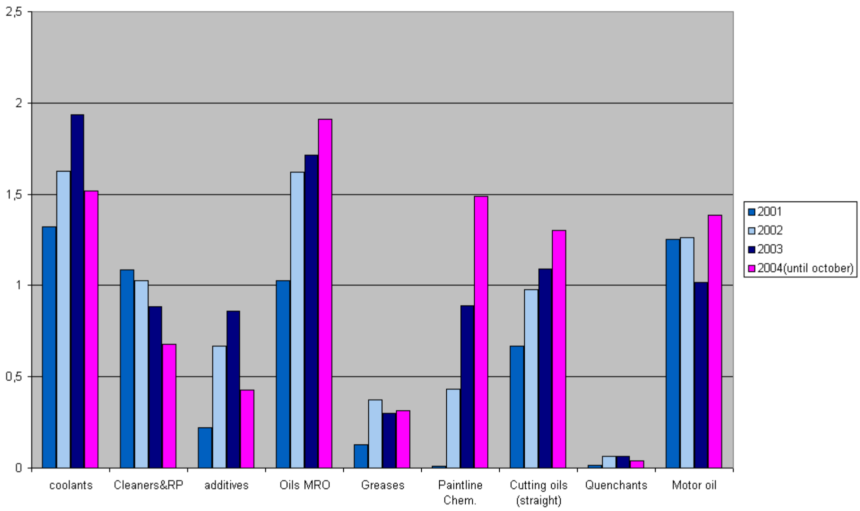

Figure 5-9 Fluid use in a cost per volume contract

There are no clear results when comparing fixed price models with CPU models. Customer managers are more satisfied with the risk sharing element in CPU contracts and the fact that the FMS expenses follow the income. However, large changes in production volumes have shown to be a source of worry and conflict in the CPU-based partnerships that may affect trust negatively. On the other hand, fixed price models have to be based on a proper total cost of ownership evaluation for the fluids. As mentioned, the best performance has been when this fixed price has been based on the main services of wastewater management and hazardous waste cost and then secondly-added, fluid maintenance and chemical purchasing costs.

Both the customer and supplier need proper organisation in order to develop a functioning continuous improvement in the FMS partnership. Correct organisation within the partnership is needed to efficiently deal with different issues on different levels. FMS personnel need to take part in daily meetings and improvement or operational development teams. Interviews with suppliers also suggest that the supplier organisation needs to have KPIs that are not volume-based. The interviews showed that this was often the major obstacle in setting up and maintaining a functioning organisation for FMS supply.

Process, quality and environmental demands (such as recycling, hazardousness etc.) have to be secured in the FMS contract. KPIs and level of detail in the monitoring of these have to be included in the contractual agreement between the partners. This is often forgotten and unclear statements on what KPIs that should be reported and how they are calculated have been cause of disagreement. Lack of trust and not getting the best performance out of the partnership has been the result in some cases.

Within Volvo, some different experiences of fluid concepts and recycling has been seen. Experience shows that there is technology for conceptual improvements available. In three FMS plants and one plant with internal FM, some different reuse solutions have been tried. The limitations of using these concepts at other sites are mainly financial obstacles and lack of continuous improvement work:

- Oil recycling: Straight oil (cutting oil) in machining is collected from chips, filtered and reused in machines with less demanding processes (stated in the contract).
- MWF reuse: MWF emulsions are standardised; Single machine's fluids are frequently changed. Instead of discharged, they are rather filtered and reconditioned (topped up) then reused in less demanding processes. This service has its own chapter in the contract.
- Cleaner reused as MWF: Some cleaning processes use the standardised MWF in intermediate cleaning process that is reused in the MWF central system when it gets too dirty to be used as a cleaner (this has been the case in FMS as well as in internal FM).
- Internal cleaner reuse: Cleaners are standardised and a simple emulsion-based low temperature cleaner is used in all cleaning operations; the cleaner is frequently discharged, filtered and topped up and then reused in operation with low chemical demand (the contract states discharged volume as the main KPI).

Experiences from the Volvo FMS pilot showed a need for contractual agreement on running of recycling equipment. The main obstacles for increasing and maintaining recycling practice were equipment costs, operation cycle-time demands and floor space. Other experiences from Volvo plants were that in volume-based contracts no recycling was done.

Another fluid concept tried is to use non-mixable oils and MWFs in order to keep each fluid easily controlled and make sure that contaminants may be cleaned out. Synthetic polymer-based MWFs have in a certain temperature range only a water phase, making it is easy to separate any oil from the system. These MWFs keep the material clean and intermediate cleaning may often be omitted.

In the contractual set-up it has been found to be successful to use a standard fluid list with a specification of each fluid function to be used in equipment purchasing. When any equipment is purchased it is specified that it has to use one of the fluids on the list. The list can also be used when there is need to renew contracts and ask other suppliers to compete with the current supplier.

FMS has mainly been considered when there has been lack of internal resources to take care of FM. However FMS can be considered also when the fluid systems are too small to fill up one employee position or if the supplier can provide the service much cheaper. From a business perspective, it has been found that a good approach is always to compare FMS calculated cost with internal fluid management costs.

Purchasing has followed the decrease in the number of different chemicals on each site. To decrease the number of chemicals is important for many reasons. The results show that progress in reducing the number of products is slow, but positive for FMS sites (decrease by one or two products per year) and slightly negative for most internally managed plants. Experiences show that optimally a MW plant should be able to go down to 1-2 fluids of each type of process; cutting, grinding, honing, cleaning and around 10 lubricants. To reach this a KPI has to be set at management level and included in the contractual goals.

Finally when going into a contracting procedure the following list has been used:

Steps in FMS contracting:

1. Profitability potential – Loss analysis of today's operations.
2. Gains by partnering – what are the: labour, knowledge, product, equipment gains?
3. Benefits with outsourcing – Does supplier have more efficient or cheaper labour?
4. Contract design – Goals, scope, responsibilities, and business model.
5. Organisational design – Organisation of customer and suppliers partnership.
6. Data management – What targets and KPI should be monitored?
7. Implementation plan – What steps to do and when?

CHAPTER

SIX

6. Discussion

6.1 Discussion of the results

As it has been shown in Chapter 5, fluid management service (FMS) alone does not automatically result in a fluid management with much lower environmental impact, but it is one enabler to get increased cooperation with the supplier. The supplier cooperation is needed to develop from a process that uses consumable chemicals into a process that uses chemicals as a fluid asset.

The main force in an FMS to reach cooperation between the user and the producer towards lower fluid use is the aligned economical motive. However, the basics of neoclassical economics that states that all actors; buyers and sellers, act for maximising profits is not providing a full picture, since the actors consist of individuals who have different possibilities to act towards economical optimum. The research points out two obstacles, lack of knowledge needed to know how to reach an optimal situation, and lack of organisational support to the actions needed. On the macro level there is also a link to the so-called rebound effect – the most important being that the user may make decisions that increase fluid use since there is no cost involved for the user anymore. Another indirect effect, working as a counterforce, is that the fluid providers often have lower product cost than internal fluid management (FM) in traditional business. Therefore, for an FMS supplier it may be easier or less costly to solve a process problem by adding fluid volume (or changing a bath) rather than using alternative measures. Both these counter forces will be reduced in strength if there is a strong proactive cooperation between the actors towards the common goal.

Also, in many supplier companies the top key performance indicators (KPIs) are still volume-based figures, explaining why the product service system (PSS) type business gets lower attention and less support by top management; FMS is thus not seen as the core business at all FMS suppliers. In those cases it may be more core business of the user than of the supplier to take care of FM. This may hinder further involvement of suppliers in the use and end-of-life phases.

Although the successful results of inclusion of the whole life cycle in the scope have been clear, the success of any particular business model has been harder to prove. Theoretically, a cost-per-unit contract should be closer to the ideal function-based contracts than fixed price, but in this study with only few cases it has been unclear if one model is superior to the other. The only clear result is that outsourcing FM to an FMS supplier but keeping supplier profit based on chemical volumes will not be beneficial in the long-term.

To include the disposal phase in the FMS scope may be done either by directly giving that responsibility to the service provider or by including the disposal company into the FMS partnership; however a three party partnership is always harder to set in place. In the long-term perspective, there is a need to have development of products considering their end-of-life. Design for reuse and design for recycling components should become the aim of the supplier.

Equipment design needs to be aligned with the fluid concepts and there is need to get a strong connection between fluid management, engineering and purchasing. An outsourced FM may actually hinder this, especially if top management believes they have outsourced the problems with fluids together with the fluid management. There is no simple resolution to the lack of proper machine fluid system design found in this study. Involvement by machine suppliers in the FMS would be the theoretical PSS answer. But if the equipment is more important than the fluid for the environmental impact should not the FMS be run by the equipment supplier instead of the chemical supplier? Besides, monitoring & control and fluid design seem to be equally important as equipment. There may be a need for innovative business set-up solutions to achieve the radical technology change needed.

Monitoring and control of the fluids in accordance with control theories should be positively influenced by introducing FMS, since the main problem seems to be lack of understanding of the non-linear and complex relation between the fluid parameters. These issues are, in general, better understood in the chemical industry. However increased knowledge of monitoring and control has not been seen in this study and the methods have not been implemented for process fluids. FMS suppliers adopting control theory and Six-sigma methods should have an advantage in attracting customers and profitability. This is a possible window of opportunity in the current FMS market. Further research in the field of sustainable fluid management on monitoring and control is needed.

Another area, evaluation of environmental performance of fluid management, is problematic due to the multi-dimensional nature of the performance indices. There is a need for further research on how to visualise the environmental performance and how to visualise environmental targets. Especially the connections between internal improvement work in Kaizen events or similar with regards to environmental performance need to be researched in order to find out how to best include them in the set-up of FMS-contracts.

In total productive maintenance the driving forces push towards using operator knowledge and experiences better. Operators, rather than someone else, should undertake regular simple maintenance tasks. At first glance this may be seen as a conflicting target to the outsourcing of FMS, but the operator support can be set up in an FMS as well as in internal FM. In this case, an FMS supplier may take responsibility and support with expertise, instructions and special investigations, while the daily operational fluid handling and maintenance stay in-house.

It is hard to quantitatively prove a positive impact of FMS on the environment. Thus the results concerning the importance of KPI monitoring on process level are valid, regardless of in-house or outsourced FM. A well functioning internal FM seems to have possibilities to perform almost as good as an FMS contract. However, for plants with lack of internal resources there are benefits with the FMS approach. In larger companies with many plants it seems like it is a good idea to keep at least one plant under internal FM in order to secure in-house knowledge for supplier management. On the other hand, FMS opens up for increased development and understanding with selected suppliers so there are definite advantages in outsourcing at least some FM. For smaller companies, where the chemical expertise may be an issue, FMS is more clearly beneficial for the customer. It may, however, be a challenge to get a scope or volume that is beneficial also for the supplier unless there are several small companies that can share the supplier service infrastructure.

In most cases the outcome seems to be positive but marginal for FMS contracts. This may be explained by limitations in the socio-technical landscape and regime (Tukker and Tischner 2004), e.g. the technical infrastructure and conservativeness in the business may limit the actions to *optimisation* within current framework. To reach further in *redesign* of the system into reusability of fluids the FMS supplier needs to take charge of the full life cycle to be able to offer the full reuse package that may give a factor two improvement. This is in line with actual results in the case study. If further improvements should be achieved a *system innovation* (Tukker and Tischner 2004) may be needed in order to get processes that demand less fluids, i.e. dry machining, clean processes with less demand of cleaners etc.

6.2 Validity of the results

Conclusions of this study are based on both quantitative and qualitative data, as well as the comparative analysis between different plants. The study has reached firm results with regards to the importance of the full life cycle approach in setting the PSS scope.

The results of this case study are presented in detail, but as always in case studies, the detailed results are only fully valid for the actual case. To get a more firm general view of this field, there is a need for more case studies from other companies and investigating and comparing process performance. This study only involved five FMS contracts; which were not all based on the functional contract or cost per unit (CPU) set-up. Furthermore, the performance outcome of the five FMS contracts may have been influenced by a number of parameters, e.g. market prices, geographical locations and difference in legal frameworks. However, interviews and surveys with experts and comparison with other companies in the MW industry support the overall results.

When it comes to the inclusion of the end-of-life phase in the FMS, the incidental evidence in wastewater figures and in the satisfaction of interviewees supports theories and previous case studies (Windsperger 2004). However, these plants were not surveyed in detail. The main pilot contract was planned to include wastewater management after three years in order to confirm the results, but for various reasons, it could not be done as a pure CPU contract within this research. During upcoming years it is recommended to follow up on wastewater volumes and recycling after wastewater management is included in the pilot FMS.

This research has been conducted during a long upturn period for automotive and MW industry. However, the situation has changed lately.

Monitoring and control will be even more difficult during downturn; with less drag-out and thus less continuous replacement of the fluids the degradation of the fluid will increase. This means that fluid costs may rise even though production decreases. Monitoring and control needs put a demand on the equipment to be designed for robust fluid control, but investment in new equipment is difficult now. On the other hand, maintenance of equipment is easier with more available maintenance windows, which increase the opportunity for standardisation and installing systems for internal recycling.

6.3 Generalisation of the results

The results seem to be generally valid for large companies in the MW industry, Volvo is not different in any of the researched parameters and in comparisons with other large companies the situation seems to be similar. SMEs however, are somewhat different and may have other business cases since they often lack knowledge and may need systems for chemical control and law compliance. Further research, covering SMEs and FMS, could be beneficial for the field.

The result that end-of-life phases needs to be included in a PSS, is probably generally applicable, especially for consumables, and follows the theoretical assumptions and studies performed in other areas. Waste management should be included in all PSS where material management is included, since there is no possibility for waste managers to work with reducing waste and internal reuse (the top of the stair in Figure 3-1) if this a separate service. Also some of the other results can be extended further to other products and services. Process knowledge, supplier goals and continuous improvement set-up are needed for long-term success of most outsourcing activities and are thus relevant for all product-service combinations working in business-to-business relations. It may not be suitable to do this as full PSS for all types of products and services due to the diversity of the industrial infrastructure, but there are definite gains to be won by breaking conflicting economic incentives and promoting knowledge exchange, continuous improvements and trust in the supplier-user partnership.

The results are most applicable to consumed products that are not part of the end-products since the business case for introducing a PSS is best if there are possibilities for reuse and reduction of usage. If the products form a part of the end-product that is essential for the end-customer, the end-of-life phase becomes more problematic. If it is a separable part, such as a battery that may be collected and reprocessed, most parts of the results of this study may still be applicable. If the chemical product is a dispersed part of the main product, e.g. paints, the results are only applicable for the non-value adding part. For example, the supplier may be involved in minimising process waste and overuse, but may not be able to influence design of the main product and thus responsibilities should to a higher degree remain with the user company.

This can be generalised and reformulated as an important conclusion. The responsibility for the end-customer value-adding part of the products and services included in a PSS should remain with the company that sells and designs the end-products, while the responsibilities of non-value adding part of product and services is best handled by the supplier company. The non-value adding part of the product use is the potential gain that can be targeted in changing business model to a functional based PSS. The same non-value adding products and processes are also targeted as losses in lean manufacturing.

Energy management services have many of the same needs as FMS with regards to the partnership but the picture is simplified by the fact that there is usually no emissions or waste in the use phase except for unnecessary loss of energy as heat emission. However, equipment impact is even worse than for fluids and thus the question of who to turn to gets more problematic. The energy provider may not have the possibility or capacity to influence machine and equipment design and technology. In that case the energy management may rather be a parameter in a PSS contract of leasing machines including energy and fluid consumption. It may be hard to facilitate the large amount of contracts needed for a whole MW production site though. Possibly it would work for "facility heating management" or another more specified process describing the actual need.

Although this research has been specifically applied on MW industry, FMS-business and process fluids, the conclusions drawn are widely applicable in other industries, businesses and products. The main conclusions may be applied to a large context of consumables if they are transferred into product service systems.

CHAPTER

SEVEN

7. Conclusions

7.1 Main findings

Fluid management is the source of a large part of the environmental impact from metalworking processes. There is a gap in traditional business between the user incentive to minimise chemical use and the supplier profitability in increasing sale of chemicals. Fluid management service (FMS) is expected to influence environmental impacts by the common goal to reduce chemical volumes used in production. The suppliers' change of incentive will result in less depletion of resources, less energy use in production of chemicals and less waste of chemicals. According to product service system (PSS) literature the achievement is dependent on the supplier knowledge of the use phase and an organisational set-up that supports the change in economic incentive.

The research questions of this study involved studying the factors influencing environmental performance of fluid management in the metalworking industry and how the elements in a model for FMS contracts can be constructed.

It is important to set up environmental targets and monitor the performance of the FMS contract. Suitable key performance indicators (KPIs) are process water use, Turn-over Time (TT), Total hydrocarbons (HC) and volumes of targeted substances. In addition, waste, wastewater and hazardous waste volumes as well as chemical consumption should be monitored. The latter figures are multi-dimensional vectors. The preferred level of detail should be that KPIs are broken down to the process level. The costs for each of these should also be monitored for each process/operation.

There are several factors that directly influence the environmental performance of the fluid processes. The concepts implemented in the fluid technology and recycling technology are important as well as the design of the equipment and strategies when investing in new equipment. Also the monitoring and control technology is important for the everyday environmental performance

Internal reuse and extending lifetime of fluids needs to be targeted separately. There is a need for clear quality demands on the fluids in order to know when a fluid is out of specification. Without a clear usability specification, it is impossible to extend lifetime or reuse. There has often been confusion on the specified parameters and how they are monitored (Kurdve and Daghini 2009).

In order to include the full life cycle and achieve the technology change that makes the fluids durable, some additional components are needed; *Standardisation* and minimisation of the number of different chemical products used in a plant is a necessary enabler for practical implementation of internal reuse and recycling. *Monitoring and control* practice generally could be improved and there is a need for further knowledge in this area. The d*esign of equipment* is important to prolong fluid life. This is something that is not automatically resolved by having a PSS with the fluid supplier. It may be resolved by introducing more specific industry equipment design standards or by collaborating with equipment suppliers in the FMS.

This research of the actual outcomes of FMS contracts in the Volvo Group shows that one of the axioms – that the supplier should have better knowledge of how to properly use the products – is not always true. Process knowledge is something that has to be built up in the partnership together with the customer. The customer and supplier can reach a higher level of knowledge together, but the **knowledge management** has to be organised properly to take place. How an optimal organisation for knowledge building should be set up needs further research, although a good starting point is described in Helman's M.Sc. thesis (Helman 2007).

In metalworking (MW) industry the supplier should take an active part in lean production and **continuous improvements** on all levels. A common view of minimising losses in time, material, labour and capital utilisation is needed. There is need for further research of Lean production in connection to sustainable production for process fluids. The trust between actors is also an important factor to take into account for setting up, organisation, responsibility allocation, data management and the business model. It is a necessary enabler for the efficiency gain to take place.

The most obvious results in the study are that the provider of FMS should get **responsibility of the entire life cycle** of the chemical products and the **business model** cannot be based on volumes of chemicals used. For FMS, it is crucial to have a process perspective and include the end-of-life in the scope. Reuse and recycling technology has to be incorporated in the product concepts and investments in equipment for recycling incorporated into the business model. To get an outstanding result of a PSS for fluids with a factor X improvement, there is need for **radical technology changes** to occur. This change should target non-value-adding product use. To give large enough environmental impact, the change should turn the fluids from being consumable goods into durable goods. This mean introducing closed loop processes, internal reuse and material recycling in every step of the processes. In the long-term perspective, there is need to have close development contacts with the operations within end-of-life to make sure that the products are designed to be easy to take care of and to put targets on lowering waste and wastewater. Design for reuse and design for recycling components should become the aim of the supplier.

7.2 Contribution to research fields

This research's main contribution is in the field of product service systems (PSS). It has provided the field with a real case pointing out the importance of a full life cycle approach in setting the scope of a PSS and the importance of continuous improvement, responsibility allocation in organising and contracting of PSS between businesses. It has also shown the important environmental KPIs in performance monitoring when it comes to chemical PSS and what factors that may influence the environmental outcome.

In addition to the results in the PSS field there have been findings contributing to sustainable fluid management and lean manufacturing fields.

The importance of monitoring & control and equipment design in the environmental performance of metalworking industry has been shown in the study. Recycling technology and conceptual system design are important factors for reducing environmental impact with a factor X and for changing fluids from being process consumables into process parts that are continuously maintained.

The importance of organising continuous improvements together with the suppliers and of visualising the environmental performance and potential loss reduction has been shown and the tools and obstacles in doing this have been examined.

The frameworks developed during the research can be used by practitioners working with fluid management and setting up FMS contracts. It can also be useful for managers who are responsible for follow up of fluid management performance.

7.3 Further research

Some important questions have emerged from the results of the research. One of the most important influencing factors, equipment design, is not well addressed in the FMS business model. The question of how to involve equipment manufacturers and give incentives to design equipment that support the FMS goals needs further investigation.

Another issue that has become more important in recent development is the connection between lean manufacturing and fluid management and the effects of introducing lean technologies on the environment. The PSS supplier involvement in continuous improvement within the customer company as well as the environmental strategies within a lean program in general needs more research.

The most suitable business model for FMS contracts can be further investigated. While it is clear that the business model has to change from the traditional volume-based, there may still be further research on what business models that are possible and which one works best in practice.

References

Arslan, L., Bernhard, R., Kytmanova, M., Morotz, A. & Timoshyna, A. (2005). *Assessment of Environmental and Economic Potentials of Chemical product services in Automotive and Electronic industry*. EU EPCEM research report 2005/2.

Asmus, R. (2007). *Miljöanpassad avfettning av transmissionsdetaljer*. Master thesis Göteborg University Environmental Science Program.

Bergman, B. & Klefsjö, B. (2001). *Kvalitet från behov till användning*. Lund, Sweden: Studentlitteratur.

Clarke, A. & Dawson, R. (1999). *Evaluation Research. An Introduction to Principles, Methods and Practice*. Thousand Oaks: SAGE Publications.

CSP. (2000a). *Case Study: Ford Taurus, Chemical Strategies Partnership*. [Online]. Available: http://www.chemicalstrategies.org/pdfs/Ford%20Case%20Study.pdf [25 October 2009].

CSP. (2000b). *Case Study: Navistar, Chemical Strategies Partnership*. [Online]. Available: http://www.chemicalstrategies.org/pdf/case_studies/Navistar_Case%20Study.pdf [25 October 2009].

CSP. (2007). *Case Study: Cummins, Chemical Strategies Partnership*. [Online]. Available: http://www.chemicalstrategies.org/pdf/case_studies/Cummins_Sept07.pdf [25 October 2009].

Easterby-Smith, M., Thorpe, R. & Lowe, A. (1991). *Management Research: an Introduction*. London: SAGE Publications Ltd.

Ekengren, Ö., Nieminen, I., Bergström, R., Säynätjoki, M., Spännar, C., Routio, M. & Wennberg, L. (2002). *Miljövänligare mekaniska metallbearbetningsprocesser*. IVL.

EPA. (2003). *Lean Manufacturing and the Environment: Research on Advanced Manufacturing Systems and the Environment and Recommendations for Leveraging Better Environmental Performance*. EPA100-R-03-005 report prepared by Ross & Associates Environmental Consulting, Ltd. [Online]. Available: http://www.epa.gov/lean/leanreport.pdf [26 January 2009].

Healy, M. & Perry, C. (2000). Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm. *Qualitative Market Research: An International Journal, 3, 3,* 118-126. MCB University Press.

Helman, D. (2007). *Engaging Service Providers in Continuous Improvement*. Masters Thesis. Lund, Sweden: IIIEE, Lund University.

Hines, P., Found, P., Griffits, G. & Harrison, R. (2008). *Staying Lean Thriving, not just surviving*. Cardiff: Lean Enterprise research centre Cardiff University.

IAMS (Institute of Advanced Manufacturing Science). (1995a). *Pollution prevention guide to using metal removal fluids in machining operations*. Developed for the United States

Environment Protection Agency Office of Research and Development National Risk Management Research Laboratory. [Online]. Available: http://www.coolantmaintenance.com/techpapers_pdf/greenfluids_manual.PDF [26 November 2007].

IAMS (Institute of Advanced Manufacturing Science). (1995b). *Shop Guide to Reduce the Waste of Metalworking Fluids - A Competitive Advantage Manual for the Metal Fabricating and Machining Industry*. Institute of Advanced Manufacturing Sciences Waste Reduction and Technology Transfer Foundation. [Online]. Available: http://www.p2pays.org/ref/02/01085.pdf [26 November 2007].

Jakl, T., Joas, R., Nolte, R. F., Schott, R. & Windsperger, A. (2004). *Chemical Leasing. An Intelligent and Integrated Business Model with a View to Sustainable Development in Materials Management*. Wien & New York: Springer-Verlag.

Joas, R. & Schott, R. (2004). Parameters for Know-How Networking. In T. Jakl, R. Joas, R. F. Nolte, R. Schott, & A. Windsperger, *Chemical Leasing. An Intelligent and Integrated Business Model with a View to Sustainable Development in Materials Management* (39-44). Wien & New York: Springer-Verlag.

Kurdve, M. (2009). *Undvikande av hälsorisker vid användning av skärvätskor*. Presentation at Metal Cutting Research and Development Centre Members Conference 26 May 2009 in Göteborg.

Kurdve, M. (2008a). Chemical Management Services: Safeguarding Environmental Outcome. In S. Schaltegger, M. Bennett, R. Burritt & C. Jasch, *Environmental Management Accounting (EMA) as a Support for Cleaner Production* (209-229). Eco-efficiency in Industry and Science, Volume 24. Springer Science + Business Media B.V.

Kurdve, M. (2008b). Applying Industrial Waste Management in Practice – Re-assessing the economics of the waste hierarchy. In K. Tang & J. Yeoh, *WASTEnomics – Turning waste liabilities into assets* (141-152). Middlesex University Press.

Kurdve, M. (2008c). *Nytänkande i att köpa kemikalier*, Presentation at Elmia seminar 20 May 2008 at Work08 Work Environment Fair Seminar on Inköp för god arbetsmiljö. [Online]. Available: http://www.arbetsliv.org/Elmia_2008/AM%201c%20Martin%20Kurdve.pdf [30 January 2009].

Kurdve, M. & Daghini, L. (2009). Sustainable metalworking fluid systems: Best and common practice for metalworking fluid maintenance and system design in Swedish industry. *International Journal of Sustainable Manufacturing.* (submitted for publishing).

Kurdve, M. & Mont, O. (2006). *Chemical management services: safeguarding environmental outcomes*. Presentation at EMAN Conference Graz 27 April 2006. Paper ID 76718.

Lillienberg, L., Burdorf, A., Mathiasson, L. & Thörneby, L. (2008). Exposure to Metalworking Fluid Aerosols and Determinants of Exposure. *Annals of Occupational Hygiene, 52, 7,* 597-605.

Munkøe, L., Harbak, L. & Juhl, P. (2006). *Waste reduction program in Danisco A/S*. Presentation at EMAN Conference "Environmental management Accounting and Cleaner Production", 27 April 2006, Graz, Austria.

Mont, O. (2004). *Product-Service Systems: Pancea or myth?* Doctoral Dissertation. Lund, Sweden: IIIEE, Lund University.

Mont, O., Singhal, P. & Fadeeva, Z. (2006). Chemical Management Services in Sweden and Europe - lessons for the future. *Journal of Industrial Ecology, 10, 1-2,* 279-292.

Oldham, J. (2003). *Policy drivers and barriers to Chemical Management Services: A UK study.* Presentation at OECD-Conference: Experiences and perspectives of service-oriented strategies in the chemicals industry and related areas, Vienna 13-14 November 2003.

Paustovskaia, V. V. (1990). Main results of experimental studies on the toxicology of inhibitors of atmospheric corrosion of metals. (English abstract only). *Gig Tr Prof Zabol, 3,* 7-10.

Qui, X. & Chen, X. (2009). *Evaluate the environmental impacts of implementing lean in production process of manufacturing industry.* Master of Science Thesis. Göteborg, Sweden: Chalmers University of Technology.

Reiskin, E. D., White, A. L., Johnson, J. K. & Votta, T. J. (2000). Servicizing the Chemical Supply Chain. *Journal of Industrial Ecology, 3, 2-3,* 19-31.

RREUSE (2006), *Remarks from RREUSE on the commissions communication on the TSPR and the revision of the WFD - version II.* [Online]. Available: http://rreuse.org/33/fileadmin/documents/00142_TSPR_and_WFD_Feb_06.pdf [20 May 2006].

Silverman, D. (1993). *Six Rules of Qualitative Research, in Interpreting Qualitative Data.* Newbury Park, CA: Sage Publications.

Singhal, P. (2003). *Transition to Chemical Management Services.* Masters Thesis. Lund, Sweden: IIIEE, Lund University.

Skleros, S. J., Hayes, K. F., Clarens, A. F. & Zhao, F. (2008). Current advances in sustainable Metalworking Fluids research. *International Journal of Sustainable Manufacturing, 1, 1/2,* 180-202.

Stendahl, P. (2006). *Utredning av tvättning vid Volvo CE Components.* M.Sc. Thesis in Arena Management och teknik i nätverk Luleå Tekniska Universitet 2006:300 Civ. Luleå, Sweden: Luleå Tekniska Universitet.

Stoughton, M. & Votta, T. (2003). Implementing service-based chemical procurement: lessons and results. *Journal of Cleaner Production, 11, 8,* 839-849.

Toffel, M. W. (2002). *Contracting for Servicizing.* Berkeley: Haas School of Business, University of California.

Tukker, A. & Tischner, U. (2004). *New business for old EuropeProduct-service development as a means to enhance competitiveness and eco-efficienct.* Final report of SUSPRONET CONTRACT N° : G1RT-CT-2002-05079 / PROJECT N° : GTC1-2001-43057.

VDI 3397-2. (2005). *Maintenance of metalworking fluids - Measures for maintaining quality, and for reducing solid and liquid waste.* Düsseldorf, Germany: Verein Deutscher Ingenieure.

Votta, T. J. (2003). *Chemical Management Services; a Promising Product-Service-System.* 1st SusProNet Conference "Sustainable Product Service Systems: state of the art", Amsterdam.

White, A. L., Stoughton, M. & Feng, L. (1999). *Servicizing: The Quiet Transition to Extended Product Responsibility.* Submission to U.S. Environmental Protection Agency Office of Solid Waste. [Online]. Available: http://www.p2pays.org/ref/17/16433.pdf [10 October 2005].

Windsperger, A. (2004). The variants of chemical leasing. In T. Jakl, R. Joas, R. F. Nolte, R. Schott & A. Windsperger, *Chemical Leasing. An Intelligent and Integrated Business Model with a View to Sustainable Development in Materials Management* (29-38). Wien & New York: Springer-Verlag.

Yin, R. K. (1994). *Case Study Research- Design and Methods.* 3rd edition, Applied Social research methods series, vol. 5. Sage Publications.

Appendix A – Fluids in MW Industry

Fluids used in Metalworking (MW)

There are several chemicals used in a metalworking plant. Some of the most important are lubricants, metalworking fluids (MWFs) and cleaners.

Lubricants

Lubricants are most often oils and greases with specified viscosity and lubricity. In addition to oil, they may also contain lubrication additives/EP additives, and sometimes emulsifiers to take care of water contamination. In some special cases, emulsions can be used instead of straight oils as lubricants.

In MW operations the most used lubricants (volumes) are hydraulic oils, spindle oils, guide oils and transmission oils. They are used to aid different moving parts in the machining tools.

Lubricant monitoring usually includes checks of fluid level, colour and temperature, sometimes also contamination of particles and water in order to monitor the proper fluid function. Especially hydraulics are sensitive to water contamination. The fluid level is monitored and maintained in scheduled programs in professional or autonomous (operator-driven) maintenance. Lubrication control is tightly linked to machine maintenance and is usually a crucial part of TPM (Total Productive Maintenance), therefore lubricant services are excluded from fluid management service (FMS) programs at times.

Lubricant consumption means depletion of scarce resources. Use and unintentional spills onto absorbents lead to emissions of CO_2 and organic compounds, respectively. End-of-life of the oils creates hazardous waste that often ends up in combustion and consequent release of carbon dioxide (CO_2), hydrocarbons (HC) and in some cases sulphur (S) or other substances. Storing, transporting and using lubricants also mean environmental risks of leakage and emission to soil in unintentional accidents.

Lubricants most often leak within machines and equipment and contaminate cleaners and MWFs. Although the primary effect on the environment, a slight increased usage to replace the leaked volumes, may be low, the secondary effects, i.e. efficiency may decrease in the cleaning and cutting process, usage of cleaners, MWFs and additives (especially biocides) may be significantly higher. Thus it is important to have lubricants that conceptually fit the fluid system.

Some lubricants will have to be changed due to contamination by water or due to excess heating. The oil can usually be either reconditioned before reuse or be sent to re-refining into new base oil. Most commonly, however, is still to send waste oil from MW to incineration even though there are several life cycle studies (RREUSE 2006) that show both environmental and system economy gains for oil recycling.

The knowledge needed in lubricant management include tribology, monitoring and control, hazardousness assessment and understanding of TPM tools.

Metalworking fluids (MWFs)

The most important group of fluids in a MW plant is MWFs. They are used in metal removal operations to lubricate the cutting/removing tool, to cool the tool and work piece and to transport the removed metal.

MWFs can be categorised by composition in straight oils, water miscible emulsions and water miscible synthetic solutions. There exists some confusion on the definitions in literature; in this research the following has been used:

- Straight oils are pure mineral or vegetable oils with additives. > 90% oils in the use phase.
- Emulsions contains 2-20 % mineral vegetable or synthetic oils, additives and > 60% water (usually 80-95% water).
- Synthetic solutions have a water phase containing soluble oils/esters or polymers and additives.

The water miscible MWF emulsions are the most used MWF within MW industry, as well as in the Volvo group, usually consisting of 90-95% water with 5-10% concentrate containing pH-buffer, lubricants, surfactants, rust protectants and biocides. The total industry use of MWF emulsion concentrates is of the same magnitude as the total use of MWF straight oils in Scandinavia (Ekengren et al. 2002)

MWFs are provided in either single sumps servicing one MW operation or in central systems servicing several MW operations (IAMS 1995a). The central systems may be partial flow, where each operation tool has its own tank or full flow, where there is only one fluid tank servicing several machines (VDI 3397-2 2005). In these MWF systems, different types of filtering and reconditioning are built in, in order to get closed loop systems. Usually the reconditioning can be more advanced in central systems since investments are needed only for one tank rather than several.

MWFs can sometimes be used as cleaners or in concentrated form as lubricants. Using them for these purposes may be a suitable option when there is large drag-over or leakage between the different fluid systems (as shown in Section 5.3.4). MWFs will in normal operations contaminate commencing process fluid via drag-over to cleaners or other MWFs. They will also contaminate the metal chips and shavings from the metal removal operation. This has to be considered when designing the fluids in the industrial system and may affect hazardousness and recyclability of the fluids.

In normal use, MWFs will primarily affect the environment by depletion of scarce resources, release of VOC and HC. These and energy use in production release CO_2 and give cause to global warming. MWFs end up as hazardous wastewater and risks of releases to soil and ground water. MWFs are also one of the most important health aspects in the metalworking industry. As secondary but significant environmental effects, MWF use affects energy needs in the MW process and the quality and productivity of the final product; it also affects other process fluids downstream, such as cleaners, other MWFs, and sometimes, surface treatment fluids (quenchants, phosphating baths etc.).

The most important way to reduce environmental impact from MWFs is to change the most hazardous components into less hazardous (Ekengren et al. 2002) and/or to close process loops so that the components are not consumed or emitted. To minimise the volume needed is the best way to minimise overall environmental impact. One way to do this is to introduce dry machining in operations where this is possible. This will, however, give special demands on equipment design, lubrication system and on the cleaning operations in the process.

MWF aerosols (MWF mist) is one of the largest factors that affect workplace environment in daily operations. Millions of workers are exposed to this every day. Although in most plants there are not acute severe effects on workers health, this will affect life quality for workers, productivity of daily operations and sick leave. Most MW plants have a higher degree than the normal population of symptoms in upper respiratory system similar to a normal cold (Lillienberg et al. 2008, Kurdve 2009).

In order to maintain function of the MWF, there may be a need to monitor pH, emulgator and oil content to maintain stable emulsions. From a work environment perspective, the control of bacteria is the most important (Ekengren et al. 2002); therefore contamination of tramp oil, particles and bio contaminants (bacteria and fungi) is monitored. In addition to this, the foaming properties, rust protection and temperature may be important to measure in order to maintain the fluid functionality to support the metal removal operation. Colour and smell may be important indicators of faulty fluids as well.

MWFs are consumed by drag-out with parts and with metal chips. Some of these can be recovered and possibly reused by centrifuging the chips. MWF baths may be reconditioned when they get too dirty or contaminated with other fluids. This can be done continuously within a system or in separate reconditioning systems where, often, single sump fluids are reconditioned. When the MWFs are out of specification, the water can usually be reused to new MWF after evaporation or filter systems. The oily phase can be re-refined into new base oil but the contaminants may be difficult to handle, which is why the oil phase is usually combusted as hazardous waste. Metal chips with up to 25% of the volume consisting of MWF, are recycled in metal melts where the MWF get combusted. Grinding filings with metal mixed with MWF and inert material from the grinding disks are difficult to dispose and often end up as special landfill for hazardous waste

If fluid maintenance fails, this may lead to severe health problems and in worst case, the process has to be stopped completely for cleaning so that the system can be operated without risk. MWF services are usually critical for a MWF plant, which is why there has to be a thorough allocation of responsibilities if these are outsourced. Knowledge in a wide area of fields like health and safety, metal cutting, tribology, heat exchange, filtration techniques and monitoring and control is needed in order to operate MWF services. This knowledge and experience is rare and may be hard to find both for the user and for suppliers.

Cleaners

Cleaners are used in the cleaning operations where their main function is to clean work pieces from chips, particles and oil/fluids from previous operations. Choice of washing process and cleaner depends on the type of dirt to be removed and on the demands from the next operation. There are two classes of cleaners, aqueous and solvent cleaners. Acid (pH < 7), neutral (pH 7 to 10.5), alkaline (pH 10.5 to 11.5), and high alkaline (pH > 11.5) cleaners are examples of aqueous cleaners. Emulsion cleaners and hydrocarbons are classified as solvent cleaners.

The most important chemical components in a cleaner are surfactants, complex builders, corrosion inhibitors, and preserving agents. There are four types of surfactants; anionic, non-ionic, cationic, and amphoteric. Anionic surfactants are based on sulphate, sulphonate or carboxylate anions and they are high foaming. Non-ionic surfactants like fatty alcohols are low foaming. Positive charged surfactants are used as demulgators and biocides. An addition of chloride ions can be needed to reach better cleaning result

Commonly, washing systems are operated by single systems, i.e. one tank is connected to each washing machine although there are central systems also. Industrial cleaning processes include cleaners, washing machines, cleaning mechanisms, and recycling of cleaners (Stendahl 2006). To be able to choose an environment-friendly cleaning process, it is necessary to have knowledge in all these areas.

In most Volvo plants, as in many large MW plants, some type of standardised cleaner is used in most intermediate washing and possibly in the final cleaning (Stendahl 2006, Asmus 2008).. Special cleaners are used in connection to surface and/or heat treatment (e.g. phosphating or hardening processes).

Cleaners often get contaminated by large amounts of all other process fluids, which is why their respective chemistry needs to be taken into account when choosing and monitoring the cleaning operations. The cleaner in turn often contaminates the next process in line, which may be important especially if the next fluid is sensitive to the surfactant chemistry of the cleaner. Usually the surfactant level, the conductivity and particle levels are monitored. Temperatures are usually controlled by thermostats.

Reconditioning is possible and a common practice in large washing machines and central systems where the cleaners are continuously reconditioned. There are also reconditioning systems for single washing machines, but this requires a logistic system and standardisation of cleaners.

Most wastewater in MW plants comes from cleaning processes and paint booths. The water is usually filtered or evaporated. If the waste is then released to surface water, even small residues of persistent surfactants may harm the environment.

Other fluids and commonalities

In addition to the above mentioned, there may be several other fluids such as quenching agents, coolants, rust protectants, phosphating baths etc. used in a MW plant. These all have their specific service and management needs, but there are also large similarities in components in the fluids, knowledge needed and equipment needed.

Several components are of the same kind in the different fluids. These have adverse effects on environment but it also has to be considered how they mix and affect each other during use and end-of-life phases. These components are often hazardous to environment as well as to human health. They also require a lot of energy in the chemical production process and in many cases they are based on components originating from mineral oil (Skleros et al. 2008).

Many fluids contain an oil phase that may consist of mineral oil or of vegetable or synthetic oils/esters. Their environmental aspects are partly due to the production phase that requires energy in refineries and, possibly, use of fossil-originated resources, but also due to the use phase with emission of hazardous compounds, often carbohydrates.

Most MW process fluids contain surfactants that contribute largely to the negative environmental aspects. On top of these, there are also biocides, antifoaming substances, pH buffers and lubrication additives that exist in different amounts in different fluids. Surfactants accounts for a large part of the environmental emissions in the life cycle of water-based MWFs (Skleros et al. 2008).

Preserving agents, including bactericides and fungicides, prevent fluids from biological break down, discoloration, oxidation and bacterial decay. They are often needed in fluids that are kept below 60 ^{O}C and are by their functions hazardous to environment and health.

Corrosion inhibitors are often amines (TEA, MEA, DEA) or potassium salts that prevent parts and cleanings machines from being exposed for corrosion by forming a protecting layer on metal surfaces. Most corrosion inhibitors are hazardous (Paustovskaia 1990).

The complexity of each fluid, and the fact that the fluids will affect each other, means that it is important to consider the industrial system as a whole, rather than to only consider each operation and its fluid as a separate entity. In addition to this, the fluids will affect the MW process energy use, breakdowns and quality output. Energy-demand factors, such as torque for engines/tools, temperature on washing, cooling demand etc. are affected to a large extent by the fluid systems. Quality, mainly errors from MWFs and cleaners in their processes, can give scrap parts and thus increase total material use and process work. Failing lubes can destroy equipment and cause production stops.

Appended papers

The following papers are appended to the thesis:

Paper I: Kurdve, M. (2008b). Applying Industrial Waste Management in Practice – Re-assessing the economics of the waste hierarchy. In K. Tang & J. Yeoh, *WASTEnomics – Turning waste liabilities into assets* (141-152). Middlesex University Press.

Paper II: Kurdve, M. (2008a). Chemical Management Services: Safeguarding Environmental Outcome. In S. Schaltegger, M. Bennett, R. Burritt & C. Jasch, *Environmental Management Accounting (EMA) as a Support for Cleaner Production* (209-229). Eco-efficiency in Industry and Science, Volume 24. Springer Science + Business Media B.V.

Paper III: Kurdve, M. & Daghini, L. (2009). Sustainable metalworking fluid systems: Best and common practice for metalworking fluid maintenance and system design in Swedish industry. *International Journal of Sustainable Manufacturing.* (submitted for publishing).