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Master Thesis:

Simulation of the IKEA Distribution Centre in Peterborough, UK

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SUMMARY

Title Simulation of the IKEA Distribution Centre in Peterborough, UK

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Key words Capacity simulations, bottlenecks, efficiency, AutoMod, and effectiveness.

Problem IKEA want to avoid building a DC with insufficient capacity, and with imbalances in the material flow, therefore they want to run simulations of the system to see if the material flow is of satisfaction. The focus of this report is aimed towards capacity simulations of the Silo, the automated high storage area.

Purpose Run different scenarios of the Silo with different conditions in order to evaluate where bottleneck can upraise and aim for optimal solutions with retained efficiency in the material flow.

Method The report is built on both quantitative and qualitative studies. Information gathering has been done from interviews and CAD-drawings in combination with secondary sources. Information from secondary sources was gathered from literature as books, brochures and articles in addition to the Internet.

Objective Run capacity simulations of the Silo and look for bottlenecks in the material flow.

Conclusion The analysis made of the number of cranes states that four cranes are insufficient and five to seven cranes manage the demanded throughput. We believe the best solution is to use six cranes. Five cranes manage the flow but taken maintenance and breakdowns into consideration six cranes are to prefer. Seven cranes do not increase the throughput according to the analysis and therefore we find seven cranes unnecessary. Hence six cranes are the best solution.
The analysing of the storage mode and the number of zones in the Silo shows differences in the throughput. Though for both cases there cannot be any statistically secured results, using the confidence level of 95%. When considering the variation of the number of zones we consider the zoning could be done in a different way. Because of the fact that there are not SRM's in every aisle the cranes have to change aisles. Using the zoning from the front to the back the cranes have to move a long distance when changing aisle for the fast-moving articles in the front of the Silo. Instead we believe the zoning should be done from the left to the right (or the way around) and the cranes in the fast-moving zones should have a crane in every aisle. The other zones could share the other cranes.

Preface

This Master Thesis is the result of collaboration between the Division of Packaging Logistics, at Lund Institute of Technology and IKEA in Thrapston, UK. The collaboration is to demonstrate attainable benefits with simulations. The simulation software used in this project is called AutoMod.

We would like to thank our tutor Professor Mats Johnsson and Darrel Harvey, Logistic Manager at IKEA in Thrapston for great support and feedback during the project. We would also like to thank Daniel Hellström, PhD candidate at the Division of Packaging Logistics, for great guidance within the software AutoMod and finally Adri Kraa, Rick Hadley, Keith Morris and Miranda Stephens for good insight of the logistics at the DC's in Thrapston and Doncaster.

Lund, 2003-04-11
William Jovalli
Gregor Nalepski

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1. Introduction

This introductory chapter deals with several fundamental parts of an academic report. The chapter begins with a short background. Followed by problem setting, the objectives of the report, demarcations, target group and the last part illustrates the structure of this report.

1.1 Background

Today's companies require higher product quality and faster deliveries. This, among other things, increases the demands on the distribution systems. To be able to satisfy these increased demands, IKEA needs to improve and develop their distribution systems and storage facilities.
The IKEA distribution strategy in UK is to build Distribution Centre's (DC's) at two additional sites over the next two to three years. The first of these two are the DC in Peterborough. The site is placed in Peterborough in order to take advantage of the planned Customer Distribution Centre (CDC) that has potential synergies. The DC will be similar in design to the Doncaster DC. It will be a combination of conventional storage and automated crane based Silo.
IKEA have a clear construction plan including the physical layout for the implementation, but during the building process they want to do a capacity control of the DC.[1]

1.2 Problem setting

IKEA wants to avoid building a DC with insufficient capacity, and with imbalances in the material flow, therefore they want to do a simulation of the system to see if the material flow satisfies the requirements and to see if the DC's capacity is sufficient. The focus in this report is towards capacity simulations of the Silo, the automated high storage area.

1.3 Objective

Our main goal with this project is to do capacity checks of the Silo and look for bottlenecks in the material flow, where maximum efficiency and productivity is of first priority by the case of simulation. We will run scenarios with different conditions in order to evaluate where bottleneck can be developed and find the best and most optimal solution for an efficient material flow. Two important activities:

- Run capacity simulations of the Silo
- Look for bottlenecks in the material flow

[1] Ikea Intranet, Thrapston, 2002-10-15.

1.4 Demarcations

The Peterborough DC includes a Custom Distribution Centre (CDC), but we will not take this part into consideration during this report. Thirty percentage of the total material flow are picked pallets[2], though this influence on the material handling this will not be taken into consideration. Further we will not do any economic calculations nor will we consider any organisational restructions. We will not do any collection of empirical input data. We will have the data and information needed from already existing CAD-drawings, done by IKEA. Further more we will not collect or measure the input data to the simulation our self, this is also done by IKEA.

1.5 Target group

This report is mainly aimed towards the management of IKEA, Thrapston in UK. Though, this report is written by authors who have been studying at least six terms at different scientific faculties in Sweden. And while we consider our frame of reference to be theoretical, we have also chosen to direct this report to other students and teachers with equivalent knowledge. However, this does not prevent people with interests in the same field to read the report.

[2] Interview: Darrell Harvey, Logistic Manager, 2002-10-10.

1.6 Structure of the report

Structure scheme of the report

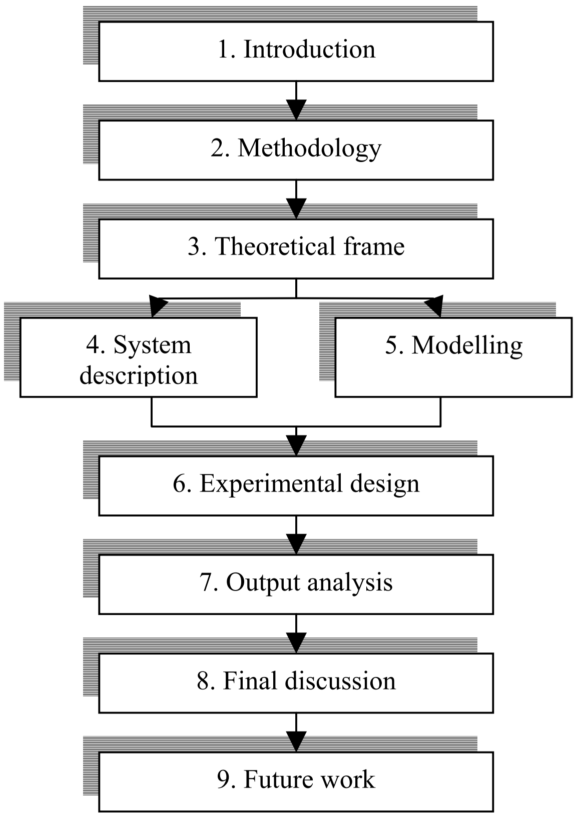

Figure 1: Structure scheme of the report

In the introductory to our choice of subject we initialised our main course of structure for the report as demonstrated above.
The introductory part of the report was discussed and was structured as the foundation where we wanted to build the forthcoming report. This first chapter also includes the main building blocks for the report together with the methodology chapter. Regarding the methodology chapter, we aimed for a hybrid approach. This chapter was then structured to explain the certain more mandatory parts of the report. Important in this chapter is our criticism regarding our research method and our sources of information. This demonstrates our awareness regarding possibilities and difficulties when writing an academic report.
The main purpose with the system description is to give the reader a quick overlook and to simplify the understanding of the model and simulation. Regarding the modelling chapter, this is a thorough description of the model, including system, procedures and algorithms. Further on the experimental design show chosen scenarios and in data. In the output analysis we present the results from AutoStat. We started to analyse the parts using a more integrated form of mind not to loose our main objective. Further after a thorough analytical performance we went on to our final discussion, thoughts and conclusions. Finally we discuss the future work and approach of this project.

2. Methodology

In this chapter we will describe the scientific approach, the scientific method and which method the authors have chosen to work from. Classic instrument are presented to facilitate the understanding for the readers who are not familiar with these scientific conceptions and also to verify our choice. The authors will show how these instruments have been used to secure the quality and the correctness of the report. Further we present how we have gathered the data for the report, followed by criticism of the sources.

2.1 Scientific approach

Science is about to interpret and understand. Through science it is possible to create understanding and knowledge about the reality we live in. To be able to examine and explain the reality, we have to do assumptions about how this reality looks like[3]. The assumptions made, results in different approaches. Today there are two different main approaches; positivism and hermeneutic[4].

2.1.1 Positivism

Positivism is built upon experiments, quantitative measurements and logical discussions. The positivism describes and explains, which means observation and examination. The positivistic consider an objective reality, which is depending on the viewer and can be studied without being influenced[5]. This means that the positivism have an objective approach.

2.1.2 Hermeneutic

The hermeneutic studies demand an entire understanding, an insight. Hermeneutic, it self, means learning about interpretation[6]. Unlike the positivism, which has an objective approach, the hermeneutic approach is subjective. Within the hermeneutic approach our own understanding and our own experience is used to interpret and understand other people's understanding and experience[7]. In other words it is our own interpretations of the reality that control how we act.

2.2.2 Choice of scientific approach

We have chosen a positivistic approach. Our project is unique and built upon a concrete problem. Further on our measurements are of quantitative characteristic and our project is also built on logical discussions and because of the fact that our conclusions are objective a positivistic stance has been selected.

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3 Arbnor, I. & Bjerke, B. (1994). *Företagsekonomisk metodlära*. Studentlitteratur, Lund.
4 Eriksson,L T. och Wiedersheim-Paul,F. (1991). *Att utreda, forska och rapportera*, Liber, Malmö.
5 Thurén, T. (1991). *Vetenskapsteori för nybörjare*. Runa.
6 Eriksson,L T. och Wiedersheim-Paul,F. (1991). *Att utreda, forska och rapportera*, Liber, Malmö.
7 Thurén, T. (1991). *Vetenskapsteori för nybörjare*. Runa.

2.2 Scientific methodology

You can discern two different scientific methods[8]. The starting point is how you examine soft data or hard data; these are called qualitative methods or quantitative methods.

2.2.1 Qualitative method

The qualitative method is distinguished of a close contact to the science object, which leads towards increased understanding of the reality, which is studied. The strength with the qualitative method is that it renders a possibility for increased understanding in social processes and social consistence[9]. A characteristic of the qualitative method is flexibility. That is because of the possibility to change the approach during the implementation. Another characteristic is that the qualitative method does not use any hard data, which is numbers or figures[10].

2.2.2 Quantitative method

Studies with the quantitative method should be able to be measured and the result should be able to be presented with numeric data. Experiments and surveys are examples of quantitative methods. In opposite to the qualitative methods the quantitative methods are inflexible, standardized approaches are often used. New knowledge uprising during the implementation must not lead to changes in the approach of the examination. The strength with the quantitative method is that collected data render possibilities for generalisation[11].

2.2.3 Choice of scientific methodology

This report departs from a quantitative point of view. Our project is mostly built on figures and numbers; therefore we prefer the quantitative method in front of the qualitative method. Our result will also be presented numerical which is strengthening the quantitative approach. Though we have not totally rejected the qualitative method, we have actually chosen a hybrid between the two scientific methodologies. Like described above our project departs from the quantitative approach with measurements. The translation of the hard facts between the CAD-drawings and the graphics in AutoMod are strictly quantitative. But when it comes to the translation of the reality or real life scenarios into syntax, which means interpretations and simplifications of the reality we have chosen a qualitative approach. Interviews have been done, which have had a qualitative characteristic.

2.3 Validity

"A result shows high validity when you measure a phenomenon you have planned to measure and nothing else"[12]

[8] Holme, Idar M. & Solvang, Magne K. (1997). *Forskningsmetodik. Om kvalitativa och kvantitativa metoder*. Studentlitteratur, Lund.
[9] Ibid.
[10] Backman, J. (1998). Rapporter och uppsatser. Studentlitteratur, Lund.
[11] Holme, Idar M. & Solvang, Magne K. (1997). *Forskningsmetodik. Om kvalitativa och kvantitativa metoder*. Studentlitteratur, Lund.
[12] Andersen, H. (1990). Att skriva vetenskapliga rapporter. Studentlitteratur, Lund.

It is of the outmost importance that the material made for the interviews is gathered and structured in a thorough manner. In this course of action we aimed for maximum level of preparation before the interviews, we were ready and prepared for our aim: establishing a high level of validity and reliability (see *Reliability*). By preparing in this way and conducting the research process thoroughly we also minimised potential misunderstandings, which is of great importance regarding validity and reliability. The formation of the questionnaire was a result of this process. The questions were of an open nature.[13] The reason for this was that open questions are not likely to lead the respondent's answers in any direction, thus giving way for better and more reliable validity and reliability.
The validity indicates the correctness of a method. In order to obtain a high level of accuracy, information has been gathered thoroughly. Surveys has been made and sent to a number of persons relevant to our studies and our objectives of this report.

2.4 Reliability

Reliability means the degree of authenticity within a measure, which is the lack of random errors[14]. Another definition is "In what degree the results from a measure are not inflicted by accidental occurrence"[15].
Previous to the interviews we discussed and considered different kinds of problems that could inflict and affect our attempt in gathering relevant and correct information from the respondents. It is of great importance that the respondent correctly understands the questions asked from our side. By asking the same question but in different ways and by formulating it differently we can secure the consideration of the respondent's level of understanding the question, to some extent we can also verify the answer in this way. The method mentioned above has been used throughout the interview process in aim of reaching the highest possible reliability for the report.
We will have the input data and information needed from already existing CAD-drawings, done by IKEA. The reliability in the input data and measurements are thereby hard to secure. However we have been in close contact with IKEA, explaining how the program is working and in what form we wanted the input data. Hence we feel confident in the reliability of the input data and measurements.

2.5 Method of collection

There are two main approaches when collecting data. The first technique is collecting of primary data and the other one is the collecting of secondary data.[16]

2.5.1 Primary data

The primary data is the material that the researcher collects him self, for the settled purpose with the examination.[17] In order to do our simulation as true as possible, the primary data collection is very vital for our project. Therefore we spent a lot of effort on this part.

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[13] Holme, Idar M. & Solvang, Magne K. (1997). *Forskningsmetodik. Om kvalitativa och kvantitativa metoder*. Studentlitteratur, Lund.
[14] Arvidsson, P. & Rosengren, K.E. (1992). *Sociologisk metodik*. Liber, Lund.
[15] Winter, J. (1973). *Problemformulering, undersökning och rapport, Liber*.
[16] Arbnor, I. & Bjerke, B. (1994). *Företagsekonomisk metodlära*. Studentlitteratur, Lund.
[17] Eriksson,L T. och Wiedersheim-Paul,F. (1991). *Att utreda, forska och rapportera*, Liber, Malmö.

2.5.1.1 Interview

To gather the primary data we made interviews with persons, who have been working in IKEA for several years, with expert knowledge's within the area requested. During the interview the tasks within the project group where strictly divided. One member of the group put general questions as well as specific questions and the second member had the answers written down.
Furthermore, we used an open time schedule during the interviews, which made it easier for us to gather information, a character of a more freely held discussion. Also, this made the respondent more relaxed and not strictly questionnaire focused. We found this alternative approach to be very complementary in our search for information regarding the interviews.

2.5.1.3 Survey

Surveys have been done in order to establish further confirmation in our quest for correct and relevant information. The surveys have been carefully assembled and the aim was twofold; we searched for either new information or either to confirm or reject the thesis from our interview process. The surveys have been made continuously throughout the project. We have sent the surveys to several persons with the aim of receiving correct information. This strengthens the report's validity and reliability from the perspective of information gathering (see *Validity* and *Reliability*).[18] From this point we feel very confident that we still reach a high level of validity and reliability in our analytical process of the report.

2.5.1.2 CAD-drawings

The translation between the CAD-drawings and AutoMod is of great importance. To make the simulation true, the measurements need to be correct. In order to attain the main goal (see *Objective*) we have done a careful examination of the CAD-drawings of the DC in Peterborough. Our measurements are carefully implemented so we find that the graphic in our model is equal to the CAD-drawings. To make the model and the simulation as close as possible to the conditions in real-life, we have been in close contact with our tutor at IKEA this to increase the correctness of the method.

2.5.2 Secondary data

Secondary data is material that has already been produced in books, magazines, newspapers, and articles etcetera. We have minimized the need of secondary data collection. This project is unique and therefore there have not been any performed investigations before.

2.6 Source criticism

2.6.1. Background

We have performed a hybrid examination between a quantitative process and a qualitative process and need to take considerations from this point of view regarding our source of material for information gathering. In qualitative examination processes the influence of the researcher cannot be stated merely enough. In a quantitative examination process the statistical character of the information would suppress our personal and more subjective

[18] Eriksson,L T. och Wiedersheim-Paul,F. (1991). *Att utreda, forska och rapportera*, Liber, Malmö.

views. There is also the potential risk of misunderstanding the respondent in some way. Also, there is a more vital loss in the information gathering process were the respondent, subconsciously or not, is hiding information from us.

2.6.2. Criticism of primary data

The people we have been in contact with during our research and examination period have been very forthcoming and interested regarding the interviews. Most of the questions were answered without hesitation during the interviews. Though taken into consideration is the respondent's position within the company. The reason for this is that the respondent does not want to relate bad will towards the company nor himself/herself. On the contrary, companies tend to reflect themselves in a more positive manner. It is important to be aware of this as researcher and interviewer. The input data for this project has been collected by IKEA. This is important to point out. Concerning the translation from the CAD-drawings into our model, we aimed for maximum level of equality and we feel confident in the accomplishment. Though the absolute best result could be established if there would have been a direct translation between AutoMod and AutoCAD.

2.6.3. Criticism of secondary data

As described we have minimized the need of secondary data. Though scientific articles and literature, within the area of our objective, dominates the chosen secondary data. We did this to secure the correctness and reliability of the collected information. We do consider the secondary data we use is covering the area selected for the report's problem setting in a satisfying way.

3. Theoretical Frame

In this chapter we want to establish a frame of mind that will enhance the special aspects, which should be taken into consideration when simulating in AutoMod. The content in this chapter though, is mainly presented as an introductory foundation of simulations using the AutoMod software.

3.1 Introduction

AutoMod is simulation software for material handling systems. It helps design and optimises facilities. It combines CAD, 3D animation and a flexible simulation language to create realistic simulation models of manufacturing facilities, material handling systems, and Distribution Centres (DC's). Through experimenting with a facility in the virtual computer world, optimal configurations, equipment specification, and operational improvement can be determined for implementation in the real world before any change or capital outlay is made.[19]

Simulation is the imitation of a real-world process over time. Simulation is an indispensable problem-solving methodology for the solution of many real-word problems. Simulation is used to describe and analyse the behaviour of a system, ask " what if" questions about the real system, and aid in the design of real systems. Both existing and conceptual systems can be modelled with simulation. Whether designing a new system or modifying an existing one, engineers want to take the estimation out of finding the best possible solution. While there are many analysis methods for designing industrial systems, simulation remains the method that provides the highest level of confidence that a system will perform. A well-written simulation model can be a valuable tool in the design, analysis, and operation of manufacturing and other complex systems.[20]

3.2 Background

The main focus of the AutoMod simulation software is on manufacturing and material handling systems. With the release of AutoMod version 10.0 in 2001, graphics in AutoMod are more realistic. New VR-Graphics allows creation of visually accurate 3D scenes in their models, making them more convincing. Additional graphical enhancements include templates for conveyors and path movers that provide realistic graphics for widely used material handling systems. Material movement systems include: [21]

- Path Mover (vehicle systems such as fork lifters and AGV'S)
- Conveyors
- Automated Storage and Retrieval Systems (ASRS)
- Robots
- Bridge Cranes

[19] Brooks Automation Inc. (2001). *AutoMod User's Manual*. Bountiful.
[20] Banks, J. (2000). *Getting Started with AutoMod*, Brooks AutoSimulations Division.
[21] Brooks Automation Inc. (2001). *AutoMod User's Manual*. Bountiful.

- Power and Free Chain Conveyors
- Tanks and Pipes

To define material movement systems, the user simply defines movement elements, such as paths and stations, and then inputs the operating parameters, such as velocity and acceleration. AutoMod then automatically creates the corresponding model logic. 3D animation is created automatically as well, providing a realistic picture of how a facility will look and operate. Model animation can be viewed from any angle or perspective in real time, providing visualization capabilities unmatched in other simulation tools. AutoMod's key strengths are:[22]

- Flexibility to model complex systems accurately
- Unlimited size of models
- High performance simulation engine
- Best in class statistical analysis features
- Graphic environment for creation of geometry
- True to scale import from CAD tools

The model execution environment is very interactive, allowing the user to stop and start the simulation, run without animation in an accelerated time scale, and select objects from the animation screen to gather detailed statistics about the system being modelled. Statistics can be viewed at any time during a simulation run. These model execution features make it easier to verify and validate models of complex systems.[23]

3.3 AutoMod interface

An AutoMod model consists of one or more systems. A system can either be a process system, in which flow and control logic are defined, or a material movement system. Each model must contain one process system and may contain any number of movement systems. Loads can move between processes with or without using movement systems. All inter-arrival and event times can be represented by deterministic values or be derived randomly from one of many statistical distributions. AutoMod's interface is window-oriented, utilizing pop-up and pull-down menus.[24]

3.4 AutoMod's world view

Any number of movement systems can be defined in an AutoMod model, and a process system connects the movement systems to the logical flow of products. In the process system, loads (articles, parts etcetera.) move between processes (locations) and compete for resources (equipment, operators, and queues). The load is the active entity, executing action statements that are connected to the processes. Typical action statements give users the ability to: [25]

- Use machines/operators

[22] Brooks Automation Inc. (2001). *AutoMod User's Manual*. Bountiful.
[23] Ibid.
[24] Ibid.
[25] Ibid.

- Move into queues
- Clone new loads
- Change load types
- Wait on user-defined delay lists
- Increment/decrement counters
- Set variable values
- Read from data files
- Send to other processes

3.4.1 Processes

The process system is the spine of an AutoMod model, providing modelling a wide range of real-world problems. While material movement is important, it is not always critical in manufacturing. No value is added to product while it is being moved around a manufacturing facility. Machines and people perform value-added operations. AutoMod's process system includes a simulation language based on action statements. Action statements combine the power of a structured language with the ease of use of English-like, manufacturing-oriented syntax. AutoMod models are not limited in any way, so model logic can be of any size and complexity. The power and flexibility of the AutoMod language makes is easy to model almost any real-world situation.[26]

3.4.2 Loads

Loads are the active entities in AutoMod and can be created in many ways. The inter-arrival rate for loads can be read from an external data file or attached to a statistical distribution. AutoMod has predefined random distributions that can be used to fit most real-world random events. Loads can have attributes such as colour, priority, and time in the system. Attributes can be accessed and modified in AutoMod's action statements. Loads have 3D shapes and dimensions like most other entities in AutoMod.[27]

3.4.3 Resources

Resources in AutoMod are used to represent machines, operators, fixtures, containers, and any other finite capacity objects. There are two default categories for a resource's state. The first is the working category (busy or idle), and the second is the availability category (up or down). During the animation, state colours indicate the status of each resource. Statistics are automatically collected for every resource in a model. Loads use resources for specified processing times. Resource cycles can be created and attached to specific resources to indicate when or how often events such as random failures.[28]

3.4.4 States

The user can define states other than the default states. These states might be used to represent conditions such as blocked, starved, offline, etcetera. The state of a resource can then be changed using AutoMod's actions so that statistics can be tracked for each state. In

[26] Brooks Automation Inc. (2001). *AutoMod User's Manual*. Bountiful.
[27] Ibid.
[28] Ibid.

addition, state monitors can be defined and used to track states for entities other then resources, such as vehicles, conveyors, or particular areas of a facility.[29]

3.4.5 Queues and Order Lists

Queues in AutoMod are both graphical and statistical elements, and they can have any user-defined capacity. When a queue has reached its capacity, the next load trying to enter that queue must wait until there is space available. Queue contents can be shown dynamically in the animation, and loads can be stacked in any direction in the queue.
Loads that are at a queue or process may be sorted or delayed until they are explicitly ordered to leave. To determine which action should take place next, the loads must place themselves on order lists.
An order list (OL) is not a physical entity like a queue, but a logical element that provides a way to sort loads that have been delayed for any reason. To remove a load from an order list, another load must execute an order action. Loads can be ordered to move to another process or order list, or to simply continue where they left off in their processing. Order lists can be sorted by load priority or other load attributes, either in ascending or descending order.[30]

3.4.6 Blocks

Blocks control the number of entities occupying a physical space, making them very useful for controlling path mover vehicles. Blocks may have any capacity from one to infinity. Path mover vehicles (fork lifters, AGV's, etcetera) and loads increment blocks automatically when moving through the physical space defined by the block. Loads can also claim blocks in process logic, as directed by the user. Blocks can have any shape.[31]

3.4.7 Variables and Counters

Data may be stored in an AutoMod model using variables. Variables can be used in calculations or can be compared to other variables. In addition to integer, real, and string types, variables can also be used to store references to other process system entities, such as processes, queues, resources, order lists, counters, loads, and locations. Storing these references gives the users more power and flexibility to expand and extend models to match modifications of the actual system.
Counters have a maximum capacity, making them useful for traffic control. When a load tries to increment a counter that is at its capacity, the load will be delayed until another load decrements the counter. Statistics for counters are collected automatically.[32]

3.4.8 Functions, Subroutines and Source Files

Functions and subroutines are used to create modular models. This allows the models to be extended more easily. Users can define their own functions in the AutoMod and these functions can be called from any where in the AutoMod model.
Subroutines help eliminate duplication of action statements in the model.
Source files contain the logic for the model.[33]

[29] Brooks Automation Inc. (2001). *AutoMod User's Manual*. Bountiful.
[30] Ibid.
[31] Ibid.
[32] Ibid.
[33] Ibid.

3.4.9 Labels

AutoMod provides the ability to use text labels to enhance model understanding. Labels may be added to any location in the model's physical space, and they can either be static or dynamic during the simulation. Labels can rotate when the animation view changes or can be attached to a fixed position on the screen. Tables in AutoMod supply the user with the means to collect statistics on any model entity and to classify those statistics for better understanding of their distribution. Tables automatically provide average, standard deviation, maximum, and minimum for all values entered in the table.[34]

3.4.10 Types and Random Streams

Types in AutoMod provide users with a powerful tool for creating, among other things, lists of entities such as resources or stations, and then making complex decisions based on the contents of the lists.

Random streams may be defined to give each element of randomness independence from other elements. The number of different random streams used by AutoMod models is without limit. The current version of the software (10.0) supports the Linear Congruential Generator (LCG).[35]

3.4.11 Run Control

Run control in AutoMod allows users to define the warm-up and steady-state periods for the model. Reports can be printed for any run control period. Business graph output can be automatically created. Post-processed animation periods used by AutoView are also defined in the run control.[36]

3.4.12 Business Graphics

Graphs in AutoMod are easy to define and they update in real time with the animation. Graph types include bar charts, pie charts, and timelines. Any model entity can be attached to a graph, including transporters vehicle velocity, number of loads on a conveyor section, or average utilization of a machine. Graphs can be printed or plotted.[37]

3.5 AutoView

Post-processed animation extension can be used to view the animation records created by running an AutoMod model. The AutoView product allows the user to predefine all views and time periods in the model animation, and then play them back to generate presentation-quality animation files.

AutoView also has single-frame capture capability to AVI and MPEG format files. This feature allows users to create animations that can be shared with others without the need for any additional software.[38]

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[34] Brooks Automation Inc. (2001). *AutoMod User's Manual*. Bountiful.
[35] Ibid.
[36] Ibid.
[37] Ibid.
[38] Brooks Automation Inc. (2001). *AutoMod User's Manual*. Bountiful.

3.6 Graphics in 3D

Both dynamic and static objects can be displayed during model execution. Dynamic objects represent loads, vehicles, resources, queues, and statistics.
The static layout is the background graphics of the plant, such as columns, aisle markings, and walls. Labels can identify specific areas in the facility. There are several ways to create a layout of the system to be modelled. AutoMod comes with a three dimensional graphics editor (ACE) that allows the user to construct objects from standard graphics primitives.[39]

3.7 Run-time environments

In keeping with AutoMod's interactive features, the user has complete control of the model in the run-time environment. The model can be viewed with the animation on or run with the animation off. AutoMod uses concurrent animation; the simulation progresses as the animation picture is being updated. With animation off, the simulation does not render the animation, but it performs all simulation calculations. The user can suspend the simulation at any instant to review statistics through pop-up windows, to take resources down, to set break points or alarms, or to control the view of the animation without constraint.[40]

3.7.1 View Control

AutoMod provides a comprehensive and flexible method of interacting with a model during model execution. If the simulation project is in the experimentation phase where only parameter changes are made and the model needs to be re-run several times AutoMod provides the ability to run in batch mode without animation.[41]

3.7.2 User Interaction

AutoMod provides advanced debugging and trace facilities. A model can be single-stepped at any time during the animation. Also, the ability to set breakpoints and alarms allows the user to suspend the simulation when a certain event occurs or when a specific clock time is reached. AutoMod also provides comprehensive reports. The reports can be displayed on request at any time during the simulation.[42]

3.8 AutoStat

The AutoStat product is the statistical analysis tool in the AutoMod product family. AutoStat does extensive output analysis on an AutoMod model, including:

- Confidence intervals
- Warm-up determination
- Sensitivity analysis
- Factor-response analysis
- Design of experiments

[39] Ibid.
[40] Ibid.
[41] Ibid.
[42] Ibid.

- Optimisation using evolution strategies

AutoStat also has support for running scenarios across a network of machines. Support for multiple machines and CPU's give users the ability to make many more runs of the simulation than was possible before. The evolution strategies algorithm used by AutoStat is well suited to finding the optimum solution without getting "trapped" at a local optimal value.[43]

[43] Brooks Automation Inc. (2001). *AutoMod User's Manual*. Bountiful.

4. System description

This chapter is mainly intended to simplify the understanding of the simulation system. The chapter starts to describe what approach the authors have chosen to work from, where the simulated system will start and where it ends. The chapter continues with a layout description to give a visual simplification and thereby an increased understanding of the simulation system.

4.1 System simulation

To simplify the simulation approach we divide the system into three parts. The first part is the inbound logistics, the second part is the material flows inside the DC and the third part is the outbound logistics (*see Figure 1.*).

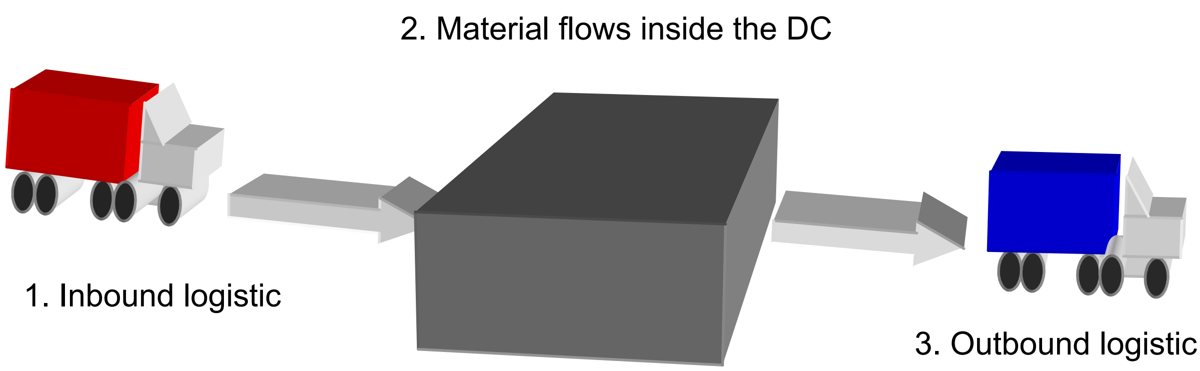


Figure 1: Schematic drawing of the system.

4.1.1 Inbound logistics

The simulation system begins with the inbound system. The inbound logistic begins when trucks arrive to the Distribution Centre (DC). The frequency of the arriving trucks depends on the given prognosis. The trucks drive to an empty inbound dock.

4.1.2 Material flows inside the DC

At the dock the unloading procedure starts. Fork lifters from the DC start to unload the pallets in the truck. Depending on what kind of article/load type that is unloaded, the fork lifters drive the load to a specified pallet location either into the Silo, which is an automated high storage area or to the Lowbay, which is a conventional storage area (*see Figure 2*).

Depending on the specified prognosis or specified demands for the outbound loads the demanded or outbound load is picked up by a fork lifter, which drives from the pallet location to an outbound dock.

4.1.3 Outbound logistics

At the outbound dock the load is set down and the domestic truck arrives, waiting to be loaded. Fork lifters from the DC are loading the domestic trucks. When the loading procedure is finished the domestic trucks depart and the simulation system ends.

4.2 Layout description

The schematic figure below (*see Figure 2*) illustrates the layout of the DC in Peterborough. The Silo or the high stacking area is in the middle of the DC. On both sides of the Silo there are Lowbay areas or conventional stacking areas. Automatic storage cranes (SRM's) are working inside the Silo. Standard fork lifters are operating in the conventional stacking area. The inbound docks and the outbound docks are located along the longs sides of the DC.

Schematic layout of the Peterborough DC

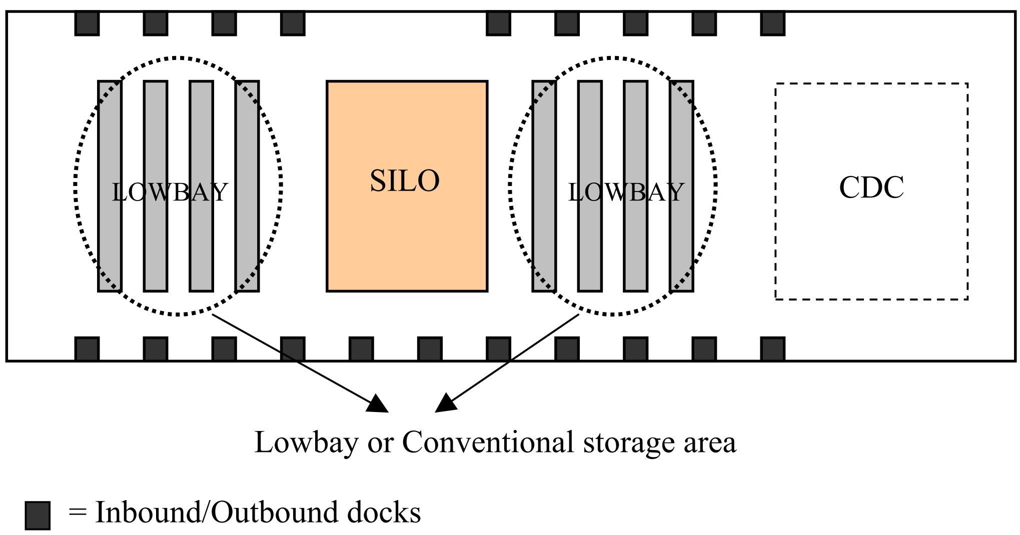


Figure 2: Schematic top view of the Peterborough DC

4.3 Facts and figures (Peterborough DC):

- The DC building is 313 (excluding the CDC) metres long by 186 metres wide
- The surface area of the DC is therefore 58,218 square metres.
- The high bay (Silo) area of the DC has 24 aisles and 70,000 pallet locations.
- The external roof height of the high bay (Silo) of the DC is 23 metres.
- The external roof height of the low bay (conventional) area of the DC is 12 metres.
- The maximum storage capacity of the DC is 98,000 cubic metres.
- There are 78 loading and unloading docks in the DC.

The Peterborough DC will be a similar design to the Doncaster DC. It will be a combination between conventional storage and crane based Silo. A third party operator will run the Peterborough DC. It is common to use a third party operator in UK. The option of IKEA operating the DC has been considered and rejected. This external service provider (ESP) is using the FIFO-rule. They will use the ASTRO warehouse management system.[44]

[44] Ikea Intranet, Thrapston, 2002-10-15.

5. Modelling

This chapter will describe how the real life scenario is converted into modelling and which systems used, in AutoMod. The chapter will also deal with the different processes that appear in the simulation. This chapter will also describe how the authors have chosen to model the different procedures in the system.

5.1 Modelling description

A similar schematic system description will be followed as in chapter three. The inbound logistics, the Peterborough DC and the outbound logistics (*see Figure 3*). Under each part we will more thoroughly describe the system used in AutoMod.

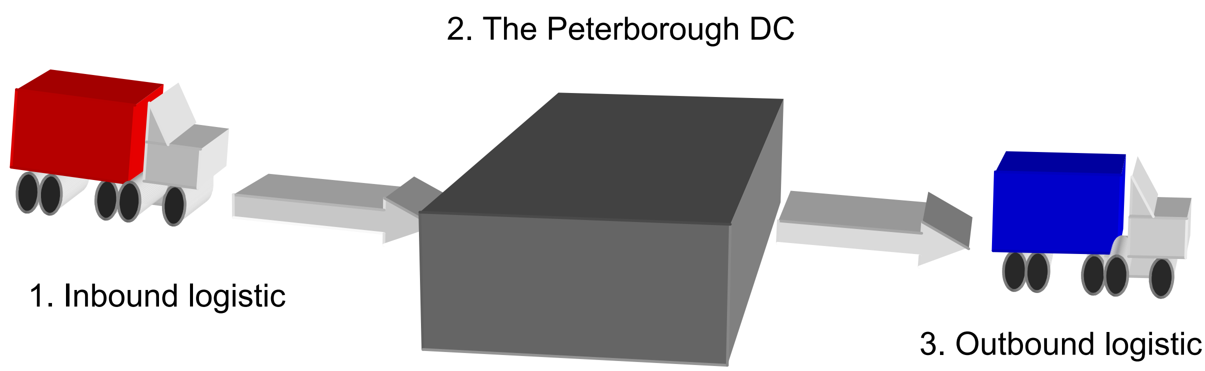


Figure 3: Schematic drawing of the system.

5.1.1 Inbound logistics

5.1.1.1 Articles/Loads

In the simulation there are four different load types. Each load type represents a group of articles in the IKEA assortment.

- The first load type represents euro pallet type and is dedicated to the Silo.
- The second load type represents euro oversize pallet type and is dedicated to the conventional area.
- The third load type represents Ikea oversize pallet type, which also is dedicated to the conventional area.
- The fourth load type is a special pallet with overhang. Especially hard to manage.

Euro oversize pallet differs from the Ikea oversize pallet in dimension. This means that there are certain racks and which in other words means that there are certain areas dedicated for each pallet type in the conventional stacking area (*see Figure 4*).

Pallet type location in the Peterborough DC

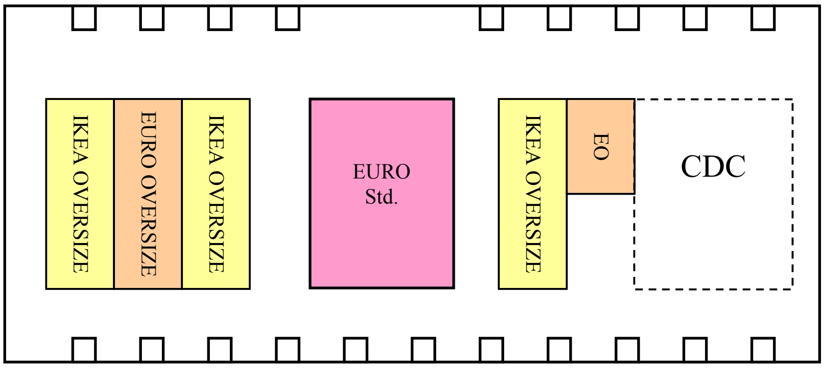


Figure 4: Schematic pallet type layout of the Peterborough DC

Each load type has a number of attributes, which are set during the simulation. For example which origin country the load type is coming from. In which dock the load is loaded/ unloaded. The direction of the load is of importance, when the fork lifters prioritise the work in their work lists. The load types also have attributes for their destination. For example what aisle, what bay and what tier they are going to.

5.1.1.2 Arriving trucks

The arriving trucks are simulated in a path mover system in AutoMod. The path mover system is build separately. The arriving trucks can be varied up to eight different kinds of trucks. The variation represents different trucks from different countries. Depending on what prognosis we have the arriving frequency will vary. Likewise, what kind of load types the arriving trucks contains will vary.

5.1.2 The Peterborough DC

5.1.2.1 Inbound dock

The docks are represented as queues in AutoMod. This is the meeting point for the arriving trucks in the “outside” path mover system and the fork lifters in the “inside” path mover system. The loads are moved from the trucks into the queues by a dispatched fork lifter. Well at the queue the load is waiting to be picked up by the other fork lifters.

5.1.2.2 Fork lifters

As mentioned above the fork lifters in the DC are simulated in a path mover system in AutoMod. It is only one path mover system in the DC. This means that we have not discerned the inbound flow from the outbound flow in the DC. This is done to be more flexible for changes, to minimize the paths and thereby the computer power. The fork lifters are working either in demarcated zones (*see Figure 5.*) or randomly all over the DC.

Fork lifters operating in zones

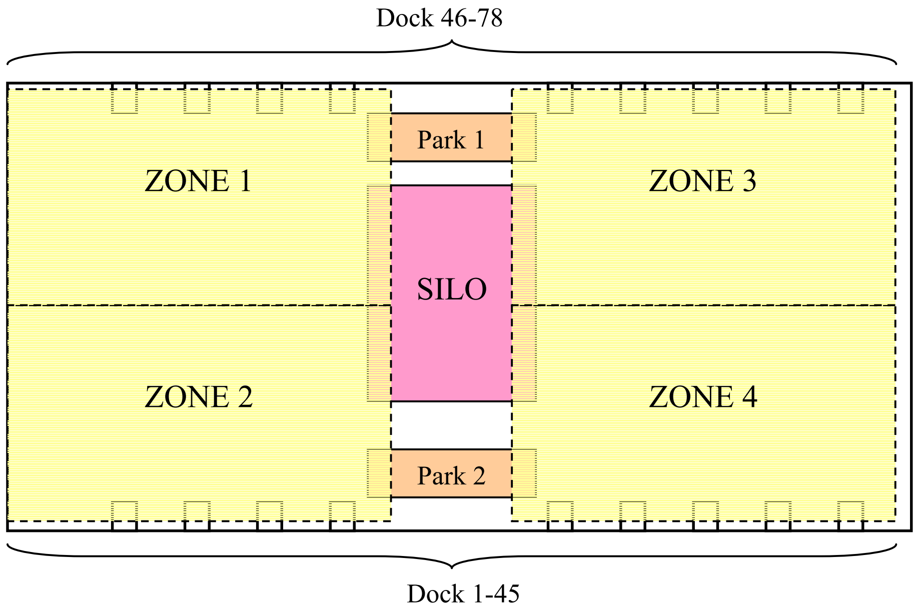


Figure 5: Schematic grouping into zones

Using zones

The fork lifters are divided into two different types. ForkLifter1 and ForkLifter2. Referring to figure 8 above:

- ForkLifter1 are operating in the upper part of the DC and they are serving dock 46 to 78. They use Park 1 as their parking lot.
- ForkLifter2 are operating in the lower part of the DC and they are serving dock 1 to 45. They use Park 2 as their parking lot.

The DC storage can be divided into four different zones, as a maximum. The fork lifters are operating in zones in their work list to create a more foreseeable material flow in the DC. The zones decrease the distances for the fork lifters. They also minimize collisions in the DC.
The fork lifters are ranking their works in order of priority. The work list for ForkLifter1 appears as follows (*see Figure 6*):

Work list: Using zones

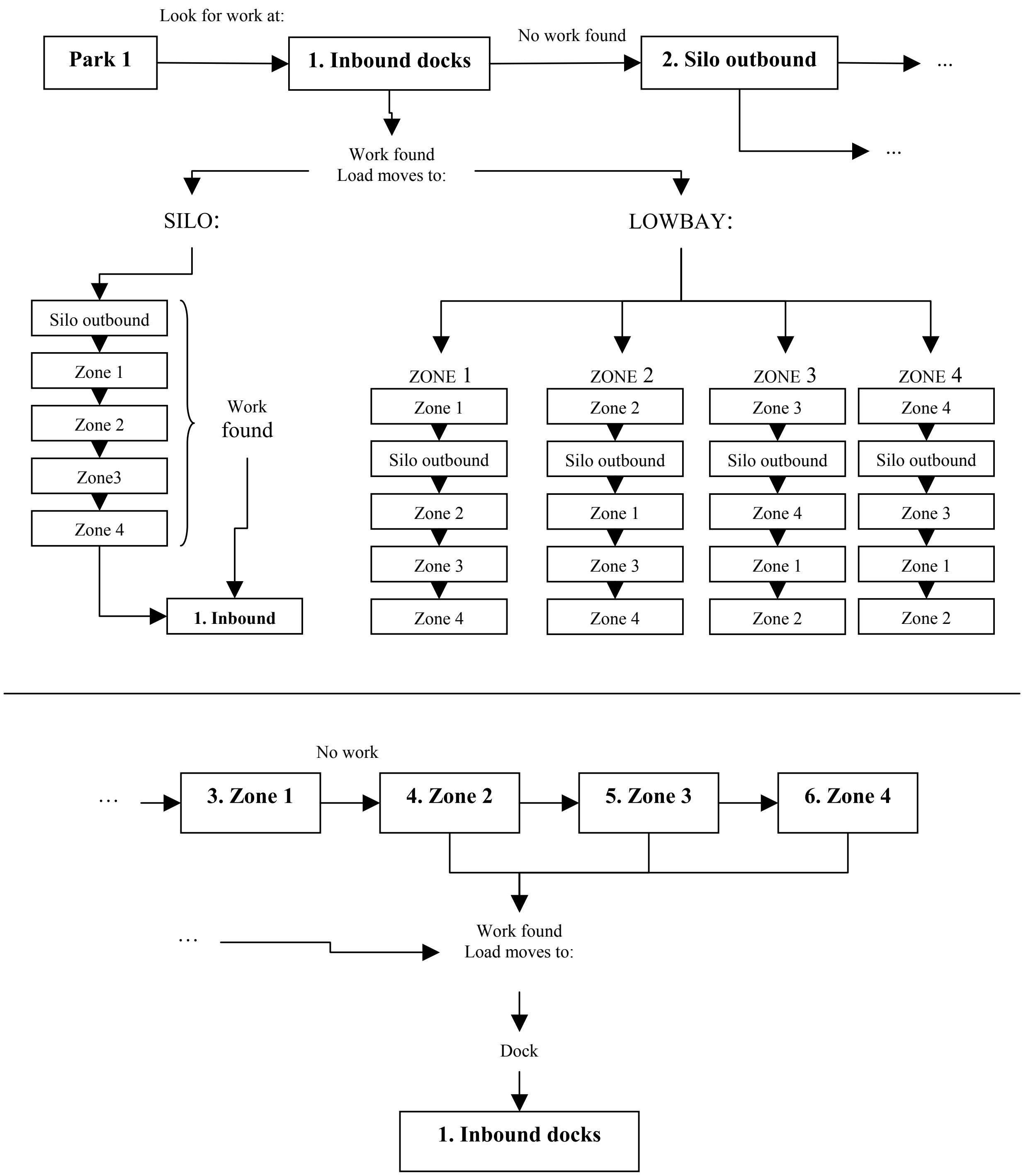


Figure 6: Work list for Forklift1

The work list for ForkLift2 is almost identical to the work list for ForkLift1. Though with some minor differences. ForkLift2 uses Park 2 as their parking lot, and they serve dock 1 to 45 instead.

Randomly

The random situation is actually a special case of the, above described situation when, the fork lifters are operating in zones. Instead of four zones (*see Figure 5*), the DC is divided into one zone only. This means that the assignments are spread all over the DC. The work list appears as follow (*see Figure 7*):

Work list: Randomly

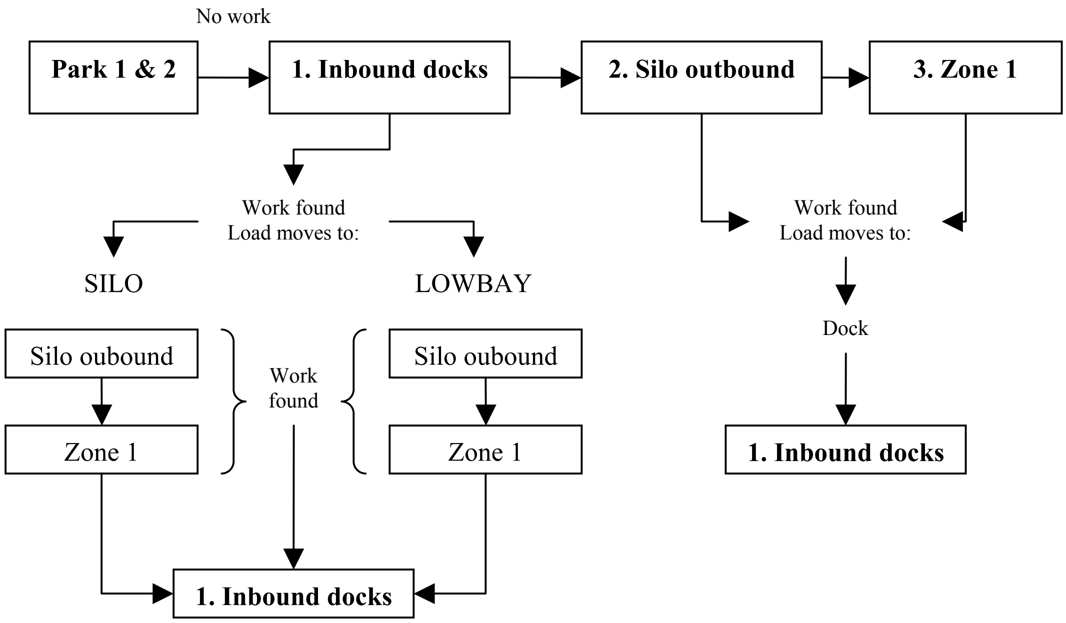


Figure 7: Work list ForkLift1&2

5.1.2.3 Lowbay / Conventional storage

The Lowbay area or conventional storage area is divided into two parts in AutoMod, the visual part and the numeric part.

- Visual part: The physically, the racks, is done as ASRS systems. These systems are not active they are static; it is just for the eye. To be able to show the loads we used a conveyor system with the velocity zero. Every station in that system represents one storage place in the Lowbay area. The dynamic part is the Loads in the racks.

- Numeric part: The Lowbay area in the numeric part is simulated as a matrix, to keep the computer power at minimum.

5.1.2.4 Highbay / Silo

Inbound flow

There are four inbound point to the Silo, one point in every corner. The four points are inbound stations in a conveyor system, which serves the Silo.

Silo

The Silo is simulated with two ASRS systems in AutoMod. The Silo is fully automatic, which the ASRS systems fully represent. (*see Figure 8 and Figure 9.*) When the load travel on the conveyor and enters the Silo there are two SRM's working across the aisles and serving a buffer. The buffer rack is also placed perpendicular to the other racks in the Silo. The buffer is simulated with an invisible conveyor system. From the buffer the load then can enter the "real" storage. The Silo is also divided in one visual part and one numeric part just like the Lowbay (*see 5.1.2.3 Lowbay / Conventional storage*).

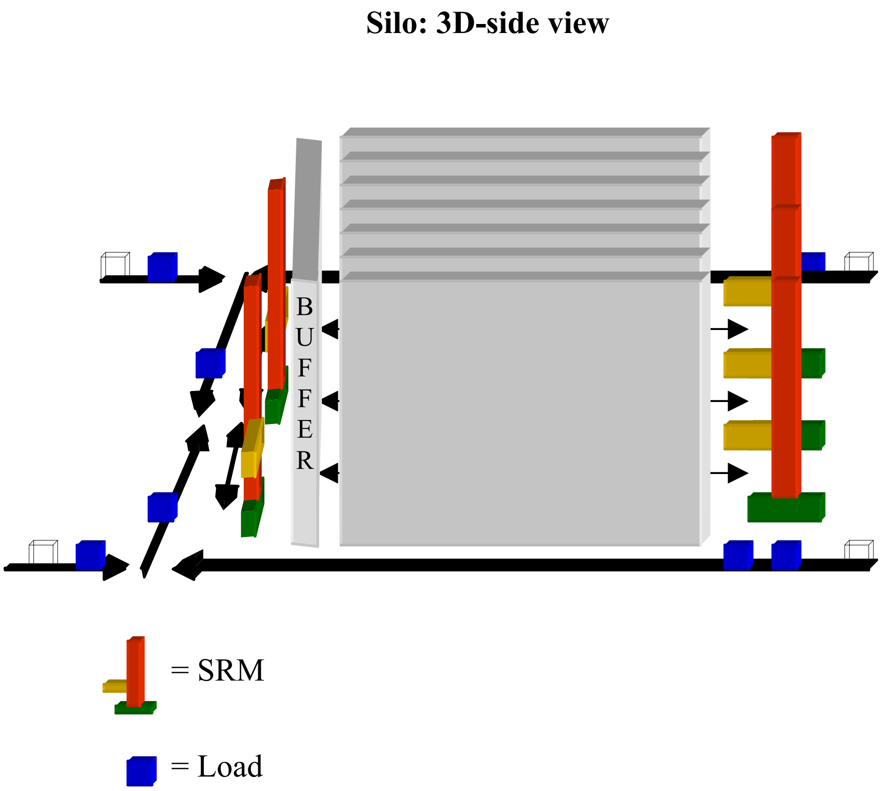


Figure 8: 3D-view of the Silo

Schematic top view of the Silo

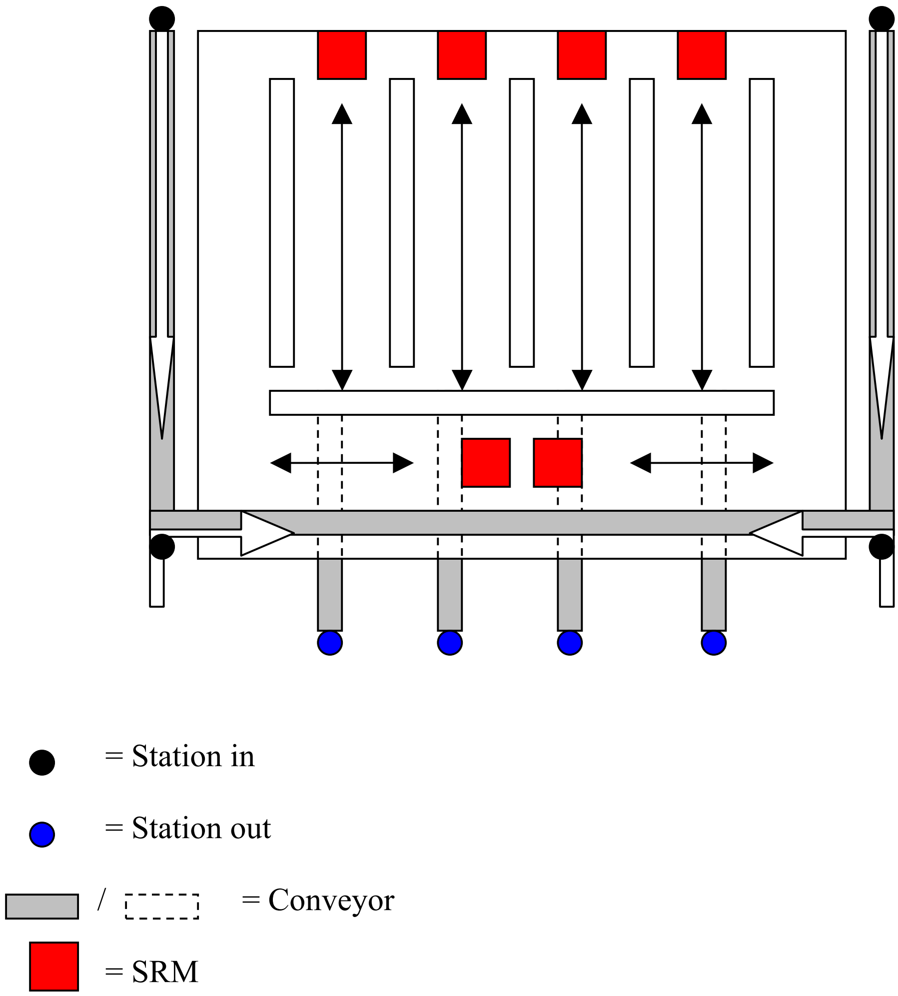


Figure 9: Silo Top view

There are six possible attributes, which can be set for the Silo. This means that two different choices can be set. The first choice sets the Silo to one zone all over, which means when a load enters the Silo the load can be placed randomly all over the Silo. The second choice divides the Silo into six different zones (One attribute is equal to one zone.). This means that frequent articles/loads could be placed as close as possible to the exits and this implies, shorter distances and thereby increased efficiency and increased throughput (*see Figure 10*).

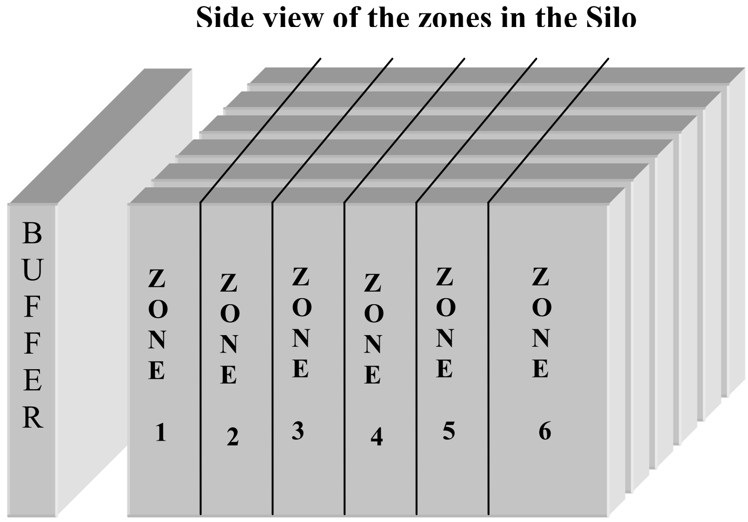


Figure 10: Silo divided into zones

Outbound flow:
The outbound flow is simulated with a conveyor system. The number of conveyors and outbound stations is equal to the number of aisle in the Silo.

5.1.3 Outbound logistics

5.1.3.1 Outbound docks

The docks are represented as queues in AutoMod. This is the meeting point for the fork lifters in the "inside" path mover system and the departure trucks in the "outside" path mover system. The fork lifters in the DC dispatch the loads to the queues. At a dock one single fork lifter continues to dispatch the loads into the truck.

5.1.3.2 Departure trucks:

The departure trucks are simulated in the same path mover system as the arriving trucks. Though there are eleven different departure trucks, each represents different stores in UK.

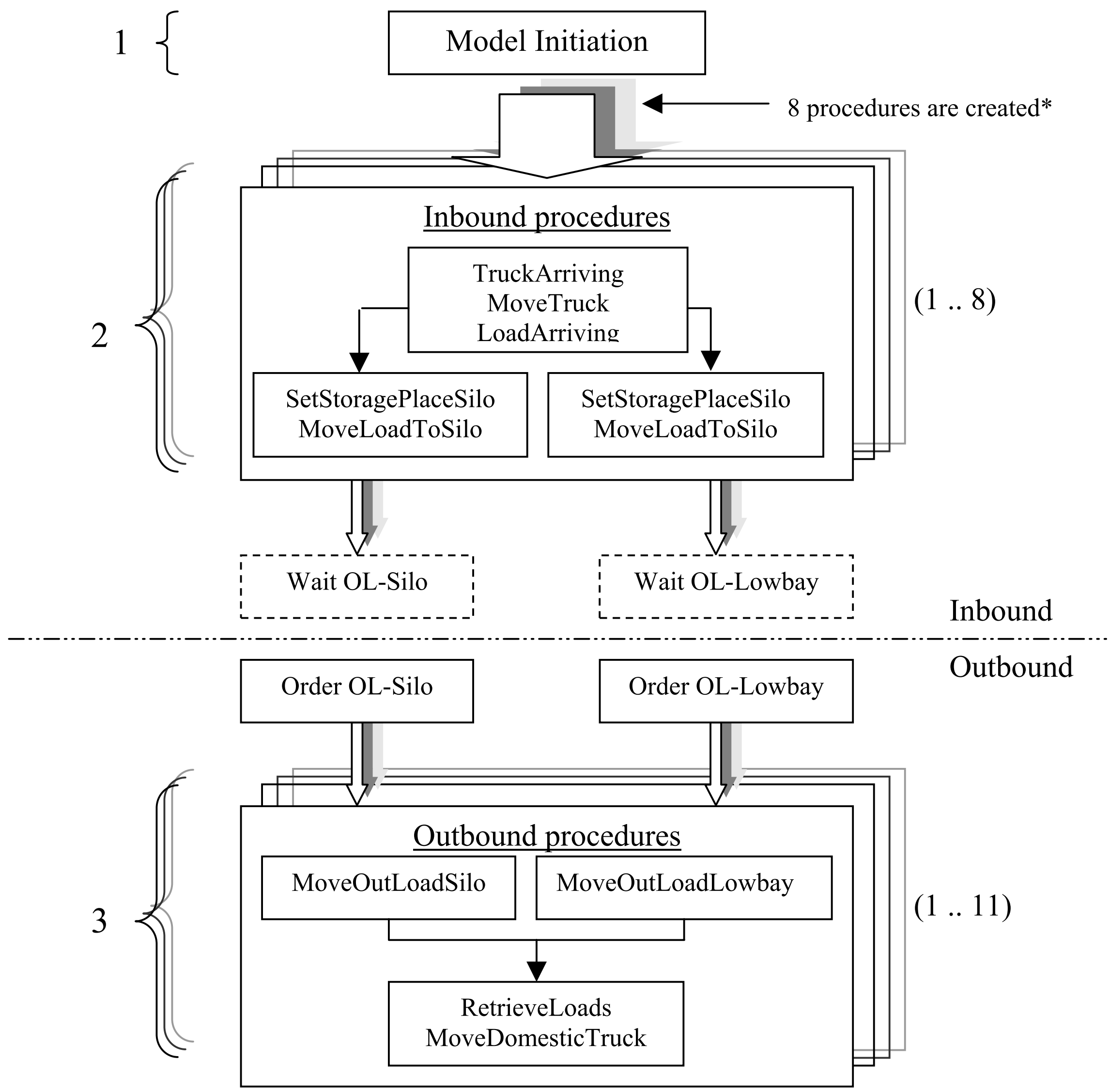
5.2 Graphic description

The graphic in the different systems in AutoMod represent only a minor part in the simulation. Most of the graphics in the model are built and imported from ACE. The graphic is unique and customized for the DC. The Peterborough DC is mainly built with static graphics. The only dynamic graphics are the fork lifters and the SRM's in the DC.

5.3 Procedure description

To make it understandable we will start to illustrate a schematic program structure on a basic and comprehensive level (*see Figure 11.*). Further we will present and illustrate the procedures on a more detailed basis, though simplified by following one load throughout the simulation, this will show what different choices and algorithms the load undergoes. An additional and more detailed and thorough description of the program structure are illustrated in *Appendix: Program structure*.

Schematic program structure



* 11 Outbound procedures are also created, waiting to be called upon

Figure 11: Schematic Program Structure

5.3.1 Processes

5.3.1.1 Model Initiation

The model initiation is the first part of the program and the starting point of the processes. This part is needed to do the processes ready for simulation.

Initiation function:
The function initiates the procedures and makes them ready for simulation.

P_Set:
In this process all the variables in the simulation are set. For examples; the number of incoming trucks, what frequency, number of different load types in each truck and choice of either mixed inbound/outbound flow or not.

P_Init:
This procedure set certain procedures/variables to zero and initialise certain procedures. For example you can make a choice in this procedure, which starts the simulation either with an empty DC (no loads in the racks) or with loads in the racks.

5.3.1.2 Inbound procedures

P_TruckArriving:
The initiation part starts up eight procedures (one procedure for each incoming truck). The procedures are waiting, but when an incoming truck is initiated one procedure is activated. The procedure is run trough and when that is done the procedure is ready for another truck to initiate it again (looping). The procedure simulates the arrival sequence of a truck from different countries, finds a suitable dock according to load types and country.

P_MoveTruck:
This procedure moves the trucks to a specified dock in the path mover system. This is the visually part of the arriving trucks. Eight different trucks can be visualised. It creates the number of loads in the truck. It also does a capacity check, which calculates the maximum number of loads allowed in the truck.

P_LoadArriving:
This procedure creates one procedure for each load type. The P_LoadArriving procedure can set up to twenty-eight load types in each arriving truck. The loads are placed outside the truck into the dock zone. This procedure sets the frequency attribute. The load now stands in front of two storage alternatives in the simulation. The storage depends on what kind of type the load belongs to (*see Figure 12*).

Alternative storage

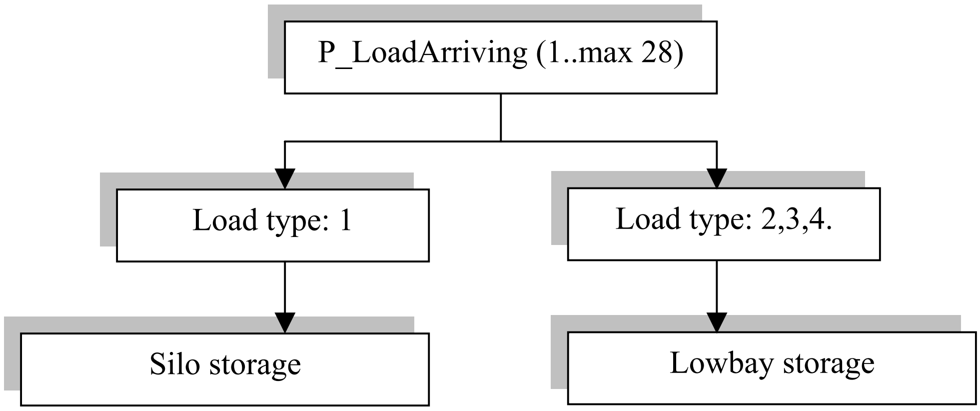


Figure 12: Alternative storage

Additional, the two alternative storages create two different paths. The different paths are illustrated below (*see Table 1.*). According to which processes the load is entering the load can end up in either Order Lists Silo (OL-Silo) or Order List (OL-Lowbay).

Load type:	**1**	**2**	**3**	**4**
Alternative:	**Silo storage:**	**Lowbay storage:**		
Processes:	P_SetStoragePlaceHigh P_MoveLoadToSilo	P_SetStoragePlaceLow P_MoveLoadToLowbay		
Order List:	OL-Silo	OL-Lowbay		

Table 1: Alternative paths.

Silo storage

P_SetStoragePlaceHigh:

Sets a storage place for the load, according to predefined pattern (racks associated to this type of load). There are two possible choices, which can be set up for the Silo.

- The first choice assigns a random place in the rack(s), and from this place the load finds the first available storage place. If no storage place is found the load is send to a Dump place (queue).

- The second choice uses zones. The Silo is divided into six different zones. Here the algorithm first tries to find a storage place as close as possible to the exits, and secondly it searches for empty places further back in the Silo. This alternative minimizes the distance to the exits. If no storage place is found the load is send to a Dump place (queue).

P_MoveLoadToSilo:
This procedure moves the load from the dock to a specified storage place in the Silo. This procedure takes us through four systems. It starts at the docks (control points) in the path mover system inside the DC and moves on to the conveyor system, which is feeding the Silo. After the conveyor the load is moving into the buffer, which is simulated with an invisible and stationary conveyor system (*see 5.1.2 The Peterborough DC / Highbay/Silo).* From the buffer the load is entering the ASRS system in the Silo and finally the load finds the specific storage place.

Order List (OL):
When a load has found a storage place in the Silo, the load is placed in an Order List. Here the load is waiting to be called for.

Lowbay storage

P_SetStoragePlaceLow:
Sets a storage place for the load, according to predefined pattern (racks associated to this type of load). There are two possible choices, which can be set up for the Lowbay storage.

- The first choice assigns a random place in the rack(s), and from this place the load finds the first available storage place. If no storage place is found the load is send to a Dump place (queue).

- The second choice uses zones. The Lowbay area is divided into eight different zones, each zone referring to a country. Here the algorithm first tries to find a storage place as close as possible to the floor within the zone, and after that it searches for empty places in the same tier. If this is not possible it changes to the next tier above and so on. This alternative minimizes the distance to the floor and thereby the docks. If no storage place is found the load is send to a Dump place (queue).

P_MoveLoadToLowBay:
This procedure moves the load from the dock to a specified storage place in the Lowbay area. It all takes place in the same path mover system inside the DC.

Order List (OL):
When a load has found a storage place in the Lowbay area, the load is placed in an Order List. Here the load is waiting to be called for.

5.3.1.3. Outbound procedures

P_MoveOutLoadSilo:
After the load is being claimed, this procedure moves the load out of the Silo. The load is moving in the backward order referring to P_MoveLoadToSilo, though with the slight difference of exiting the Silo through the exit stations in the conveyor system.

P_MoveOutLoadLowBay:
This procedure take the load from the control point in the Lowbay area and moves it in the path mover system inside the DC to an outgoing dock (control point).

P_RetrieveLoads:
Sets the amount of outgoing loads for the domestic trucks, depending on truck, load type and country origin. Finds a suitable (and free) dock for the truck.

P_MoveDomesticTruck:
Moves the truck in, the path mover system outside the DC, to the dock. Here the truck waits to be full according to the order and then it drives away.

6. Experimental design

This chapter describes the input data. The chapter also contains different scenarios aimed to attain our problem definition and our objective. The first scenario will investigate the optimal number of Automated Cranes, for the best throughput, in the Silo. This scenario underlies further analysis of the Silo. The following scenarios will depart from this optimisation and investigate how different storage mode will affect the throughput

6.1 Input data/prognosis

For figures of input data view *Appendix: Input data/prognosis*

The run control of the simulation is set to:

Run time: Six days a week, based on a sixth teen hours working pattern in the weekdays and eight hours shift on Saturdays. Eighty-eight hours total, a week.

6.2 Scenario structure

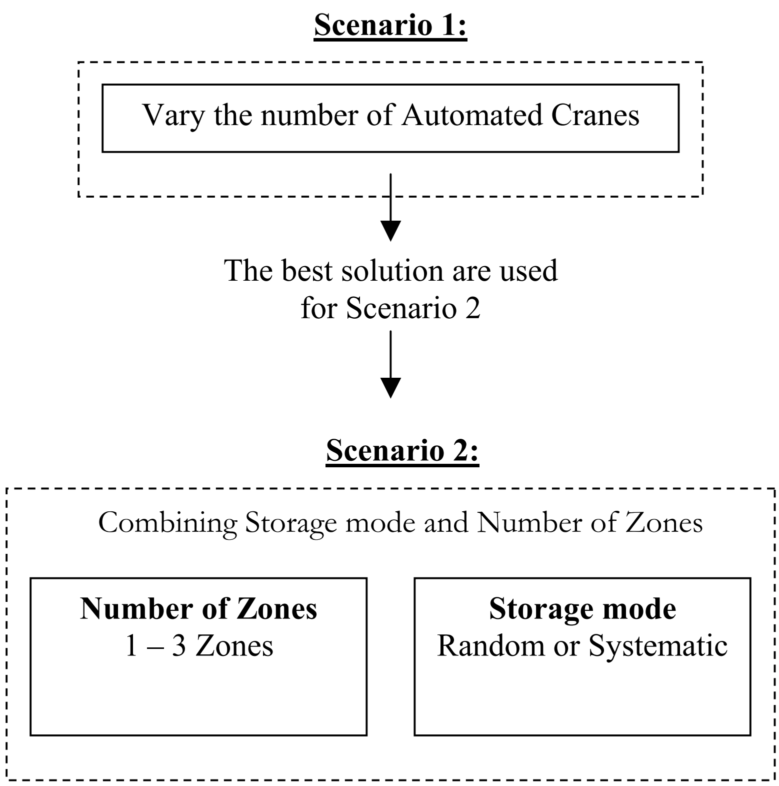


Figure 15: Structure of the scenarios

Common assumptions for the scenarios:

- Both scenarios start with loads in the Silo and the conventional stacking area. There are already twenty thousand loads in the DC. Randomly spread.
- The DC utilizes mixed inbound and outbound docks.
- The security level of the Silo is set to ninety five percent.
- The fork lifters are operating in zones.
- FIFO-rule is used.
- Hundred fifty inbound trucks arrives to the DC every week.
- Hundred fifty outbound trucks arrives to the DC every week.

We will shortly describe the analyse methods used when analyses were done in AutoStat.

One factor analyse:
This model analyse how the model behaves when you change one factor, while keeping other factors constant. A factor could be for example the number of resources or a machine's processing time. What the output analyse will focus on is what happens with the Silo throughput and how it affects when factors are varied.

6.3 Silo Scenarios

6.3.1 Scenario 1

6.3.1.1 Number of Automated Cranes

We will focus on the Silo and isolate it from the rest of the DC. We will consider variations in the number of Automated Cranes. This scenario underlies further analysis of the Silo. Though isolating the Silo, each scenario is taking the whole system into consideration. From the arriving trucks, the material flows through the DC and finally when the loads are leaving the DC with the departure trucks. The scenarios are aimed to attain our problem definition and our objective (*see 1.2 Problem setting, 1.3 Objective*).

Number of Automated Cranes

Factors:

- Vary the number of Automated Cranes (SRM'S) between 4 and 7.

Response:

- Silo-throughput per hour*

*measured against the demanded output from the Silo

Figure 13: Scenario: Number of SRM's

6.3.2 Scenario 2

6.3.2.1 Storage mode

According to the scenario described above we will use the optimal number of Automated Cranes for the following scenarios.

Random mode

Using the random method the loads in the Silo are placed with a random algorithm. The algorithm finds a location randomly. If that specific storage location is vacant the load is placed in that location. If the specific location is occupied the algorithm searches for a location next to the previous until a vacant location is found see figure 15 below.

Systematic mode

The systematic algorithm is shown below (*see Figure 14*). The Silo is divided into two zones. According to the frequency, the loads with the highest frequency are placed in the front and the loads with minor frequency are placed in the back. The algorithm finds the bay nearest the exit (still within the zones). Then the load is placed from the bottom location to the top location within the bay. When the bay is full the algorithm searches in the next bay and so on.

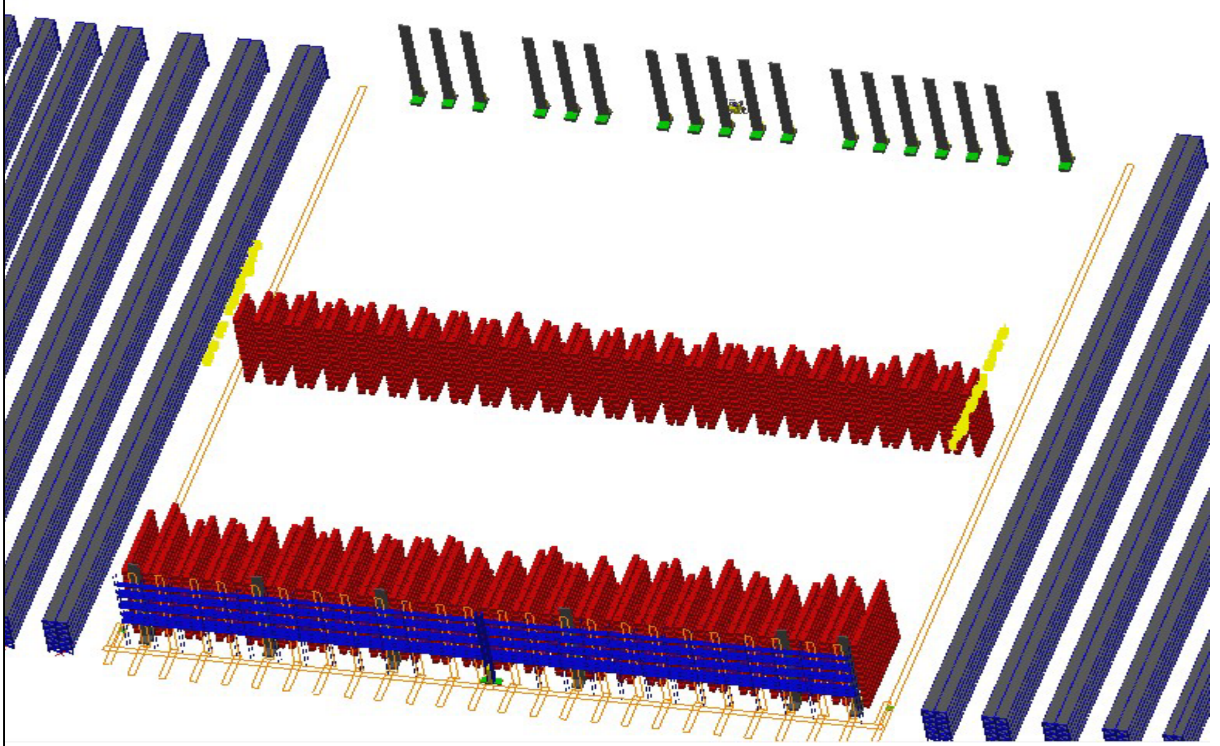


Figure 14: Systematic storage method

6.3.2.2 Number of Zones

Random storage using 1 zone

The Silo is not divided (*see Figure 15*). One zone is the total area of the Silo. The loads are placed randomly all over the Silo. Twenty thousand loads are the initial value.

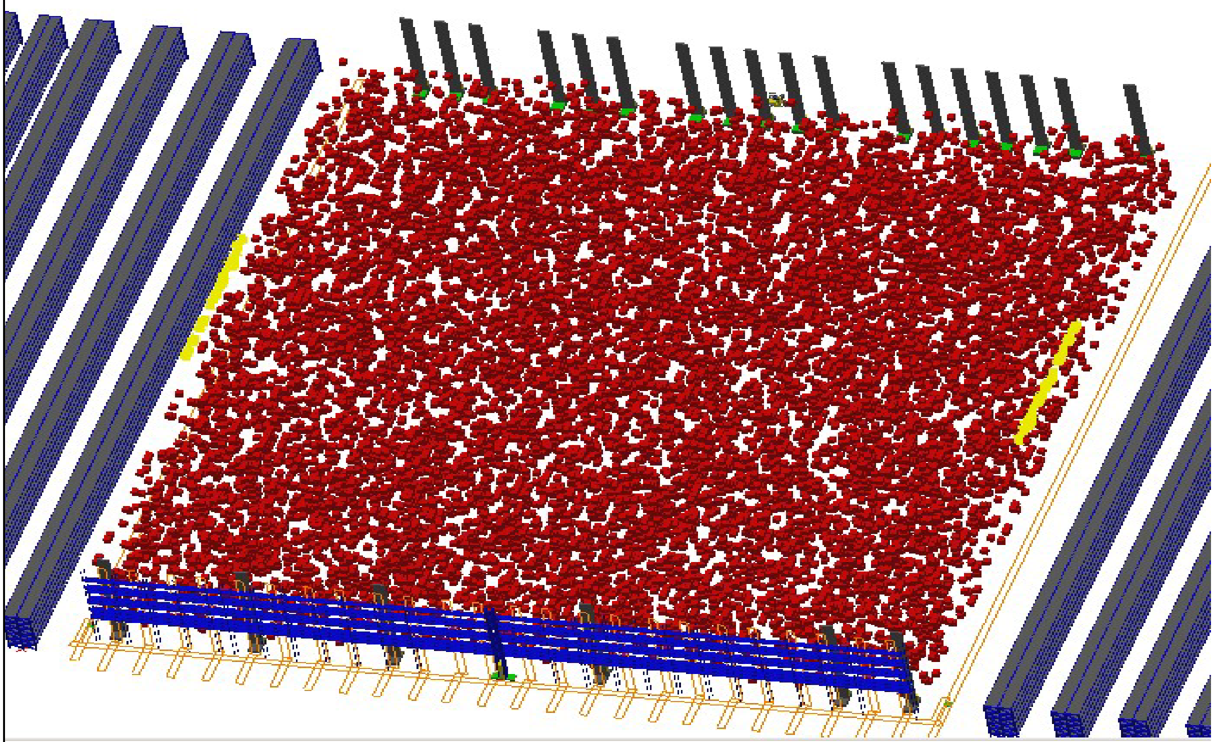


Figure 15: Random storage 1 zone

Random storage using 2 zones

Like described above, though the Silo is divided into two zones (no illustration picture are shown). The loads are placed randomly all over the Silo. More frequent loads are placed in the first zone in the front. The second zone in the back is used for the least frequent loads.

Random storage using 3 zones

The Silo is divided into three zones. More frequent loads are placed in the first zone, lower part of the figure below, and thereby closer to the exits. The middle zone is used for minor frequent loads and the third and last zone in the back are used for the least frequent loads. The loads are placed randomly within the zones.

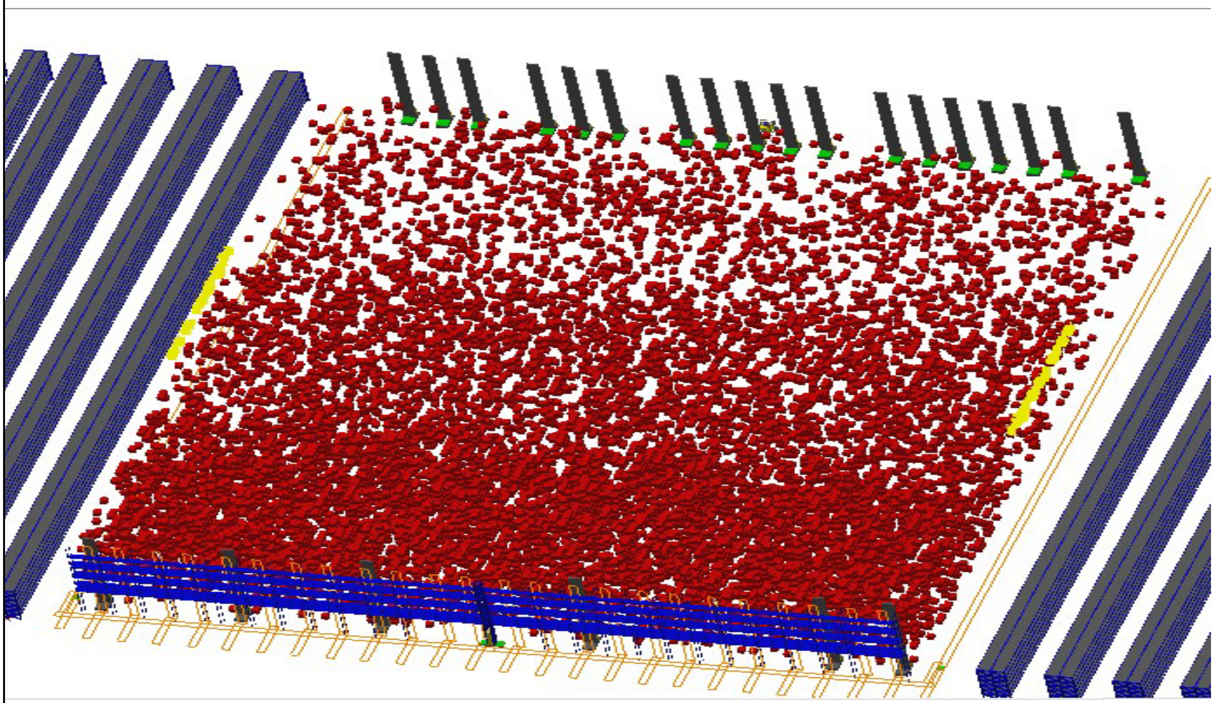


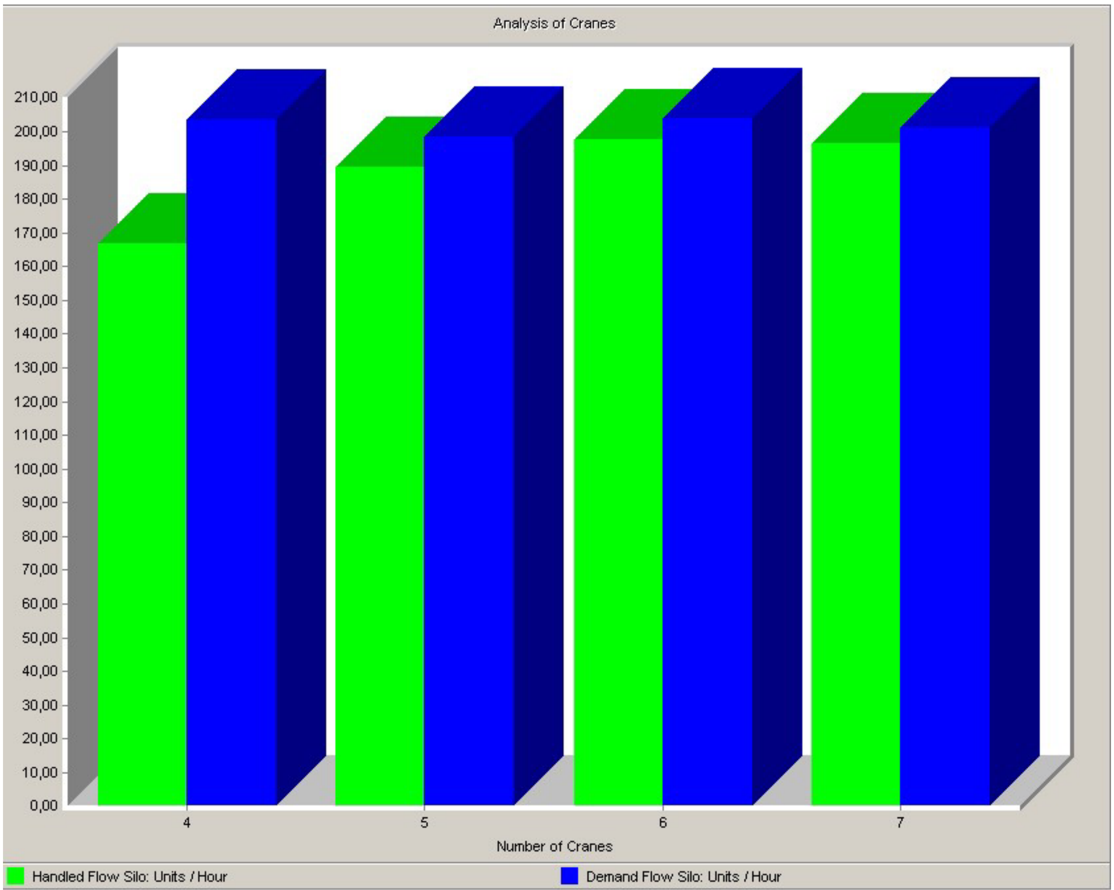
Figure 16: Random storage 3 zones

7. Output data analysis

This chapter will present the AutoStat analysis. In this analysis chapter our model and scenario connections will be put together. There will be a minor discussion under each headline with the objective to illustrate the main questions and to present the authors own findings.

7.1 Analyse Scenario 1

Number of Automated Cranes



= Handled Flow in the Silo Units / Hour

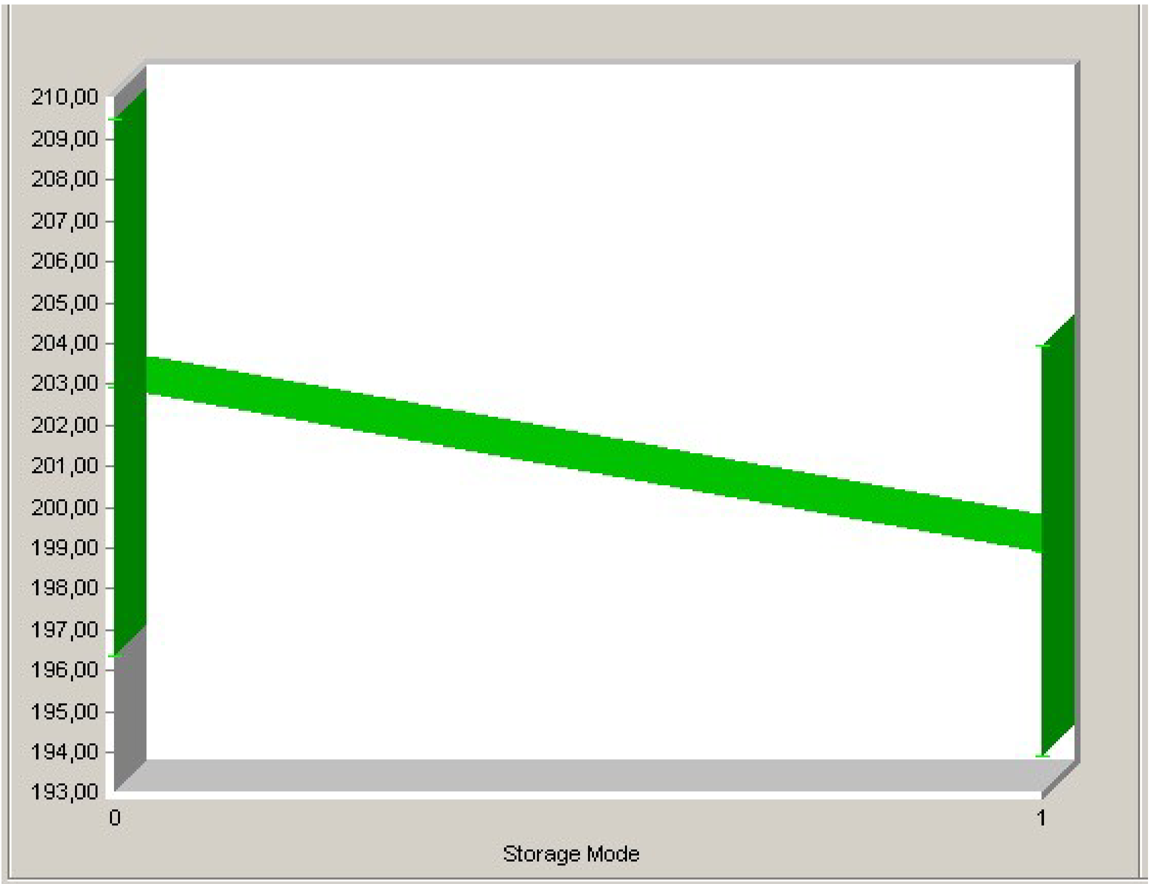
= Demanded Flow from the Silo Units / Hour

Figure 17: Silo throughput

The analysis of the Silo in AutoStat is shown above (*see Figure 17*). The y-axis displays the total Silo capacity per hour, while the x-axis displays the number of Automated Cranes. From the staple diagram you can make the conclusion that four SRM's operating in the Silo is insufficient. The SRM's cannot deliver the demanded loads. We consider five SRM's the capacity is sufficient within the margin. Six cranes as well as seven cranes are sufficient (within the margin). The difference between six cranes and seven cranes considering the throughput are slight.

7.2 Analyse Scenario 2

Storage Mode



0 = Systematic Storage Mode
1 = Random Storage Mode

Figure 18: Storage Mode

Figure 18 above shows the difference between the systematic storage mode and the random storage mode. Though the analysis is done with the confidence level of 95% and the figure is showing that the difference between the modes cannot be statistically determined. The differences are within the interval.

Number of Zones

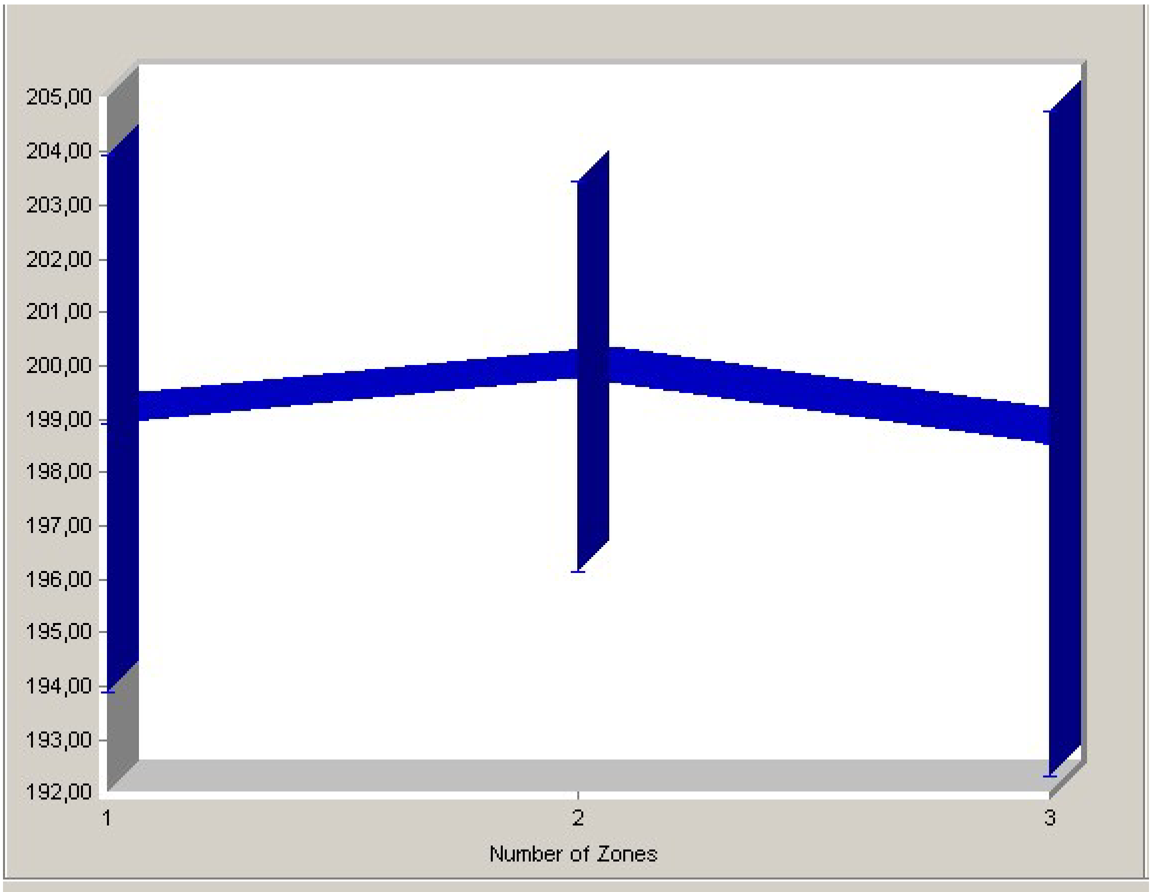


Figure 19: Number of Zones

The analyses of the Silo when divided into zones are shown above in figure 19. The analyse states that the usage of two zones shows the best throughput. Though, as described for the analyses of the storage mode, the difference cannot be statistically determined, with a confidence level of 95%.

8. Final discussion

This chapter will present the authors own findings. There will be a minor discussion with the objective to illustrate the main questions and connect the analysis with the authors' own findings.

When looking at the first scenario and the analysis made of the number of cranes it shows that four cranes are insufficient and five to seven cranes manage the demanded throughput. We believe the best solution is to use six cranes. Five cranes manage the flow but we have not taken maintenance and breakdowns into consideration. Seven cranes do not increase the throughput according to the analysis and therefore we find seven cranes unnecessary. Hence six cranes are the best solution.

The second scenario analysing the storage mode and the number of zones in the Silo differences can be shown. Though for both cases there cannot be any statistically secured results, using the confidence level of 95%. When considering the variation of the number of zones we consider the zoning could be done in a different way. Because of the fact that there are not SRM's in every aisle the cranes have to change aisles. Using the zoning from the front to the back as described the cranes have to move a long distance when changing aisle for the fast-moving articles in the front of the Silo. Instead we believe the zoning should be done from the left to the right (or the way around) and the cranes in the fast-moving zones should have a crane in every aisle. The other zones could share the other cranes. Doing this we believe the time it takes to change aisle could be minimized.
When looking at the staple diagram all the staples show a slight insufficiency considering the capacity. We though believe a longer simulation time would equalise the staples.

These analyses show only a small part of what can achieved with the simulation. Many other things and factors can be varied and calculated upon, but this is a project for future studies.

9. Future approach

This chapter will present the authors findings of future work. The chapter is divided into two parts, which is two different approaches. The first part present future work within the capabilities of the model and the second part presents future expansion of the model.

The model is build to be able to simulate the total internal material flow of the Peterborough DC. In this report though, we have chosen to focus on a minor part of the DC. The Silo is isolated and it is only this part that we have chosen to analyse in AutoStat. The future approach we would like to see is continued simulations and measurements of other parts of the system. We think the following questions of issue and investigations could be of interest:

Future analysis

Run capacity analysis of the dedicated racks, in the Lowbay area:

- Is the capacity of the dedicated areas enough?
- Possible bottlenecks?

Run analysis of the fork lifters:

- What happen when they are working all over the DC?
- What happen when they are demarcated into zones?
- Number of fork lifters needed in the DC?
- Utility?
- What happens with the input/output?

Mixed inbound/outbound:

- What happens with the fork lifters pattern?
- Total material flow?

Future model expansion

A future model expansion and approach would be to investigate how picking inflict on the material flow. Almost thirty percentages of the total pallets are picked pallets in the material flow. This has a big impact on the material flow and we see this as an interesting area to look into. Another suggestion of future works and expansion of the model would be to take the Customer Distribution Centre into consideration.

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Interviews

Thrapston Distribution Service:

- Darrell Harvey, Logistic Manager
- Adri R. Kraa, Business Support Manager
- Miranda Stephens, Logistic Trainee
- Nick Ridley, DC layout

Doncaster Distribution Service:

- Keith Morris, DC Manager

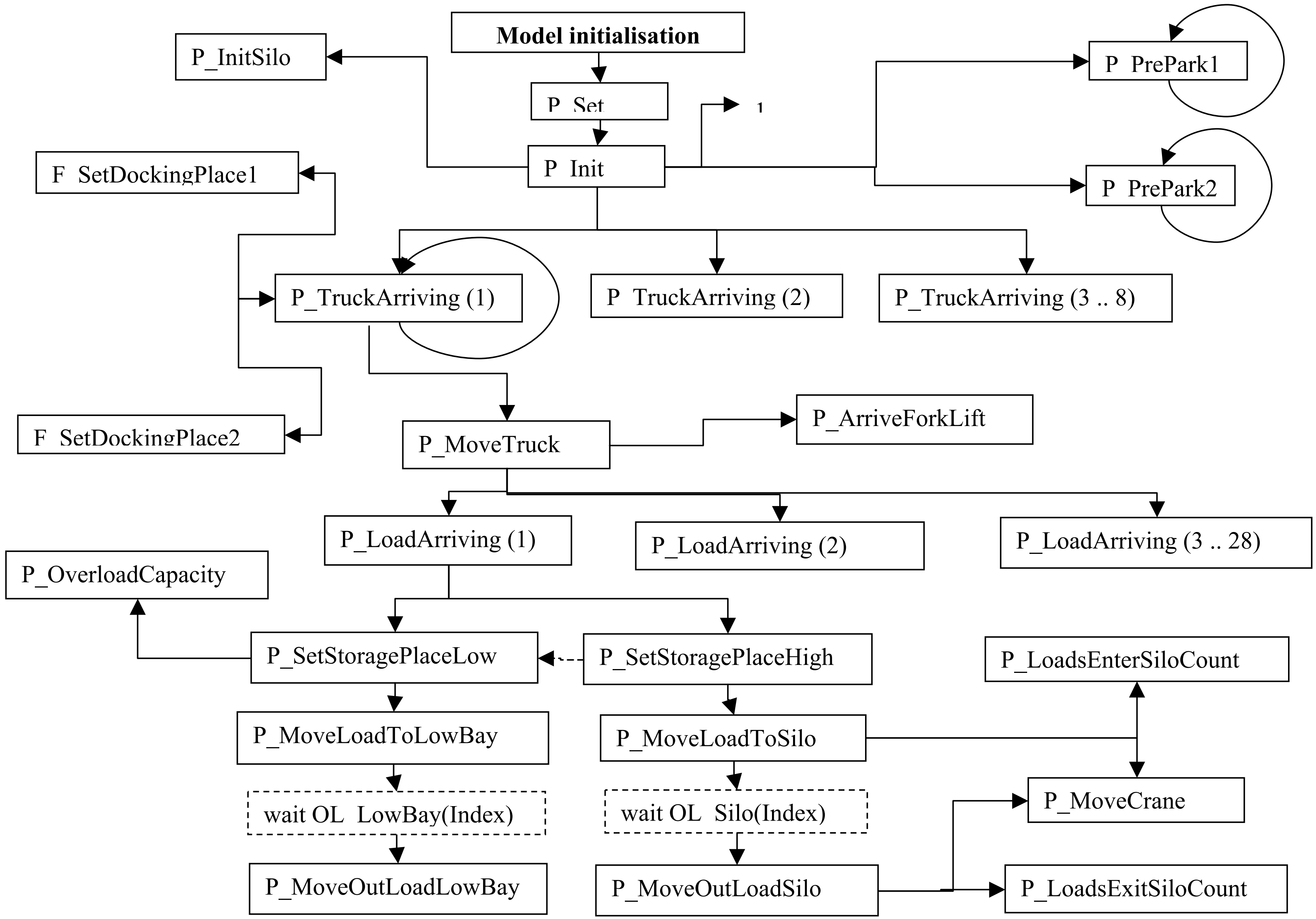
Appendix

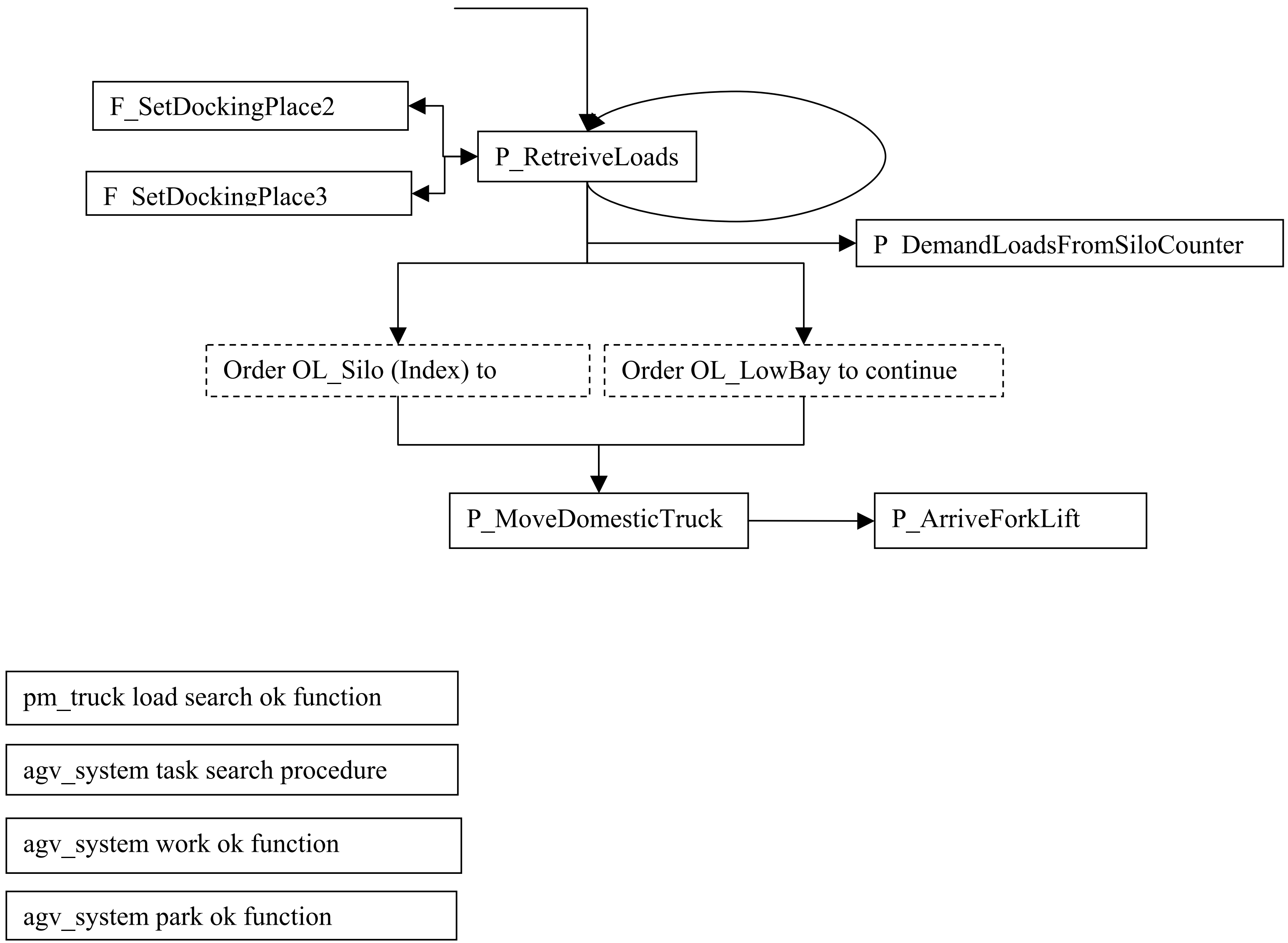
Input data/prognosis

Truck	Arrive Every (h)	Deviation	Amount per week	Type1	Dev	Type2	Dev	Type3	Dev	Type4	Dev
1	4	0	22 (88)	10	5	5	2	5	2	5	2
2	5	0	18 (90)	10	5	5	2	5	2	5	2
3	10	0	9 (90)	10	5	5	2	5	2	5	2
4	7	0	12 (84)	10	5	5	2	5	2	5	2
5	3	0	29 (87)	14	1	5	2	5	2	5	2
6	4	0	22 (88)	14	1	5	2	5	2	5	2
7	3	0	29 (87)	12	5	5	2	5	2	5	2
8	8	0	11 (88)	12	5	5	2	5	2	5	2
		Total	152								

Truck	Retrieve Every (h)	Deviation	Amount per week	Type1	Dev	Type2	Dev	Type3	Dev	Type4	Dev
1	6	1	15 (90)	10	5	5	2	5	2	5	2
2	8	1	11 (88)	10	5	5	2	5	2	5	2
3	5	1	18 (90)	10	5	5	2	5	2	5	2
4	10	2	9 (90)	10	5	5	2	5	2	5	2
5	7	1	12 (84)	10	5	5	2	5	2	5	2
6	6	1	15 (90)	14	1	5	2	5	2	5	2
7	3	1	29 (87)	14	1	5	2	5	2	5	2
8	8	1	11 (88)	14	1	5	2	5	2	5	2
9	15	1	6 (90)	12	5	5	2	5	2	5	2
10	9	1	10 (90)	12	5	5	2	5	2	5	2
11	6	1	15 (90)	12	5	5	2	5	2	5	2
		Total	151								

Program structure




F_SetDockingPlace2
F_SetDockingPlace3
P_RetreiveLoads
P_DemandLoadsFromSiloCounter
Order OL_Silo (Index) to
Order OL_LowBay to continue
P_MoveDomesticTruck
P_ArriveForkLift
pm_truck load search ok function
agv_system task search procedure
agv_system work ok function
agv_system park ok function

Questionnaire

CAD-DRAWING:
We have opened the CAD-drawing from an AutoCAD viewer. Some information where missing.

- Which parts of the DC are we suppose to focus on? The:
  - "DC high bay racking R/G/86"?
  - "DC low bay racking R/G/83"?
  - "DC low bay racking R/G/84"?

  The CDC:
  - "DC low bay racking R/G/85"? Or all of them?

- At the meeting here in Lund you mentioned a distribution (60%-20%-20%) between the different racking systems. Did you mean:
  - 60% to the "DC high bay racking R/G/86"?
  - 20% to the "DC low bay racking R/G/83"?
  - 20% to the "DC low bay racking R/G/84"?

- To be able too draw the DC as well as be able to do a proper simulation we need some dimensions:

  - Height of the racks?

  - Number of tiers (storage places up)?
  - How high (m) per tier (height per storage place)?

  - Number of bays per rack (storage places along the rack)?
  - Width per bay (width per storage place)?

  - Depth per bay (storage place)?

- Which docks (what are the dimensions of a dock?) are intended for the incoming flow (loads) and which ones are intended for the outgoing flow (loads)

- As we understand there are cranes (SRM's in AutoMod) only in the "DC high bay racking R/G/86", and one-crane support 4 aisles. Is this accurate?

- Do the other sections use fork lifters (trucks)?

- We will need to have data of the SRM's and the fork lifters. E.g. velocity, pickup time, set down time.

IN DATA:
For the capacity check:

- Are there any articles that have to be addressed to a specific rack (zone) or do it not matter?

- Is the arrival fixed or with probability (per day)

- What kind of arriving/departure procedure

- How many trucks are incoming / day?
  - We can set up to 8 different trucks.

- How many trucks are outgoing / day?
  - We can set up to 11 different trucks.

- How many loads are in each truck?
  - We can set up to 4 different loads for each different truck (both outgoing and incoming): fixed number or with deviation (for instance: 28 or 24 +- 4). For the outgoing trucks we can also set the country origin for the load.

- The number of racks (and location of the racks) that are dedicated for each country?

SILO:

- How do the loads enter and leave the silo?

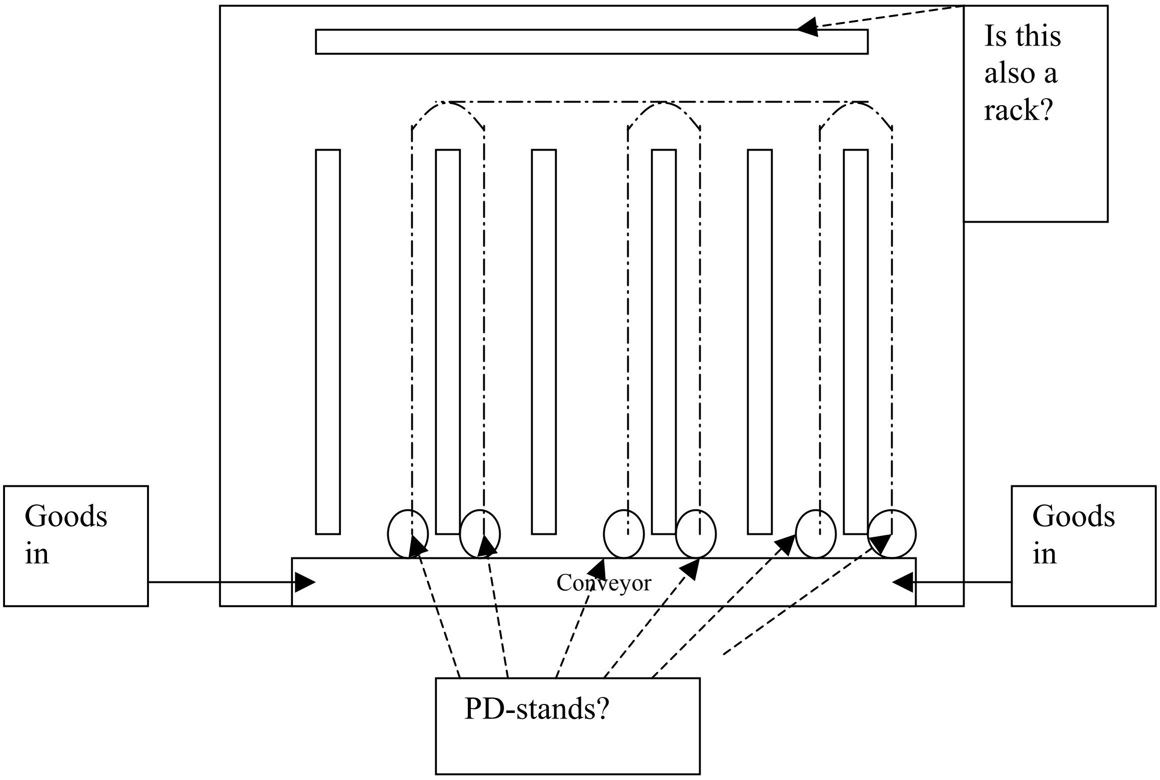
- The CAD-drawing and the excel-sheet differ from each other, concerning the flow of gods in. We have trouble to interpret them.

- Is the entering and leaving processes to the silo taking place from two directions?

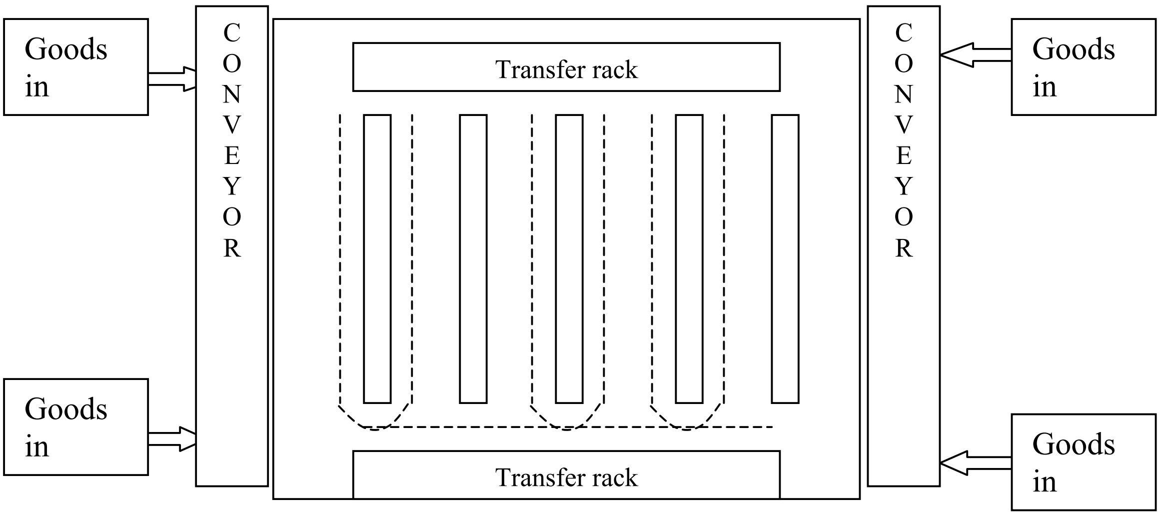
- PD-stands where?

- How long time does it take for a crane to change aisle?

Referred to the CAD-Drawing:



Excel sheet: (note: The excel sheet is upside down compare to CAD-drawing)



- Which of these schematic drawings above are most accurate?

- Maybe you can give an example of the transfer for one load: entering process→ transfer process→ storage process→ leaving process

- Can you explain how the flow of goods to the Silo is working, please? What function do the conveyors have? Where can a load enter /leave the silo?