Improving logistic planning in the construction industry using Wireless Sensor Networks and Multi Agent Systems

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Management Summary

Construction sites are heavily dependent on logistics. Also many construction processes are highly dependent on each other and the supply of building resources. A delay in the beginning of the supply chain could lead to a lack of supplies at the end which could cause a halt. Planning the logistics of the construction industry is a challenging task. Large savings can be made by increasing planning efficiency. This research focuses on the logistic planning of Remix which produces dry mortar for the construction industry. Remix places silos at construction sites and refills them when needed. Currently the silo statuses are checked manually and on irregular intervals. This results in high priority orders, which are more difficult to plan on time with a tight schedule.

In this research the supply chain of the construction industry has been analyzed in order to improve the logistic planning. Wireless Sensor Networks are used for measuring the environment. Wireless sensor networks can support the delivery company managing orders by providing information about inventory levels. In this case WSN are used for gathering silo information located at construction sites. This information supports the planning department to prevent silo stock outs.

Multi Agent Systems can also use this data to create a view of the environment in which they need to act. Depending on their level of control they can alert the foreman when a silo gets to a critical level or placing an order automatically.

A prototype application has been developed to show the benefit of using information gathered by WSN. Planners can easily view critical silo statuses and contact the construction site for placing an order on time. Also foremen of construction sites can use the prototype to view their silo statuses and place orders when needed. Such an application reduces the time needed for entering orders, because orders can be placed by the customers themselves. Also the availability of the information will lead to fewer urgent orders.

Also a simulation application has been built to simulate the usage of intelligent agents and evaluate its performance. A set of hypotheses are tested against the output of several simulation runs with each different input settings representing different scenarios. The result of this simulation provides an impression of the performance of a multi agent system for the logistic planning of the construction industry.

The prototype application clearly shows the usefulness of data gathered by the wireless sensor network and providing this information to the planners. Planners can now actively view silo statuses and take action when needed.

Applying Multi Agent Systems for the logistic planning is possible and can result in performance improvements. However in order to make such a system an improvement of the current situation the agents have to deal with a lot of information and make the right decision with this information. The simulation tool developed in this research simulates the processes in the supply chain of a mortar company. Different scenarios have been analyzed and evaluated with different settings for the agents. The outcome provides a better understanding of the forces influencing the performance of the agents.

Implementing such a solution in the business environment requires a few changes to the planning process. Depending on the level of control of the agents, agents can place orders automatically

without interference of the planner. The role of the planner changes from planning actively to verify the planning made by the agents. This reduces the time needed to create an optimal planning, which can cope well with changes in an existing planning. An optimal planning also reduces fuel costs and the amount of man power needed.

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Preface

In September 2008 I started this graduation research. The first few months I spent on reading a lot of literature and defining my research approach. During this time my supervisors helped me a lot by providing possible directions for my thesis. Obviously, this project would not have been as successful as it has been without certain people that supported, and pushed me along the way.

First of all I would like to thank Jos and Silja, my supervisors from the University of Twente. Jos helped me a lot with giving me advice for the direction of my thesis. Silja helped me a lot in the process of structuring the document.

Secondly I would like to thank the expert group, who provided me a lot of valuable feedback during several presentation sessions. Also valuable information about the wireless sensors of Ambient was discussed during these sessions.

Also I want to thank the participating companies (Jonker B.V., Ambient Systems) for their time and effort. Both parties also attended the presentation session, in which a lot of relevant information was discussed about this project, but also helped me a lot getting on the right direction.

I also want to thank Remix for the opportunity of visiting them during an evaluation of the TClick software by Jonker. This provided some extra insights I otherwise would not have been able to get. The last company I would like to thank is Dhr A. Vaster of Roosdom Thijhuis for evaluating the usage of my prototype application.

Finally I would like to thank my parents for supporting me in these stressful times. This leaves me with nothing more to say than that I hope you will enjoy reading my master thesis. If you have any questions please do not hesitate to contact me, I will be happy to help you if I can.

Best regards,

Dirk Engels

PART I: INTRODUCTION

1: Research Approach

1.1: Introduction

Construction sites are heavily dependent on transportation of resources and materials. The space available on a construction site is limited. Therefore a lot of construction sites need just in time deliveries of materials in order to prevent delays. According to estimates the construction industry generates 25% of all transport on the road. A recent study on emissions shows that construction and production sites are the largest share of the world's total CO_2 emissions. [MAS10]

Considerable savings in the chain of site / contractor - transport - supplier is possible according the participating stakeholders and my supervisors. Losses occur due to lack of coordination and information sharing in the chain. Thus deviations on the construction site often do not reach suppliers in time. Variations and deviations at the construction site heavily influence the planning.

Many construction processes are highly dependent on each other. A delay in the beginning of the supply chain could lead to a lack of supplies at the end which could cause a halt. Handing over information orders or changes on time is a problem. Urgent orders occur regularly. Many disturbances in the upstream of the chain are the result. This is why planning the transportation of construction materials optimal is virtually impossible.

Using multi-agent planning technology in combination with real-time information from sensor networks decentralized coordination becomes possible. This could improve the logistics planning for the construction industry. In addition, organizational transitions are necessary coordination mechanisms and work processes.

The aim of this project is to investigate whether a different way of chain coordination in the construction industry leads to a more sustainable and efficient supply chain. The goal is to reduce transportation mileage, and thus emissions, but also decreases the amount of delays on the construction site. The focus of this project is on the logistic planning of a company producing dry mortar. Dry mortar is sold in bags or it is delivered in silos on location. The bottom of the silo is equipped with a mixing screw, which is connected to the water supply. When mortar is needed, a construction worker places a wheelbarrow below the mixer and starts mixing. The mixer mixes the dry powder with water in order to produce ready to use mortar.

The goal of this project and this research is looking for alternative ways of logistic planning using multi agent systems in order to reduce transportation costs, the amount of costly construction delays and to improve customer service.

Multi Agent Systems can support the whole supply chain using intelligent agents for automatic ordering and planning. An agent at the construction site can support the foreman in keeping inventory at the needed level. An agent at the delivery company for planning orders can support the planner to cope changes in planning. The agents can acquire information of the physical world using sensors by connecting the agents with a wireless sensor network, which is installed at a construction site.

Wireless sensor networks can support the delivery company managing orders by providing information about inventory levels of dry mortar. This information can be used by the planning department to plan deliveries and/or to prevent delays.

A producer of resources has the challenge of managing a large number of orders within a short period of time with limited information. The first challenge of this research is to find ways to improve the information available to the planner. The second challenge is to find out whether an intelligent agent can help a foreman or planner with ordering and planning.

1.2: Problem Description

Determining the current level of content in a silo is a manual task with inaccurate outcome. It is usually performed by hitting the silo and listening to the sound it makes. Using this technique the contents of the silo can be determined by some level of accuracy. When a silo makes an “empty” sound the foreman is informed so he can order a silo refill. Sometime it happens that the silo is checked too late to order in time. This may result in a high priority order for the dry mortar company or a delay at the construction site. The first option results in a more stressful job for the planners at the dry mortar company and is also extra costly. The second option is even more costly. These costs can be reduced by a system which monitors current resources and places orders in time to prevent silo from becoming completely empty (silo stock out).

A multi agent system is a system that is composed of several independent programs called agents: “An agent can be a physical or a virtual entity that can act, perceive its environment (in a partial way) and communicate with other agents, is autonomous and has skills to achieve its goals and tendencies. A multi-agent system (MAS) contains an environment, objects and agents (the agents being the only ones to act), relations between all the entities, a set of operations that can be performed by the entities and the changes of the universe in time and due to these actions.” [FER99]

The goal of this research project is to develop better insights of developing a multi agent system applied at the construction industry as a whole and a dry mortar company in particular. Agents must have access to some environmental data in order to function properly. In this case an indication of the silo content is needed for creating an agent system for ordering and planning the dry mortar deliveries. A wireless sensor network is used to acquire the data of the silo(s).

2.3: Questions

The main question of this research is:

- How to apply Multi Agent Systems and Wireless Sensor Networks at the supply chain of the construction industry to improve the logistic planning?

In order to find the answer to this question several sub questions will have to be answered.

1. What does the supply chain of the construction industry look like?

2. How can wireless sensor networks support the logistic planning of the supply chain of the construction industry?

a. What are wireless sensor networks?

b. How can wireless sensor networks be applied in the supply chain of the construction industry?

3. How can multi agent systems in combination with wireless sensor networks improve the support of logistic planning in general?

a. What are multi agent systems?

b. How can multi agent systems in combination with wireless sensor networks be applied to the supply chain?

2.4: Approach

Several research methods can be applied for conducting this research. The most applicable research method for answering the main research question is a design science research. Design science research creates and evaluates IT artifacts intended to solve identified organizational problems. “It is about the process of developing a new idea or solution using tools, methods and languages as a prescriptive form of theory. In many cases design research is combined with an empirical method (action research, experiment) to validate its effectiveness” [HEV04].

In this case a prototype for an application will be built to show the proposed work process and how agent can support these processes. The prototype will show the use of WSN for sharing the silo content information with the planning department and the customer.

The application can also be used to simulate the supply chain processes between the dry mortar company and its customers by automating its task based on preset input variables. The second goal of the simulation is to show how agents can automate the ordering process. The performance of autonomously ordering by agents will be tested by a simulation.

2.5: Structure

The research is divided into four different phases (see figure 1). During the first phase is a literature study covering three domains; supply chain management, wireless sensor networks and multi agent systems will be conducted. In the second phase the current supply chain management of a dry mortar company (particularly Remix) is analyzed. In the third phase the ideal situation will be defined by combining theory and practical knowledge from stakeholders. A prototype application will be built in order to communicate the new situation to the stakeholders. The final phase consists of the evaluation. The result is a set of recommendations for implementing WSN and MAS technology at Remix and some recommendations for future research.

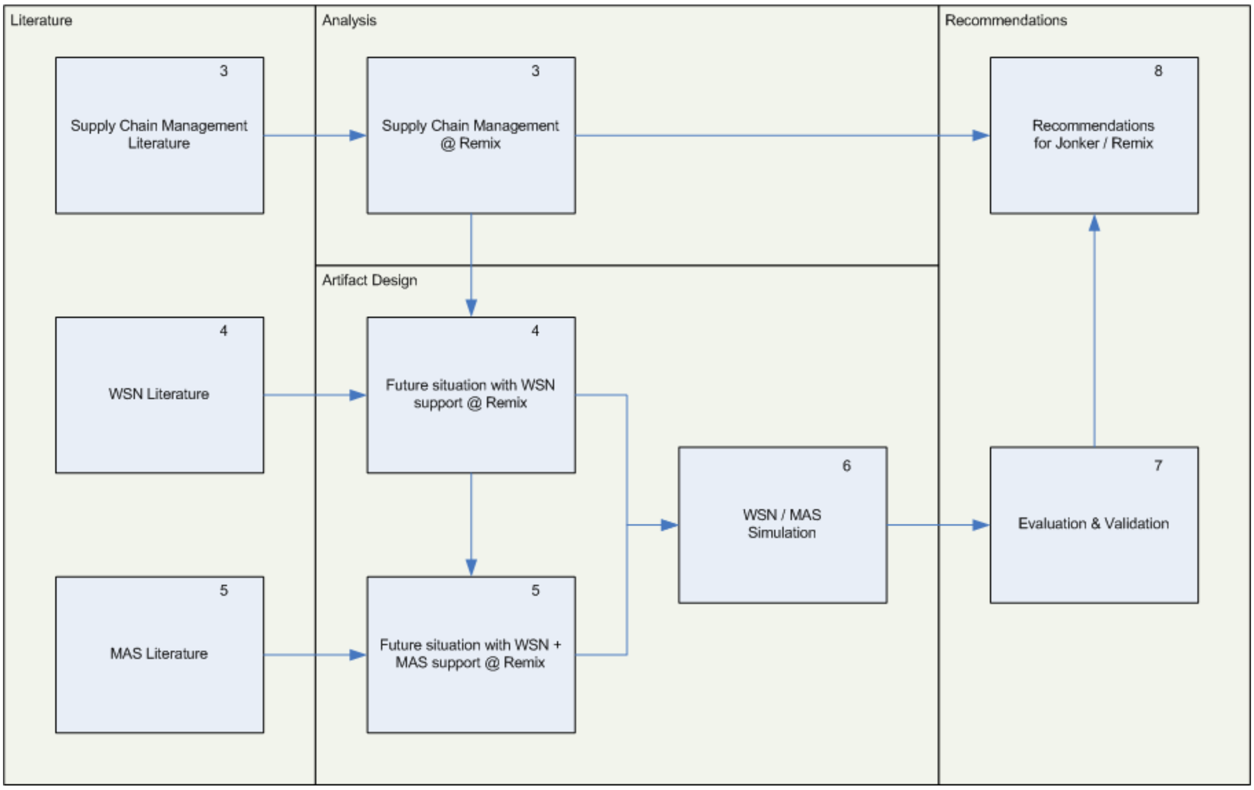


Figure 1: Research approach

2.6: Impact & Relevance

There is a great practical benefit for the partner companies, involved in this research. They can implement the solution whether it shows possible improvements. The theoretical significance of this research is to evaluate if multi agents systems are applicable to the construction industry and a dry mortar company in particular regarding the logistic planning system. The result of this research will give a better view on how multi agent systems can be applied for creating a more robust and flexible logistics planning for the construction industry.

This research is one of the first steps to see whether the supply chain of the construction industry can be supported by (intelligent) IT solutions. The results of this research can be extrapolated to logistics planning of other resources at a construction site. For example RFID sensors can be attached to move resources so tracking and tracing can take place.

2.7: Scope

A construction yard uses a lot of resources, which are delivered by many different companies. The foreman of a construction yard has the challenge of ordering all the different construction materials at the right time, which is a difficult task. Any delivery failure can result in delays which are associated with higher costs. Often the available space on a construction yard is limited. Therefore the sequence of the deliveries is also important. (Any delay of a particular delivery can result in postponement or cancellation of other deliveries.) The processes and relation between the construction site and producer are analyzed. Also a prototype of the proposed solution will be presented to support the contractor to manage orders and deliveries.

The producer of resources has the challenge of managing many deliveries within a particular time window. Forecasting is difficult because the planning of the construction yard is unknown. Deliveries for the construction sites heavily rely on the logistic planning in order to meet its building schedule. The prototype will demonstrate a simplified model of the planning process

Extra tools and/or components might be needed for installing a silo on location. These tools and components can be rented from the delivery company. The ordering of extra tools needed for silo placements and refilling are not included in the scope of this project.

Deliveries for a construction yard can be dependent on each other, which require a lot of communication. Regularly a high priority order is placed in order to prevent construction delays. This can result in changes for the logistic planning of the delivery company. A small change for a single delivery can have a huge impact on the logistic planning. The performance of the simulation is tested against a relative small number of input variables regarding the real business environment.

An UT-Spin off company, Ambient Systems, has created a wireless sensor network which is capable of attaching different types of sensors besides the built-in temperature sensor. A part of the Multi-Agent Sustainable Supply chains for Construction (MASSCO) project is to develop a sensor to measure the contents of a silo over time. Using a wireless sensor network data of several sensors across an area can be collected in a central database.

To limit the boundaries on the research, the following scope will be used:

- A prototype is created to communicate the proposed solution with its stakeholders.
- A simulation application is created on top of the prototype to simulate the performance of the proposed solution using multi-agent and wireless sensor technology.
- A list of input variables of the prototype and simulation application is defined for the business environment settings.

During this research the following task will explicitly not be performed (this list is not exhaustive):

- Implement the solution in the business environment.
- Create a prototype of the wireless sensor measuring device. The measured data is assumed to be available in some sort of database.

2.8: Methodology

The following methodologies are used in order to find an answer to the research questions.

Research Question	Methodology
1) How does the supply chain of the construction industry look like?	Literature research Interviews with stakeholders, project group meetings
2) How can wireless sensor networks support the logistic planning of the supply chain of the construction industry?	
• What are wireless sensor networks?	Literature study
• How can wireless sensor networks be applied to the supply chain of the construction industry?	Literature research Interviews with stakeholders, project group meetings Design research
3) How can multi agent systems in combination with wireless sensor networks improve the support of the logistic planning?	
• What are multi agent systems?	Literature study
• How can multi agent systems in combination with wireless sensor networks be applied to the supply chain?	Literature study Design research

Figure 2: Research methodology

1.9: Technology

Wireless Sensor Networks can provide real-time information about the silos which could be used for planning the logistic. Multi Agent Systems can use this information to create an optimal planning. A literature study has been done to see if WSN and MAS can be used for creating the delivery planning which will cover three domains: Supply Chain Management (SCM), Wireless Sensor Networks (WSN) and Multi Agent Systems (MAS).

A Wireless Sensor Network (WSN) is a network consisting of small computing devices with sensors attached and communication capabilities. These devices can actively monitor objects in operational processes and keep track of the conditions of such an object. Implementing this technology can improve the quality of goods and can lower the cost of operation. [EGPS01], [SWS04], [LZLF08], [EHK08].

Traditional systems gather the information at a single point in order to make a planning. This approach works for a single company, but is almost impossible to do for a whole supply chain because of opposite interests of supply chain stakeholders. For optimal planning a correct and actual overview of the environment is needed. A small change of the input can lead to a complete different planning. An alternative approach is applying Multi Agent Systems (MAS). MAS consists of a set of intelligent devices, called agents, communicating and working together in order to reach a certain goal. MAS is a more robust approach, because decisions can be made decentralized thus decision making is more scalable [MHH08], [JH08], [LES03], [FER99], [SCH07].

A literature study has been performed in order to find articles within three domains. The first step was to find articles which include all three domains. Only very few papers are available that address all three topics. Therefore articles including one or two domains are examined. The articles where two or three domains are included are the most valuable resources for this research.

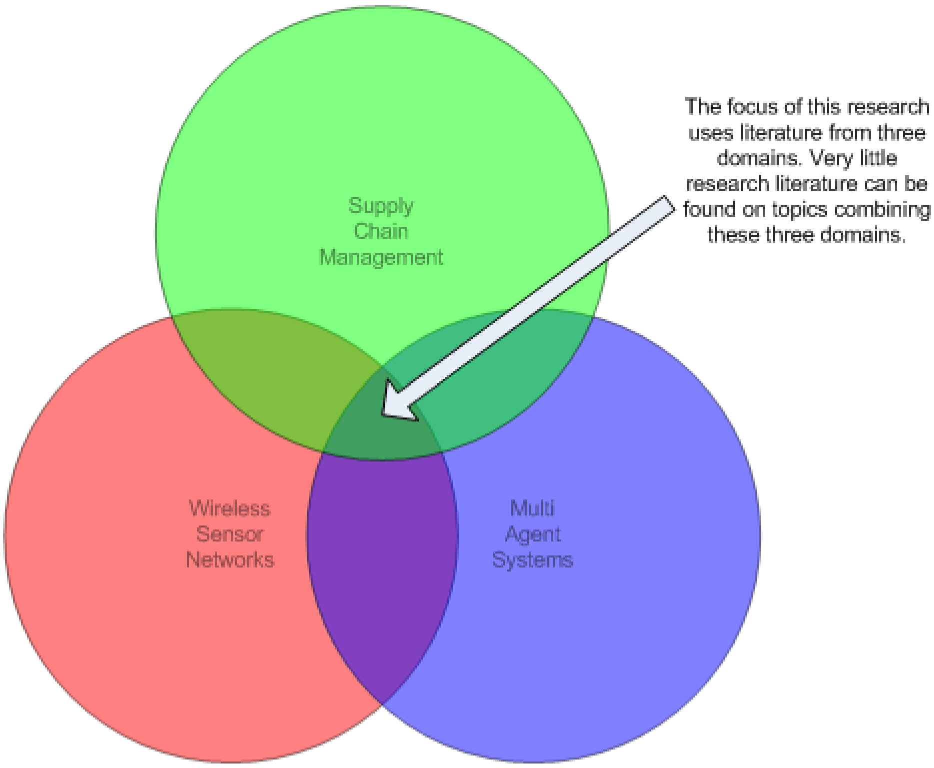


Figure 2: Focus of the literature study

1.10: Partners

This research is made possible by several companies, referred as partners of the University of Twente. This section introduces each partner and its added value for this project.

Remix

Remix Droge Mortel B.V. produces dry mortar for the construction industry. Dry mortar is made by mixing sand and cement. Remix distributes its mortar in bags and by placing filled silo's at the construction sites. The company produces several different types of mortar and currently uses more than 2000 silos. Remix has two production facilities, two silo storage depots and a head quarter, where the planning department is located. Customers order a silo, which has to delivered and filled at the construction site. After usage the silo is returned to a production facility for cleaning and re-usage.

The dry mortar company analyzed in this research produces a large range of dry mortar types with colors. The company has defined four default recipes which are produced in large quantities. These recipes are also sold in bags for the small business and consumer market. Construction sites can order special recipes to achieve a certain quality characteristic and/or color. Follow-up orders of these special recipes require the production of the product to be done in the same factory as the first order of this recipe in order to get the same quality and color. Remix produces its dry mortar at two production facilities.

Silos are rented, delivered, filled, relocated and pickup by the dry mortar company. The company owns several trucks for delivering, filling and picking-up of silos. The foreman of a construction yard is responsible for ordering on time.

The level of content of the silo is guessed by knocking on it. The sound it makes gives the foreman an indication of the amount of mortar in the silo. Although this is a rough indication, it is sufficient for ordering on time most of the time.

Jonker

Jonker BV is a software supplier specialized in the processes of dry mortar companies. On the basis of recipes add the control binder, aggregates, water and supplies in the correct ratio together.

The weighing and dosing which Jonker applies ensures that the materials in any mixture in the correct ratio be merged. This will result not only in a very constant quality concrete, also make a substantial saving on expensive raw materials such as cement. Besides weighing and also the supply of aggregates and the level reported in silos managed and recorded.

The weighing and dosing technology of Jonker guarantees that the raw materials in every mixture are added in the correct proportions. This not only results in an extremely constant quality of the concrete, but also in a considerable reduction of the consumption of expensive materials, such as cement.

Jonker BV developed the Enterprise Resource Planning application for Remix, called TClick. Incoming orders are entered manually and scheduled in the application. The information is used as input for multiple production locations, which are connected with the planning application.

Ambient Systems

Ambient Systems is a Dutch privately-owned technology firm that specializes in the development of innovative active RFID technologies based on wireless mesh networks. In contrast with other active RFID solutions, Ambient utilizes intelligent tags – SmartPoints – in combination with low-cost wireless mesh networking technology. Ambient's active RFID solutions provide integrated possibilities to monitor assets ("check"), locate people and goods ("track") and build a historical record of both ("trace").

PART II: THEORETICAL BACKGROUND

2: Supply Chain Management

2.1: Introduction

The supply chain has been defined as 'the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer' [SK05]

"A supply chain can be defined as a network of autonomous or semiautonomous business entities collectively responsible for procurement, manufacturing and distribution activities associated with one or more families of related products." These entities are highly interdependent when it comes to improving performance of the supply chain in terms of objectives such as on-time delivery, quality assurance, and cost minimization. As a result, performance of any entity in a supply chain depends on the performance of others, and their willingness and ability to coordinate activities within the supply chain. Supply chain reengineering efforts can have high impact on the performance. [SSS98]

The research of Lambert & Coopert indicated that managing the supply chain involves three closely interrelated elements: the supply, chain network structure, the supply chain business processes and the management components. [LC00]

Holloway addresses the potential usage of Radio Frequency IDentification (RFID) within the supply chain. RFID tags attached to products can be read by RFID readers within a certain distance. By using RFID is it possible to track large amounts of products within the supply chain. The flow of goods can be tracked and made visible. [HOL06]

2.2: Supply chain modeling

Providing a clear, unobstructed view of operations up and down a supply chain is critical for success. Without visibility, an organization has limited ability to plan and react to changes in its supply chain. A clear view of the supply chain processes is needed in order to suggest improvements for the overall performance of the supply chain. Modeling the supply chain using the Supply Chain Operations Reference-model (SCOR) model can create a clear view of the supply chain structure and its processes. The SCOR model has been developed and endorsed by the Supply Chain Council (SCC), an independent not-for-profit corporation, as the cross-industry standard for supply chain management. The SCOR model can be used for identifying processes, tasks and the information flow between tasks. [SCOR06]

SCOR spans:

- All customer interactions, from order entry through paid invoice.
- All product (physical material and service) transactions, from your supplier's supplier to your customer's customer, including equipment, supplies, spare parts, bulk product, software, etc.
- All market interactions, from the understanding of aggregate demand to the fulfillment of each order.

The SCOR Model is later used to analyze the supply chain of Remix. The SCOR-model provides a unique framework that links business process, metrics, best practices and technology features into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities. SCOR is based on 5 core management processes.

- **Plan**: Processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production and delivery requirements
- **Source**: Processes that procure goods and services to meet planned or actual demand
- **Make**: Processes that transform product to a finished state to meet planned or actual demand
- **Deliver**: Processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management
- **Return**: Processes associated with returning or receiving returned products for any reason.

Each of these core management processes are analyzed at least four levels.

- **Level 1:** Level 1 defines the scope and content for the Supply Chain Operations Reference-model. Here basis of competition performance targets are set.
- **Level 2:** A company's supply chain can be "configured-to-order" at Level 2 from core "process categories." Companies implement their operations strategy through the configuration they choose for their supply chain.
- **Level 3:** Level 3 defines a company's ability to compete successfully in its chosen markets, and consists of:
    - Process element definitions
    - Process element information inputs, and outputs
    - Process performance metrics attributes and definitions
    - Best practices definitions
- **Level 4:** Companies implement supply-chain management practices that are unique to their organizations at this level. Level 4 and lower defines specific practices to achieve competitive advantage and to adapt to changing business conditions.

2.3: SCOR Models

SCOR recognizes different types of models. Each serves a different purpose:

- **Business Scope Diagram**: Set the scope for a project or organization
- **Geographic Map**: Describes material flows in a geographic context; Highlights node complexity or redundancy
- **Thread Diagram**: Material flow diagram, focused on level 2 process connectivity; Describes high level process complexity or redundancy

- **Workflow or Process Models**: Information, material and work flow diagram at level 3 (or beyond); Highlights information, people and system interaction issues

The SCOR model will be applied to the supply chain of the construction industry in chapter 5.1. The most important are the workflow or process models to gain better understanding of the interaction between the different parties.

3: Wireless Sensor Networks

In this chapter summarizes the literature study covering wireless sensor networks. The second paragraph describes how this technology could be used for a dry mortar company. The last paragraph lists and evaluates some design decisions.

3.1: Introduction

[SWS04] defines a WSN as a network consisting of a very large number of small-size, low-power, wireless devices widely distributed and deeply embedded in our physical environment. "Typical sensing tasks for such devices could be temperature, light, vibration, sound, radiation, etc. All components including radio front end, micro-controller, power supply and the actual sensor form a single device, so-called sensor node." [RM04]. In regard of this research only a few sensor nodes are deployed on each location (one per silo).

"The availability of low-power micro-sensors, actuators, embedded processors, and radios is enabling the application of distributed wireless sensing to a wide range of applications, including environmental monitoring, smart spaces, medical applications, and precision agriculture. Most deployed sensor networks involve relatively small numbers of sensors, wired to a central processing unit where all of the signal processing is performed." [EGPS01]. Instead of using a central processing unit for supporting the logistic planning a decentralized way is suggested in this research.

[RM04] discusses the design space of wireless sensor networks. First of all wireless sensor networks can distinguish in deployment, mobility, cost, size, resources, energy, heterogeneity, modality, infrastructure, topology, coverage, connectivity, size, lifetime and quality of service. A set of 15 applications are analyzed based on the given classification. The main conclusion of this paper is that different WSN applications need different platforms, depending on the requirements. The case studies of the analyzed applications give a good view of the different types of wireless sensor networks applied.

3.2: Implementing WSN

Wireless Sensor Networks can be used to measure the contents of the silo. Multiple silos can be placed at a construction site. The information should be gathered and transmitted to the production company. This information is useful to forecast orders and notice the planning in advance. Planners are interested to see a function like this in the current software application.

The decision of ordering is a responsibility of the foreman at the construction site. Currently the foreman has to manually check the silos and guess their contents. Sometimes the guess is wrong or the silo is checked when it is already too late. Therefore it would be useful to share this information with the foreman. Possibly a notice is sent to the foremen when the silo almost runs out. The foreman can now place an order before the silo runs empty.

In the current situation orders are placed using a fax of telephone. Most construction site do not have an internet connection. When internet is available it usually is an UMTS connection connected to a laptop or a mobile device such as an I-phone. In all cases one of more telephones are available.

The silo status needs to be transmitted to Remix. The wireless sensor network needs to be connected externally in order to transmit the collected data. This can be done using an (UMTS) internet connection, Short Message Service (SMS) or retrieve and upload the information manually.

Some large resellers of bags have requested online order functionalities. An API for the TClick applications should be created in order to manage incoming orders automatically. This could be done by either an EDI standard, web services and/or a web interface.

Two important design decisions have to be made, which can be addressed by a question.

- What communication channel is most suitable for this particular business?
- To what extent should data be shared between partners?

3.3: WSN Design Alternatives

The wireless sensor network technology of Ambient Systems will be used in this project. Ambient Systems delivers a system composed of one gateway, optional routers and sensor devices. The default sensor measures temperature, but can be extended using different standards. For this project an extension will be developed for measuring the silo contents using sound. The sensor transmits its data through the serial connection of the sensor device.

3.3.1: Communication

The gateway will gather the data of the sensors in its network. The data can be extracted by connecting a computer using an USB cable. To transmit the data to Remix some kind of (internet) connection is needed. Research is conducted to select an appropriate method for transmitting the data to Remix. The solution is based on the capabilities of Ambients gateway. This covers only the transmitting of data from the gateway to Remix. Three alternatives for transmitting the data from the gateway to remix are analyzed.

Option 1: Manually (name: manually)

The most basic and cheapest option is to manually connect the gateway to a laptop and retrieve the gathered information. If the laptop has an internet connection the data can be transmitted to Remix. Otherwise the file(s) have to be saved onto a removable device and plug this into a device with an internet connection in order to upload the file(s). This is the cheapest solution, but has the disadvantage that is needs a manual operation.

Option 2: Internet connection (UMTS) (name: umts)

In order to eliminate the need of manual operation the gateway can be connected with a computer with an internet connection (UMTS). This is the most expensive solution, but has the most bandwidth and is always online. Silo states can be checked in real time.

Option 3: GSM/SMS (name: gsm)

A third option is to connect the router with a GSM device and use SMS messages to send the data to Remix. It is a cheaper solution that a internet connection (UMTS), but it can only sent information and not receive any. Silo states cannot be checked in real-time, but it requires no human intervention.

3.3.2: Data Usage

The data gathered by a gateway can be used by Remix to forecast ordering. This information can also be shared with the foreman of a construction site to remind him to order on time. The notice can be done using SMS, email of web application. A general reply of such notice will be an order. The second issue addresses the communication channels to see which one is the most appropriate for the construction industry?

Option 1: Data is only used by Remix (name: no sharing)

The most basic option is to use the gathered data only by Remix for planning purposes. Remix gathers data of all construction sites periodically. Planners can view this information in order to create a more efficient planning. Optionally the system alerts the planners in case of silos run out, so that they can call the construction site for an order.

Option 2: Customer retrieves silo states (name: informative)

Another option is to share the silo states with the customer. The foreman of a construction site receives a message (SMS, email or through a website) that shows the states of the silos. This can be sent periodically or only when a silo is running low. This way the customer does not need to be reminded by a planner for silos almost running out. Placing orders still needs to be done using a fax or telephone.

Option 3: Customer retrieves silo states and can order electronically (name: re-active)

This option shares the information with the customer and provides him with the ability to order electronically. Placing orders can be done besides fax or telephone using SMS, email, a web interface or a combination. By informing the foreman and giving him the opportunity to order immediately decreases the change of silo stock-outs. This results in less urgent orders.

Option 4: Customer is support by an intelligent agent (name: pro-active)

This option extends option 3 by adding an intelligent agent for advising or acting automatically. In case a silo is running low an agent can advise what to order and when. Optionally the agent can automatically order the needed products itself. This result is less ordering mistakes and can help the planning by advising in a way the planning fits best. In case of automatic ordering a decrease of labor needed for planning can be realized.

3.3.3: Combining alternatives

Not all of the options of the first design choice can be used with the options of the second choice. The table below shows if the combination of the choices can be used together.

	GSM	UMTS	Manually
No sharing	+	+	+
Informative	+	+	+/-
Re-active	+	+	+/-
Pro-active	+/-	+	-

Using a pro-active approach using intelligent agents in combination with manual data transmission is not possible, because data can only be transferred when the wireless sensor network manually is connected with the internet. The connection only exists for a small amount of time. This option is not compatible with intelligent agents, because they need to interact many times a day. The manual option is much cheaper the other two alternatives, but it is not compatible with a pro-active approach. It is also a bad option for an informative or re-active approach because of the time period between gathering the information using the wireless sensor network and transferring it to Remix or its agents.

The GSM option, where SMS will be used for communication, is a possibility for the intelligent agents, but is also not a very good option, because the costs increase dramatically with the amount of interactions between agents.

4: Multi Agent Systems

In this chapter summarizes the literature study covering multi agent systems. The second paragraph describes how this technology could be used for a dry mortar company. The last paragraph lists and evaluates some design decisions.

4.1: Introduction

[FGL02] evaluates the agent behavior execution units of FIPAOS, JADE, and Zeus with the intention of extracting reusable design elements to build a second-generation system. The various agent development platforms are evaluated on several quality aspects; primitive processing elements, data sharing, message routing, execution scheduling, protocol usage, conversation management and state machine support. "Each of the examined systems provides reusable architectural abstractions while also sharing useful implementation patterns. While incremental development is currently improving each of these frameworks individually, the agent community at large would benefit from reusing ideas across these platforms." [FLG02]

[WHSW08] proposed an automatic guided vehicle transportation system bases on a multi agent system. Traditionally the vehicles are controlled using a central server with wireless communication with the vehicles. In the proposed situation the vehicles are controlled decentralized in order to meet new and future quality requirements such as flexibility and openness. A set of important aspects for implementing MAS within an organization is listed. First of all they mention the importance of integrating a MAS in its software environment. Multi Agent Systems need to be connected with existing system in order to gather information. Also dealing with the stakeholders is an important issue. A workshop with the key stakeholders was held in order to identify and prioritize the quality attributes using scenarios.

[HD08] presented important research contributions from a baggage handling system (BHS) in a major airport hub in Asia. Moving baggage around at airports within a tight time period is a difficult task. The amount of bags that need to be transported daily is enormous. [HD08] proposes a MAS where agents were intended to substitute existing control logic, but not change the layout of the BHS, therefore design of the agent-based control software is highly influenced by the environment of the BHS. A simulation model was made in order to emulate the real BHS in order to test the simulation model against operation data.

4.2: Implementing MAS

Multi Agent Systems can be used to support the planner by advising how to plan a particular order. The agent can use silo states, forecast information, weather information and more as input for its reasoning. The planner agent can advise the planner based on its input and collaboration with other agents.

Another agent can be implemented to remind and advice the customer of placing orders when needed. It predicts when a silo will run out and advises the customer. This can be done using a email, web interface or SMS message. This agent can collaborate with the planner agent to streamline the planning and deliveries.

A construction site often has little space for storing raw materials. Managing incoming raw resources is a complicated task. An agent for a construction site is more useful when it not only collaborates with a dry mortar company, but also with other companies which need to (un-)load resources.

For example an agent is created for managing the storage area of a construction site. The available space is limited. Problems can occur when deliveries are too late or too soon. An agent managing the storage space of a construction site can collaborate with agents of its suppliers.

A multi agent system needs the information gathered from the wireless sensor network. The accuracy of the data depends on how often the data is gathered and transferred to Remix. The presented Multi Agent System is based on communication option 3 previously.

The environment in which such a system should be implemented consists of planners at Remix and construction workers at a construction site. The planners at Remix are interested in functionality for checking silo states at its customers. During the interviews at Remix it became clear that the planners are not enthusiastic of a system that does the job autonomously. The planners would like to stay in control regarding an expansion of the software.

The foreman at a construction site only uses a computer when it is instructed by their boss. Most of the communication is through fax or telephone. Introducing software solutions in this setting is a great challenge. The software should be real easy to use, work out of the box and have an (direct) advantage for the customer.

4.3: MAS Design Alternatives

Agents work best in an environment where lots of collaboration is needed in order to solve a complex problem. Fully automatic agent can collaborate and solve a problem quickly, but the quality depends on the judgment of the solution by the stakeholders. Human control is often required of strongly requested for processing involved with currencies, legal issues or safety.

Two important design decisions have to be made, which can be addressed by a question.

- What level of control should the agent support?
- Which framework suites Remix best for developing MAS?

4.3.1: Level of control

The first design decision is about the level of control of an agent. It is possible to build an agent for planning orders automatically or to build an agent for ordering automatically when silo contents run low. Mistakes can have a huge impact on planning and can be associated with extra costs. Users must have understanding and confidence in the solution in order to use it.

Option 1: Agent advises planner/customer (name: advise)

An agent is built to advise the customer placing orders. It considers the current silo state using WSN technology, but also the project details, historical data, weather forecasts, etc. Foremen are noticed and advise to place an order. Planners are offered some alternatives for planning a certain order based on the available input of an agent.

Option 2: Agent plans/orders automatically (name: automate)
This option is the almost the same as option 1. Instead of advising the planner/customer, the agent plans/orders automatically. The project agent monitors the silo contents and places and order when the total needed raw resources is not yet reached. The planner agent can assign orders to trucks automatically and shuffle deliveries between trucks when not yet set final.

This solution a foreman does not need to worry to order raw resources, but this option also requires he has confidence in the system for ordering in his name. Another option for Remix is to take over the responsibility of having full silos when needed and charge for this service.

Option 3: No agent support (name: none)
No agent support means no changes to the current process except the possible implementation of WSN. The WSN information can be used by planners, but they are not advised by any agent. A MAS would be useless when it does not receive information about the real world provided by WSN.

4.3.2: Agent Framework
The Belief-Desire-Intention model is the most used model to build multi agent systems. Several frameworks are built based on this model. In this research two frameworks are analyzed and ranked on several quality attributes.

Option 1: Jadex (name: jadex)
Jadex is an extension of the JADE agent framework. JADE is an open source framework based on the BDI model. It is created at a German university for research purposes. Documentation can be found online and a lot of development tools are available. There is a community for support and the developers are also welcome to answer questions, but it is not their main function. A web interface plug-in is available as a proof of concept.

Option 2: Jack (name: jack)
JACK is a commercial framework for agent development. It offers commercial support and has several tools for development. It includes default capabilities for web interaction.

Option 3: Custom built (name: custom)
A third option is to build the agent framework yourself and implement only the BDI concepts you need. This option is more time consuming and lacks commercial support.

4.3.3: Combining alternatives
Not all of the options of the first design choice can be used with the options of the second choice. The table below shows if the combination of the choices can be used together. A framework can help implement such complex system by providing a set of libraries and tools, but in many cases also obligate a certain methodology. The goal of the simulation is primarily to show the stakeholders how a multi agent system can help support their business processes. Therefore a custom approach is chosen.

	Advise	Automate	None
Jadex	+	+	-
Jack	+	+	-
Custom	+	+	+

PART III: ARTEFACT DESIGN

5: Analysis

In this chapter the supply chain from remix to the construction site is analyzed. This will be done using the SCOR model. The SCOR model provides four diagrams for modeling the supply chain characteristics. Secondly the workflows defined by the SCOR model, include both the mortar producer as well the consumer of mortar (construction site). These processes are examined more closely because they provide the basis for the simulation application. Finally previously identified design alternatives for implementing wireless sensor networks and multi agent systems are evaluated.

5.1: Supply Chain at Remix

The dry mortar company analyzed in this research has a large range of dry mortar types and colors. The company has defined a small set of standard recipes (default product). These recipes are also sold in bags for the small business and consumer market. Customers can order special recipes to achieve a certain quality characteristic and/or color. Follow-up orders of special recipes require the production of the product to be done in the same factory as the first order of this recipe in order to get the same quality and color.

Silos are rented, delivered, filled, relocated and pickup by the dry mortar company. The company owns several trucks for delivering, filling and picking-up of silos.

Remix produces many types of mortar. Four types are standard, which are produced at large scale. Other types are produced in batches. Customers can order a custom recipe. When an order is received with custom recipe it has to be produced at the same factory as the first time in order to get the same color and quality. The mortar is sold as two separate brands, which were separate companies (Remix and Sakrete). Each brand has its own logo and bag design. Although the product recipes (of the standard products) are the same, different product code are used for each brand.

The current fill level is estimated by knocking on it. The sound it makes gives the foreman an indication of the amount of mortar in the silo. Although this is a rough indication, it is the current practice for ordering on time most of the time. The foreman of a construction yard is responsible for ordering on time.

Remix owns several trucks for delivering the mortar and silos. Silos are delivered by trucks designed for silo transport and placement. These trucks are also needed for moving a silo from, to or within a construction site. Each truck has a capacity of 2 or 3 silos depending on the silo type (Midi or Maxi).

Mortar is delivered in bulk trucks, which can have multiple compartments for different mortar recipes. Before delivering any products the weight of the loaded truck is written down. At arrival at a construction site, a hose is connected from the truck to the silo. The truck pumps the mortar into the silo to refill it. After making the delivery the trucks weight are written down to calculate the amount of delivered goods needed for sending invoices.

Remix offers three different silos, so called MiniSilo, MidiSilo and MaxiSilo. The MiniSilo has a standard pallet size, so it can be moved by regular trucks. The Midi- and MaxiSilo have to be transported by special trucks for silo movement. A construction employee can fill his wheelbarrow by placing it below the mixing screw. The mixing screw wears out over time and as a result throughput decreases.

Bulk refill trucks	8	Maxi silos	+/- ?
Silo placement trucks	4	Midi silos	+/- ?
Average stops per route	2	Estimate last year driven distance	?

5.1.1: Business Scope Diagram

The business scope diagram identifies the entities within and outside the organization and is used to set the scope of the organization. The first step in creating a business scope diagram is to identify the suppliers, organizational entities and customers of an organization. The second step is to link these entities to reflect material and/or information flows.

On the customer side two customer types have been identified: dealers and contractors. The dealers act as a retailer for smaller contractors.

A mortar company has several key nodes within its organization. First of all there is a production facility where the products is made and shipped from. Secondly the head quarter where all the administrative tasks are processed including the logistic planning. Finally a mortar company can have some depots for storing returned or stocked silos. These depots reduce transport costs.

At the suppliers side some general suppliers are identified. The exact suppliers are not that important for this assignment, because the focus is on the customer part of the mortar company. Besides the main product of a mortar company it provides components for its customers like water tanks, aggregates, etc.

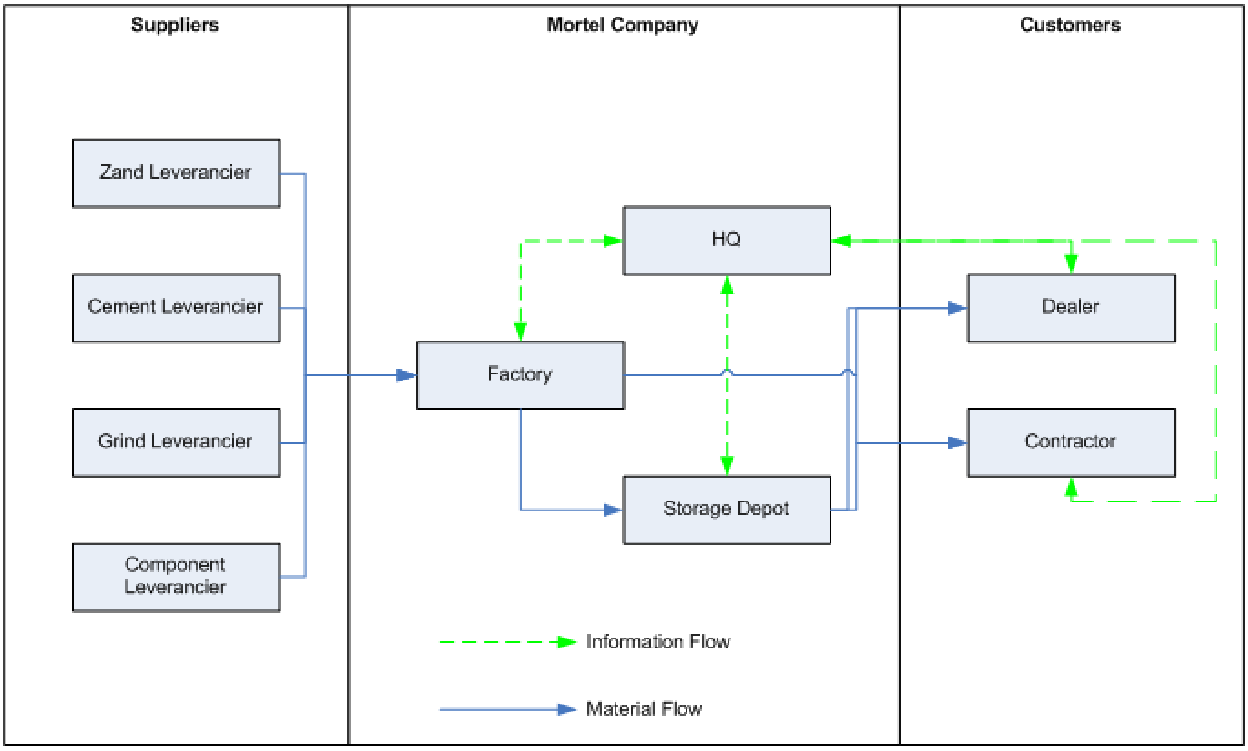


Figure 3: Business scope diagram of a dry mortar company

5.1.2: Geographic Map

The geographic map describes the material flows in a geographic context. First of all, the headquarter (P1, P2, P3, P4, P5), the two factories (S2, M2, D2) and the three storage depots (S2, D2) are displayed on the map with its level 2 processes.

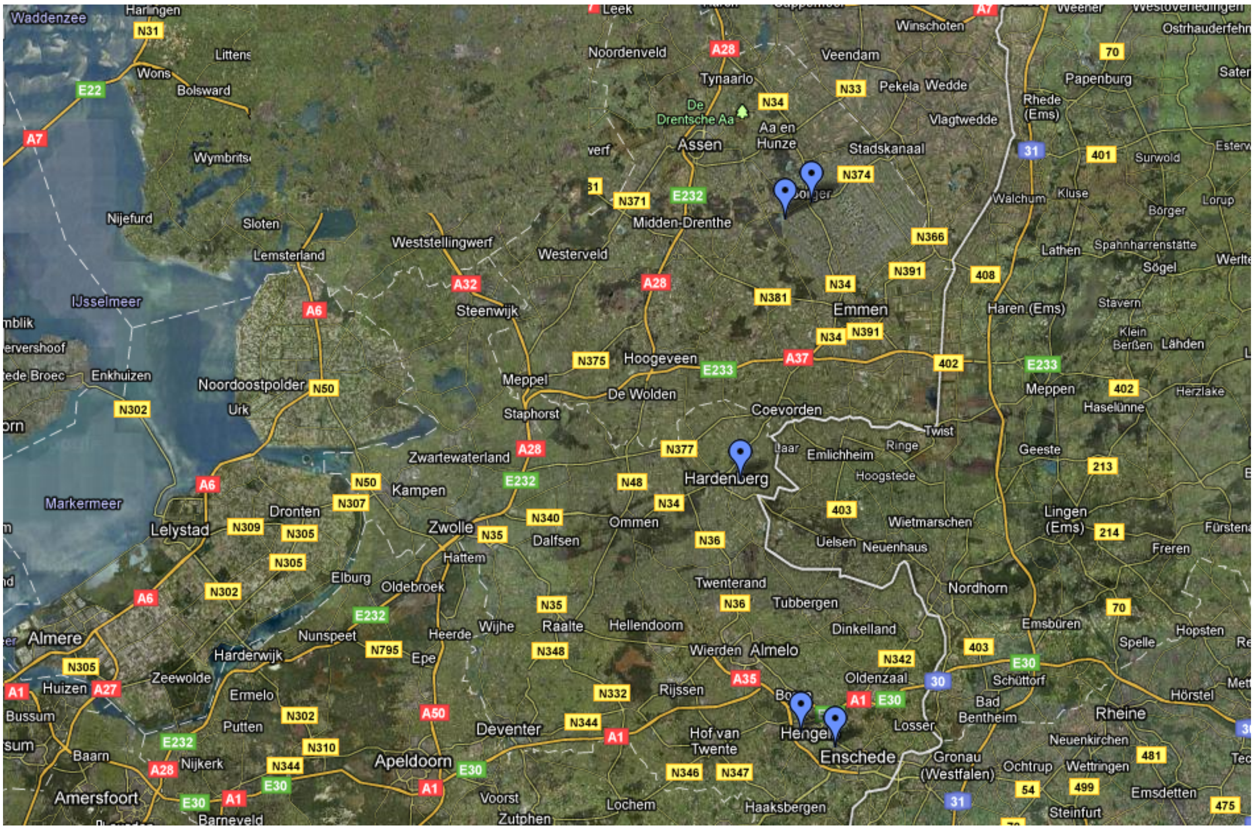


Figure 4: Geographic Map

5.1.3: Thread Diagram

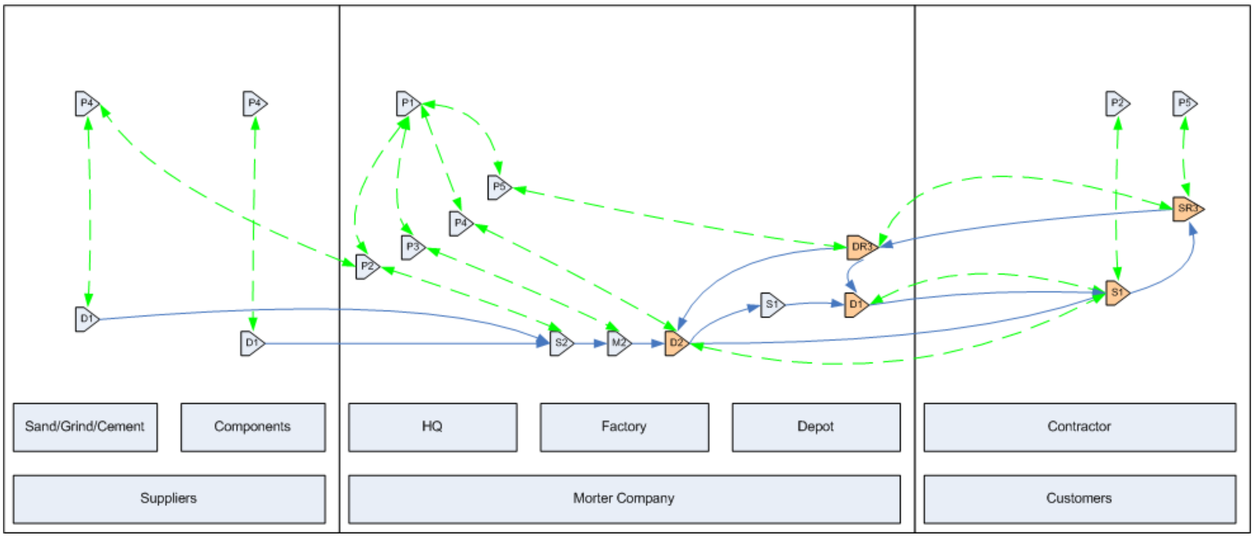


Figure 5: Thread Diagram of a dry mortar company

The thread diagram shows us the processes and their relation. The blue lines are transferred goods between different processes. The green lines indicate exchange of information between processes. A mortar company like Remix is represented in the middle. The focus of this research is on the interaction between the mortar company and its customers. The processes connected with inter-organizational flows of information (D2, DR3, S1, SR3) and goods are analyzed more closely on the next chapter.

5.1.4: Workflow Diagrams

Each line in the thread diagram (flow of information or goods) which crosses the company boundaries (mortar company <-> construction sites) is analyzed further using Workflow Diagrams. A Workflow diagram decomposes a process into tasks. A task, represented as a square, often requires or produces information. The orange squares are the tasks of the current process (D2, DR3, etc). The red lines represent the information which is needed from or sent to another process. This information is communicated between the planning and the customer. The following workflow processes are being analyzed [SCOR06]:

- **D1: Deliver Stocked Product:** The process of delivering product that is maintained in a finished goods state prior to the receipt of a firm customer order.
- **D2 Deliver Make-to-Order Product:** The process of delivering product that is manufactured, assembled or configured from standard parts or subassemblies. Manufacture, assembly or configuration will begin only after the receipt and validation of a firm customer order.
- **DR3: Deliver Return Excess Product:** The processes of the designated return center authorizing and scheduling the excess product return, the physical receipt of the item by the designated return center and transfer of the item for final disposition The process includes communication between the customer and designated return center and the generation of associated documentation.
- **S1: Source Stocked Product:** The procurement, delivery, receipt and transfer of raw material items, subassemblies, product and or services.
- **SR3 Source Return Excess Product:** The process, initiated by the customer, of returning material deemed in excess of current requirements to the designated return center. Process includes: customer identification that an action is required, determining what that action should be, requesting authorization from the designated return center, generating return documentation, and physically returning the excess product.

D1: Deliver Stocked Product

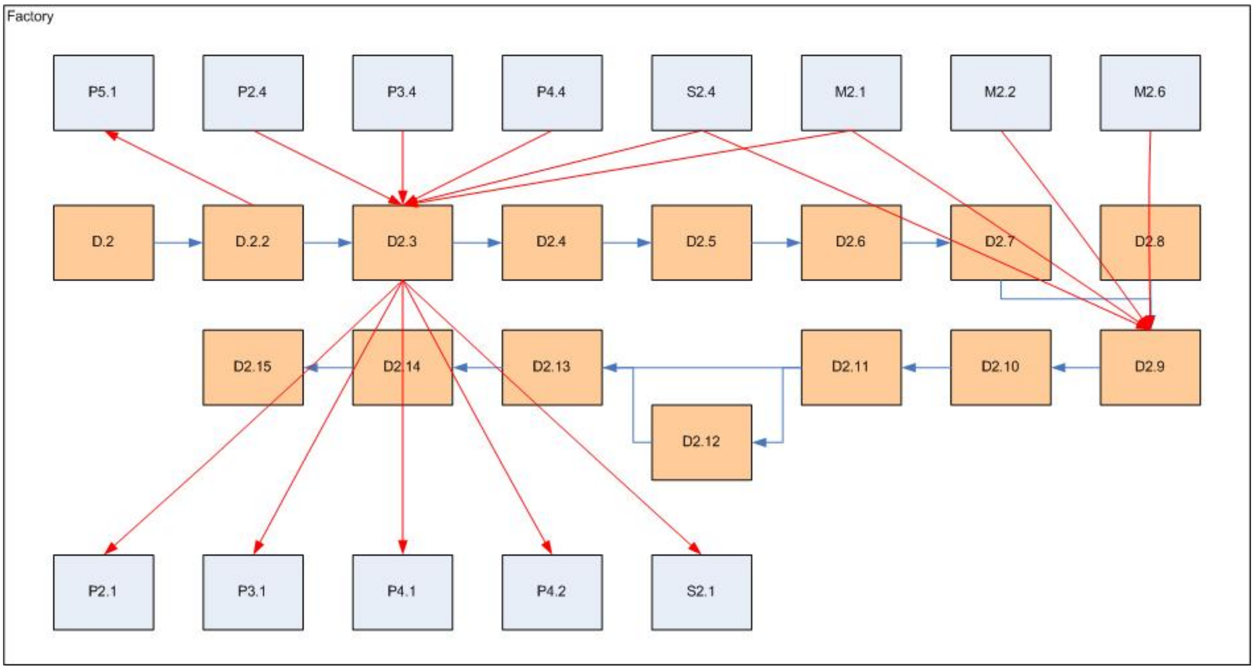


Figure 6: Workflow diagram (D1)

Process Steps:

- **D1.1 Process Inquiry & Quote:** Receive and respond to general customer inquiries and requests for quotes.
- **D1.2 Receive, Enter & Validate Order:** Receive orders from the customer and enter them into a company's order processing system. Orders can be received through phone, fax, or electronic media. "Technically" examine orders to ensure an orderable configuration and provide accurate price. Check the customer's credit. Optionally accept payment.
- **D1.3 Reserve Inventory & Determine Delivery Date:** Inventory and/or planned capacity (both on hand and scheduled) is identified and reserved for specific orders and a delivery date is committed and scheduled.
- **D1.4 Consolidate Orders:** The process of analyzing orders to determine the groupings that result in least cost/best service fulfillment and transportation.
- **D1.5 Build Loads:** Transportation modes are selected and efficient loads are built.
- **D1.6 Route Shipments:** Loads are consolidated and routed by mode, lane and location.
- **D1.7 Select Carriers & Rate Shipments**: Specific carriers are selected by lowest cost per route and shipments are rated and tendered.
- **D1.8 Receive Product from Source or Make**: The activities such as receiving product, verifying, recording product receipt, determining put-away location, putting away and recording location that a company performs at its own warehouses. May include quality inspection.
- **D1.9 Pick Product:** The series of activities including retrieving orders to pick, determining inventory availability, building the pick wave, picking the product, recording the pick and delivering product to shipping in response to an order.

- **D1.10 Pack Product:** The activities such as sorting / combining the products, packing / kitting the products, paste labels, barcodes etc. and delivering the products to the shipping area for loading.
- **D1.11 Load Vehicle & Generate Shipping Documentation:** The series of tasks including placing/loading product onto modes of transportation and generating the documentation necessary to meet internal, customer, carrier and government needs.
- **D1.12 Ship Product:** The process of shipping the product to the customer site.
- **D1.13 Receive & Verify Product by Customer:** The process of receiving the shipment by the customer site (either at customer site or at shipping area in case of self-collection) and verifying that the order was shipped complete and that the product meets delivery terms.
- **D1.14 Install Product:** When necessary, the process of preparing, testing and installing the product at the customer site. The product is fully functional upon completion.
- **D1.15 Invoice:** A signal is sent to the financial organization that the order has been shipped and that the billing process should begin and payment be received or be closed out if payment has already been received. Payment is received from the customer within the payment terms of the invoice.

D2: Deliver Make-to-Order Product

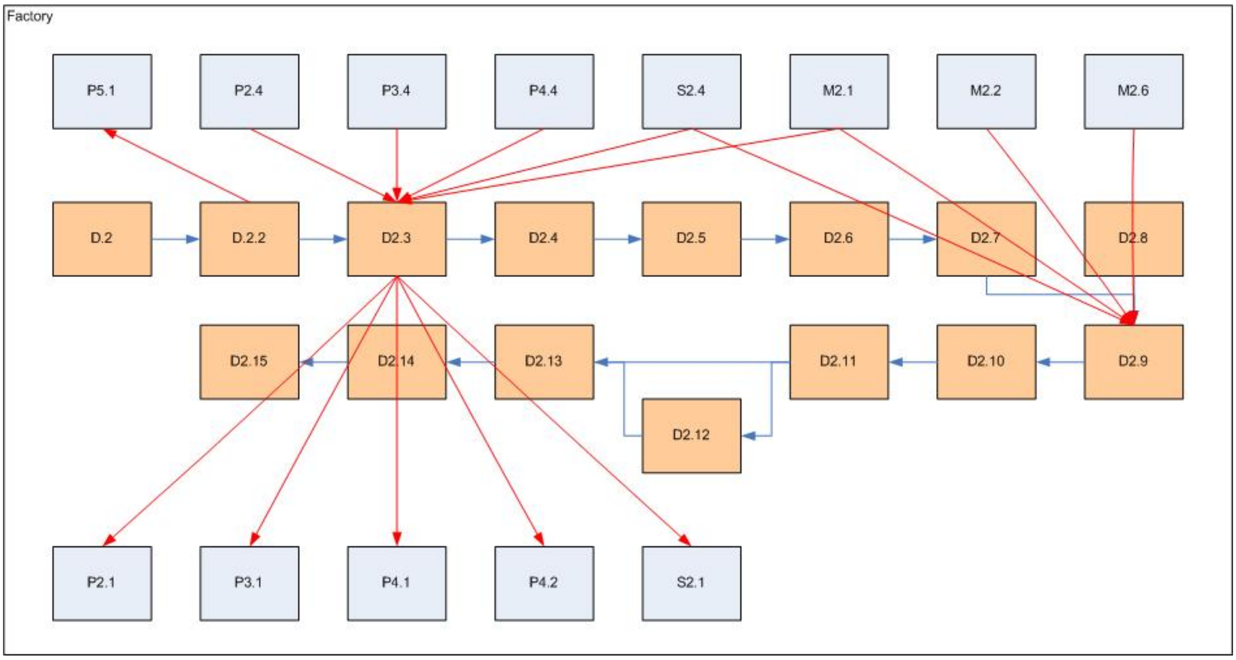


Figure 7: Workflow diagram (D2)

Process Steps:

- **D2.1 Process Inquiry & Quote:** Receive and respond to general customer inquiries and requests for quotes.
- **D2.2 Receive, Configure, Enter and Validate Order:** Receive orders from the customer and enter them into a company's order processing system. Orders can be received through phone, fax, or through electronic media. Configure your product to the customer's specific needs, based on standard available parts or options. "Technically" examine order to ensure an orderable configuration and provide accurate price. Check the customer's credit. Optionally accept payment.
- **D2.3 Reserve Resources & Determine Delivery Date:** Inventory and/or planned capacity is identified and reserved for specific orders, and a delivery date is committed and scheduled.
- **D2.4 Consolidate Orders:** The process of analyzing orders to determine the groupings that result in least cost/best service fulfillment and transportation.
- **D2.5 Build Loads:** Transportation modes are selected and efficient loads are built.
- **D2.6 Route Shipments:** Loads are consolidated and routed by mode, lane and location.
- **D2.7 Select Carriers & Rate Shipments:** Specific carriers are selected by lowest cost per route and shipments are rated and tendered.
- **D2.8 Receive Product from Source or Make:** The activities such as receiving product, verifying, recording product receipt, determining put-away location, putting away and recording location that a company performs at its own warehouses. May include quality inspection.
- **D2.9 Pick Product:** The series of activities including retrieving orders to pick, verifying inventory availability, building the pick wave, picking the product, recording the pick and delivering product to packing area in response to an order.
- **D2.10 Pack Product:** The activities such as sorting / combining the products, packing / kitting the products, paste labels, barcodes etc. and delivering the products to the shipping area for loading.
- **D2.11 Load Product & Generate Shipping Documentation:** The series of tasks including placing/loading product onto modes of transportation and generating the documentation necessary to meet internal, customer, carrier and government needs.
- **D2.12 Ship Product:** The process of shipping the product to the customer site.
- **D2.13 Receive & Verify Product by Customer:** The process of receiving the shipment at the customer (either at customer site or at shipping area in case of self-collection) site and verifying that the order was shipped complete and that the product meets delivery terms.
- **D2.14 Install Product:** When necessary, the process of preparing, testing and installing the product at the customer site. The product is fully functional upon completion.
- **D2.15 Invoice:** A signal is sent to the financial organization that the order has been shipped and that the billing process should begin and payment be received or be closed out if payment has already been received. Payment is received from the customer within the payment terms of the invoice.

DR3: Delivery Return

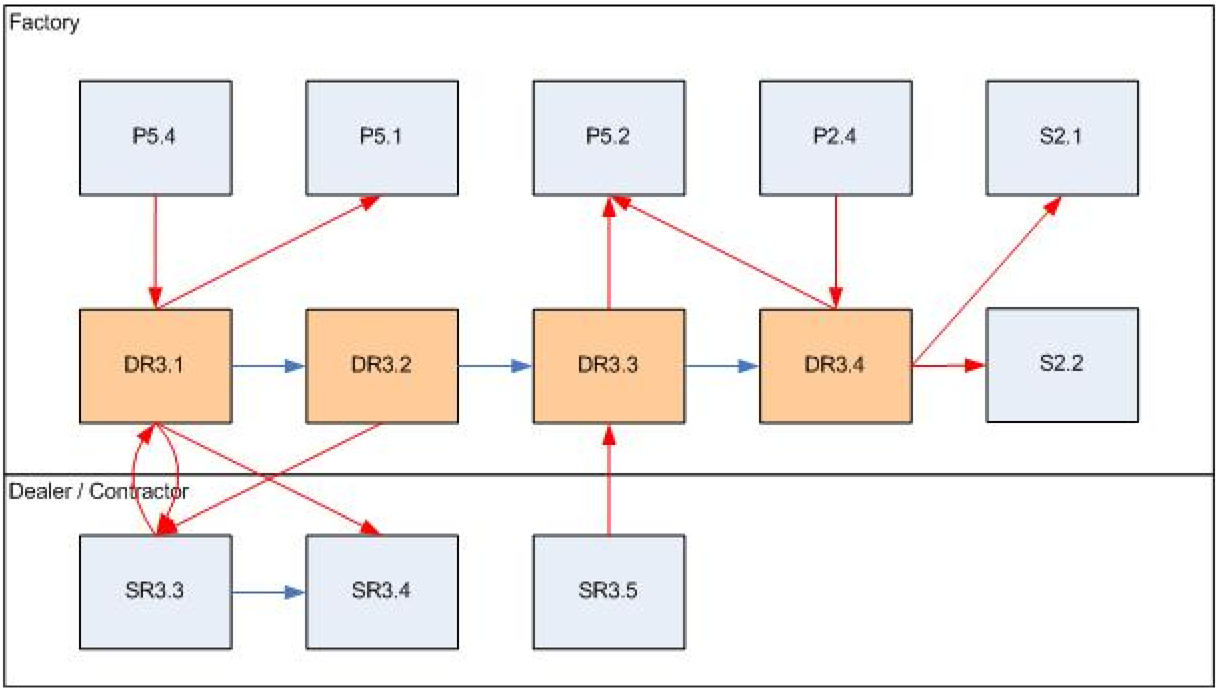
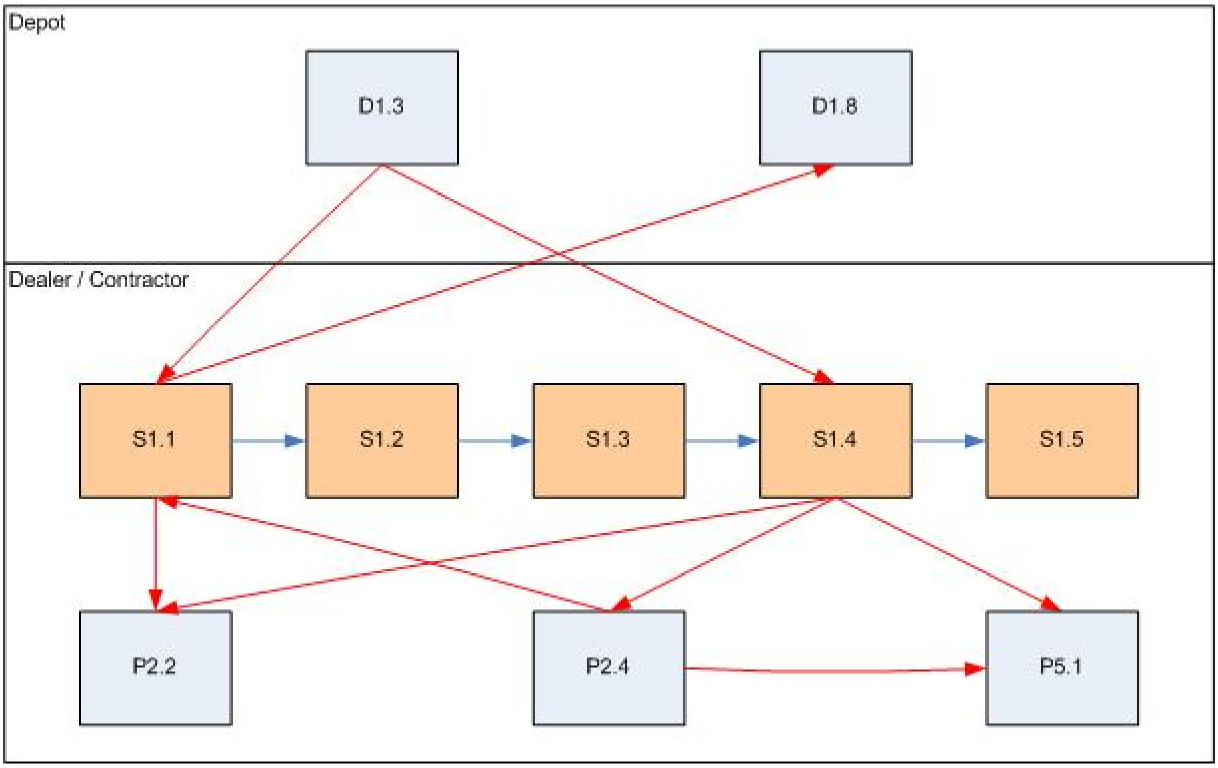


Figure 8: Workflow diagram (DR3)

Process Steps:

- **DR3.1 Authorize Excess Product Return:** The process where the designated return center receives an excess product return authorization request from a customer, determines if the item can be accepted and communicates their decision to the customer. Accepting the request would include negotiating the conditions of the return with the customer, including authorizing credit or cash discount. Rejecting the request would include providing a reason for the rejection to the customer.
- **DR3.2 Schedule Excess Return Receipt:** The process where the designated return center evaluates an authorized excess material return to determine packaging and handling requirements. This assessment will lead to the development of a return disposition decision and a return schedule with terms and conditions that will tell the Customer how and when to ship the product. The scheduling activity would also inform the Return Center's Receiving department when to expect the shipment and where to send the product, for disposition, upon receipt.
- **DR3.3 Receive Excess Product:** The process where the designated return center receives and verifies the returned excess product and associated documentation against the return authorization and other documentation and prepares the item for transfer. Administrate any discrepancies that arise.
- **DR3.4 Transfer Excess Product:** The process where the designated return center transfers the excess product to the appropriate process to implement the disposition decision.

S1: Source Stocked Product



Process Steps:

- **S1.1 Schedule Product Deliveries:** Scheduling and managing the execution of the individual deliveries of product against an existing contract or purchase order. The requirements for product releases are determined based on the detailed sourcing plan or other types of product pull signals.
- **S1.2 Receive Product:** The process and associated activities of receiving product to contract requirements.
- **S1.3 Verify Product:** The process and actions required determining product conformance to requirements and criteria.
- **S1.4 Transfer Product:** The transfer of accepted product to the appropriate stocking location within the supply chain. This includes all of the activities associated with repackaging, staging, transferring and stocking product. For service this is the transfer or application of service to the final customer or end user.
- **S1.5 Authorize Supplier Payment::** The process of authorizing payments and paying suppliers for product or services. This process includes invoice collection, invoice matching and the issuance of checks.

SR3: Source Excess Product Return

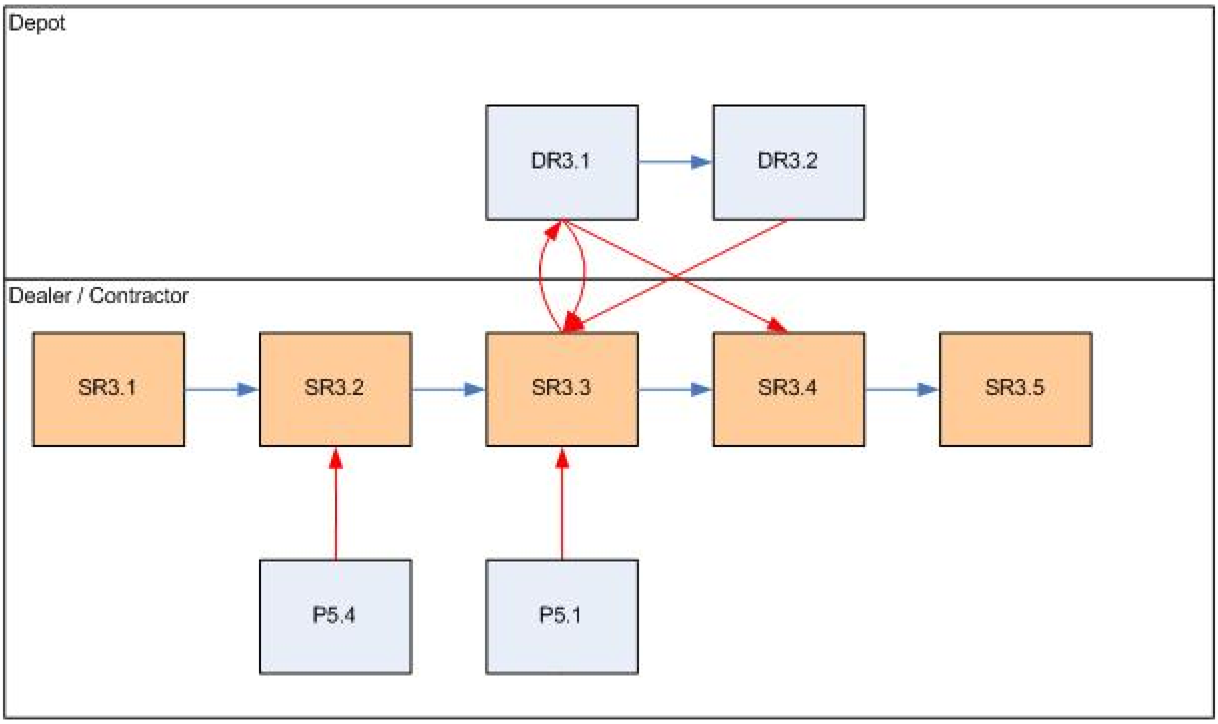


Figure 9: Workflow diagram (SR3)

Process Steps:

- **SR3.1 Identify Excess Product Condition:** The process where the customer utilizes planned policies, business rules and product inspection as criteria to identify and confirm that material is in excess of the current requirements.
- **SR3.2 Disposition Excess Product:** The process of the customer determining whether to return the excess material and identification of a designated return center a return authorization.
- **SR3.3 Request Excess Return Authorization:** The process of a customer requesting and obtaining authorization, from the designated return center, for the return of excess product. Additionally, the customer and designated return center would negotiate enabling conditions such as return credit or cash discount, packaging, handling, transportation and import / export requirements to facilitate the efficient return of the excess product.
- **SR3.4 Schedule Excess Product Shipment:** The process where the customer develops the schedule for a carrier to pick-up the excess product. Activities include selecting the carrier and rates, preparing the item for transfer, preparing scheduling documentation and managing overall scheduling administration.
- **SR3.5 Return Excess Product:** The process where the customer packages, and handles the excess product in preparation for shipping in accord with pre-determined conditions. The product is then provided by the customer to the carrier who physically transports the product and its associated documentation to the last known holder or designated return center.

5.2: Wireless Sensor Networks

"Ambient Systems provides a highly advanced mesh-network system which enables low cost, energy efficient, low data rate applications. The Ambien Systems BV mesh network consists of two types of nodes: the 'Microrouters' and the smaller 'Smartpoints' that contain less functionality. The nodes use a 'Gateway' to connect to external applications and networks. Based on their mesh-network the company rolled out multiple commercial projects all over the world and developed some dedicated nodes such as the localization point." [SCH07].

The Smartpoint of Ambient Systems standard only contains a temperature sensor. The sensor node can be extended with extra sensors using several low level communication protocol standards such as I2C. The measured data of its environment is collected at the gateway, which is connected with an external system using the Universal Serial Bus (USB). The data can be viewed using the Ambient Systems Studio application, which stores the data in a RDBMS. The data can also be transferred to other places when the gateway is connected to an external network. In the current situation this has to be done using an intermediate computing device with other network protocols (TCP/IP).

5.2.1: WSN Quality Attributes

In order to select one, the alternatives need to be evaluated using some quality attributes. For each challenge a set of quality attributes are defined. The quality attributes are described below.

Communication

Bandwidth: The bandwidth defines the amount of data that can be transferred. It needs to be high enough of transferring the data gathered by the gateway.

Connectivity: The connectivity defines the availability of the wireless sensor network from an external network. Can the silo state be retrieved in real-time, periodically or manually?

Robustness: The level a system is vulnerable to failure defines the robustness of a system. A process requiring human interaction is more likely to fail.

Costs: The last quality attribute is the costs of the system, which is important for all investment decisions.

Data Usage

Information: The first quality attribute looks at the information shared with the customer. The quality of information as well as the amount of information shared both influence this quality attribute.

Functionality: This quality attribute looks at the functionalities it provides for the customer.

Acceptance: This quality attribute looks at the risk associated with implementing an option. Less change to the current working process is easier to implement.

Costs: The last quality attribute is the costs of the system, which is important for all investment decisions.

5.2.2: WSN Design Selection

For each challenge the alternatives are analyzed and ranked per quality attribute. Next the best alternative is selected for recommendation. Arguments are given for the ranking and selection of the alternatives.

Communication

The selected alternative for communication between the gateway and Remix is option 1. It is the most expensive option, but the high bandwidth and the ability to communicate full duplex could also be used to provide internet access at the construction site.

Option 3 requires human interaction in order to send the data to Remix. People can forget to upload the data, especially when the gain is low or cannot be seen directly. Resistance against usage of the system can be a result if the task is too complex or time consuming.

Option 2 is also a good option because requires no human interaction and is far less costly than the first option. However option 2 can only send data in one direction. In regard of option 3 this communication channel cannot be used for other purposes.

	Manually	UMTS	GSM
Costs	-	+/-	+
Bandwidth	+	-	+/-
Communication	+	+/-	-
Robustness	+	+	-

Usage

The selected alternative for sharing data with the customer is option 3: sharing data with the customer and provide an ability to order electronically.

In case of option 1 the planner needs to monitor the silo states and contact the construction site when a silo runs out. The workload of the planner increases because it has to react proactively. On the other side the planner can make better decision because more information is available. Customers do not want to pay extra for this, because they have no added value themselves.

Option 2 is the second best option. It solves the problem of transmitting information to remix and share it with its customers, who have the equipment installed. It does not provide a good infrastructure for future usage in regard to option 3.

Option 4 is a good option in the long run. An agent which advises the customer and/or places orders automatically can result in more resistance to use the functionality.

	No sharing	Informative	Re-active	Pro-active
Information	-	+/-	+/-	+
Functionality	-	-	+/-	+
Acceptance	+	+	+/-	-
Costs	+	+/-	+/-	-

5.2.3: WSN Conclusion

Communication

Enabling communication on the construction site can be done using several techniques. The analyzed techniques differ in price and connection speed and direction. Manually transferring the data from the wireless sensor network to Remix (using an existing internet connection) is the most cheapest, but it requires a manual operation of the contractor. The data can be transferred using an USB stick or write it to a writable CD. This method is unsuitable for using agents, because the lacking to do the manual operations can cause an inefficient planning using agents when only a limited number of construction site transfer their data on time.

Using a GSM telephone connection and dialing in at least once a day is a good option. It is the most cost economic option at this time. It support bidirectional communication but is only available at some points in time. Therefore the data from the wireless sensor network is not real-time.

However the UMTS connection is the most expensive, it is always available and makes real-time silo information possible. Implementing a multi agent system requires bidirectional communication with the different construction sites.

Currently the cost of an UMTS connection is about 10-20 euro per month depending the amount of traffic included in the bundle. The cost of an UMTS connection is getting cheaper every day. The current price is a bit high to connect every construction site with an UMTS connection.

Also a combination of techniques can be used. For example: Using the wireless sensor network in combination with an UMTS connection for bigger construction sites and use the manual option for smaller sites.

Another advantage of UMTS is that the bandwidth is large enough to share the connection with other IT projects requiring an internet connection.

Data Usage

Option one hardly makes use of the new possibilities of the wireless sensor network. The customers of Remix have no visible benefit of adding sensors to the silos.

Regarding the data usage the best option at this point in time will be option 3. In this option the data is shared with the customers of Remix and also offer them the opportunity to order online. Option 4 is the best in the long run, but has high impact on the current work processes, because some are taken over by intelligent agents. During the interviews at Remix and a contractor made it clear that the current employees and users are eager to give away the control over the process. Option 3 is the best option for now and also prepares the environment for a possible implementation of option 4.

5.3: Multi Agent Systems

5.3.1: MAS Quality Attributes

In order to select one, the alternatives need to be evaluated using quality attributes, which has been selected from the literature. For each challenge a set of quality attributes are defined. The quality attributes are described below.

Level of control

Profitability: This quality attribute looks at the savings and revenues the investment can generate.

Acceptance: This quality attribute looks at the risk associated with implementing an option at the work place. Less change to the current working process is easier to implement.

Costs: The last quality attribute is the costs of the system, which is important for all investment decisions.

Framework

Tools: This quality attribute looks at the tools available for the framework for development and debugging

Support: This quality attribute looks at the amount of support available. Commercial support is regarded as good. The qualification of open source frameworks depends on the size, activity, and expertise of the community.

Costs: The last quality attribute is the costs of the system, which is important for all investment decisions.

5.3.2: MAS Design Decision

Level of control

The first option 'do nothing' is of course the cheapest one. Also there is no resistance because it means no change at all. This option has no effect on the costs and revenues.

In the second option intelligent agents advise the user, but do not execute actions like ordering. Implementing this solution will probably lead to less resistance than the last option, because the control is still at the user of the system. Users are informed of silo states which will result in fewer urgent orders.

	None	Advise	Automatically
Profitability	-	+/-	+
Acceptance	+	+	-
Costs	+	+/-	-

The last option, where agents act autonomously upon instruction from the user, is the most expensive one. The implementation of this option can result in a decrease of operations costs (of the producer as well as the consumer) and an increase of revenues (gaining new clients with this extra service). Resistance can be expected when implementing this system because of the changes in the current work process. Some responsibilities are moved from people to a computer program.

Framework

There are many agent frameworks to choose from when building such system [BLP03], [BLP05]. Because analyzing all of them is enough material for a separate research, I will look at two types of frameworks. The first framework is a free and open source package. The second one is a commercial package. A third option, building a custom application without an agent framework, is also tested against previously mentioned quality attributes.

	Jadex	Jack	Custom
Tools	+/-	+	-
Support	-	+	-
Costs	+	-	-/+

5.3.3: MAS Conclusion

Level of Control

This design decision defines the level of control of the users of the system. The first option is not to implement a multi agent system. The actions of ordering are the responsibility of the customer. The data from the wireless sensor network can be used to see the level of the silo and the average throughput.

The second option supports the customer by advising him, but leaves the responsibilities at the customer. It will inform the user when a silo is almost empty, so the customer can order on time.

The third option lets the agent make orders automatically based on previous defined settings. This option saves a lot of time and prevents problems (by ordering on-time). However problems about the responsibilities can occur, because the agents make order decision autonomously. In case of a malfunctioning agent (for example: order too much) can result in an issue between Remix and the customer.

Based on the input from the interviews with the planners option 2 is chosen. The planners were anxious about a system where orders are placed automatically. In this option the agents do not act autonomously, but support the customer by only informing him about silo states when necessary.

Framework

Several frameworks (open-source and closed source) are available on the market. However the open source framework Jadex has a lot of options and tools, it lacks commercial support. Commercial support is very useful when working with a complex technology such as multi agent systems. Another option is not to use a existing framework, but build your own depending on the needs. This option does not require following all the BDI concepts and rules, but only implement the wanted features. The commercial package Jack is a good option because it is shipped with a lot of tools and also offers commercial support. When building a complex multi agent system this would be a good option. Although Jack is the best option it is not chosen as the platform for the simulation tool of this research. Because of the price of Jack and its high learning curve a custom application will be built for simulation purposes [PB07], [PB05], [HD08], [BLP05]

6: Artifact design

6.1: Goal

The simulation serves two goals. The first goal is to show the users of the system how an addition of supporting the planning to the existing system could help their jobs. These users are planners and foremen at a construction site. The second goal is to show how this simulation can be used to evaluate the benefits of building planning agents.

First of all a prototype will be built to support the first goal based on the work processes of the SCOR model. The prototype is built as a web application where different users can log in. The first group of users are the customers of Remix. This group can see the information of the construction site, their silo states and previous made orders. Orders can be placed and the estimated time of arrival of orders can be viewed. The second group exists of the planners of Remix. This group can make a logistic planning by assigning trucks to incoming orders. The planner must make the route final in order to start the delivery. Both groups can be supported by intelligent agents. An option to enable the agent is embedded in the prototype web application.

Secondly the prototype application has been adapted so that a period of time can be simulated. Two scripts are created to simulate the use of different agents. A third script emulates the silo usage, because the simulation is not connected to a real silo. This script creates the output, which comes from the wireless sensor network. The Planner agent acts as a planner and assigns the incoming orders to trucks. The Contractor agent acts as the contractor and orders refilling of the silos before it becomes empty based on the average usage. The simulations are run by a command line script. The results are viewable in the prototype website where historic graphs can be found. The interaction between the agents is based on the workflow diagrams in chapter 5.

The configuration of the simulation, defining several input variables such as usage variation, order time window, etc) can be done by a simple configuration file. A list of hypotheses is defined in order to test the outcome of the simulation results. To validate the hypothesis a number of experiments are set up in which only a single variable is changed.

Many input needed for the development of the simulation tool was provided during interviews with the planners of Remix and/or a Dhr. Vasters of Roosdom Tijhuis (constructor). Also Jonker has provided a copy of the database of the TClick application which provided valuable information about the entities used in TClick and the relations between them. Only a subset of columns of the TClick database was used in the simulation tool.

6.2: Scope

The simulation tries to simulate the process of ordering and delivering, which is a difficult assignment because of the enormous amount of environmental variables. However a lot of environmental variables are implemented, some still need to be implemented or can be improved. An example of such improvement using more environmental data is to take into account the locations of the weighing facilities.

Single production location

The planning algorithm bases its planning on a single production facility. Remix has two production facilities and three depots for storing silos. Implementing these extra locations will increase the possible planning combinations exponentially. Adding extra production facilities also enforces an extra rule; Special recipes have to be produced at the same production facility as the first order in order to get the same quality and color.

Focus on bulk transport

The focus of this simulation is on the bulk transport of dry mortar. The ordering and planning of silo transport is implemented for manual usage, but is excluded in the agent script. Current simulation runs start and end with the same amount of silos delivered to construction sites.

Planning algorithms

The most basic algorithms of planning are selected for creating delivery routes. The current algorithm constructs routes by inserting an extra stop and calculate the extra distance. The extra stop will be assign to the route with the lowest extra costs. Choosing a more optimal planning algorithm leads to better results, but it is not the focus of this research. An example of a more optimal planning algorithm would be an algorithm which takes traffic peaks or historic data into account.

6.4: Implementation

The first goal will be supported by building a web interface for placing orders and planning them into routes. The web interface will connect with a database for storing the orders and routes. The RDBMS used is similar the RDBMS Jonkers uses in its Tclick application. Several screenshots of the web interface of the simulation program can be found in the appendix.

Figure 10: Construction site overview (Contractor)

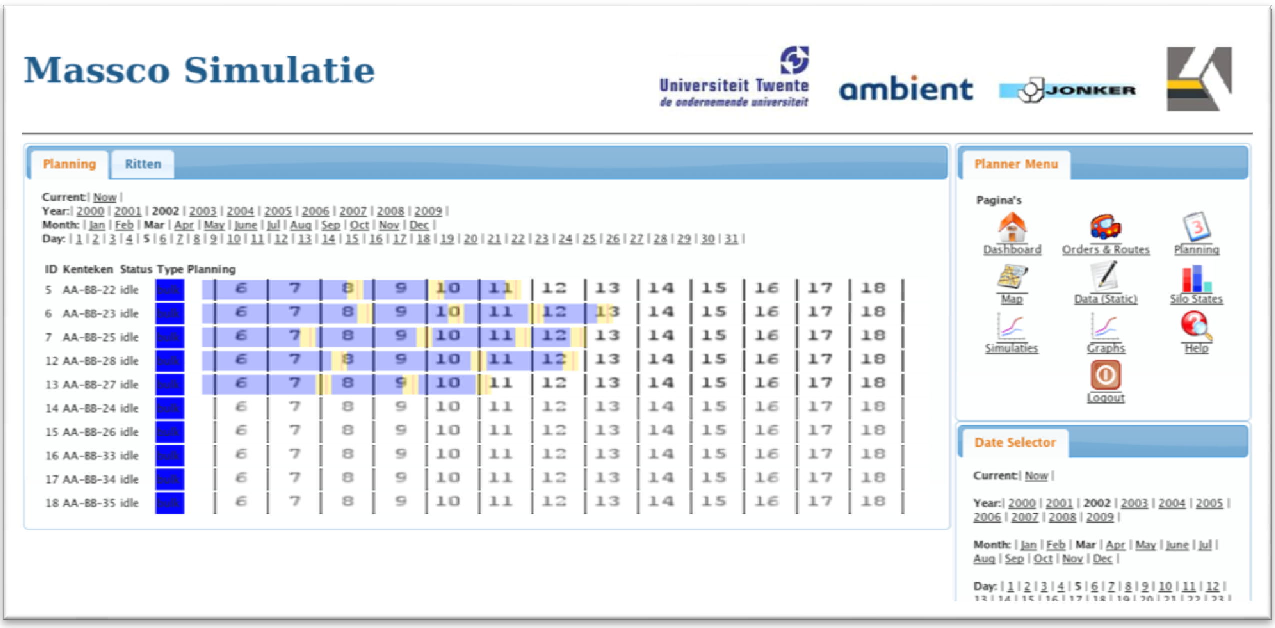


Figure 11: Day Planning (Planner)

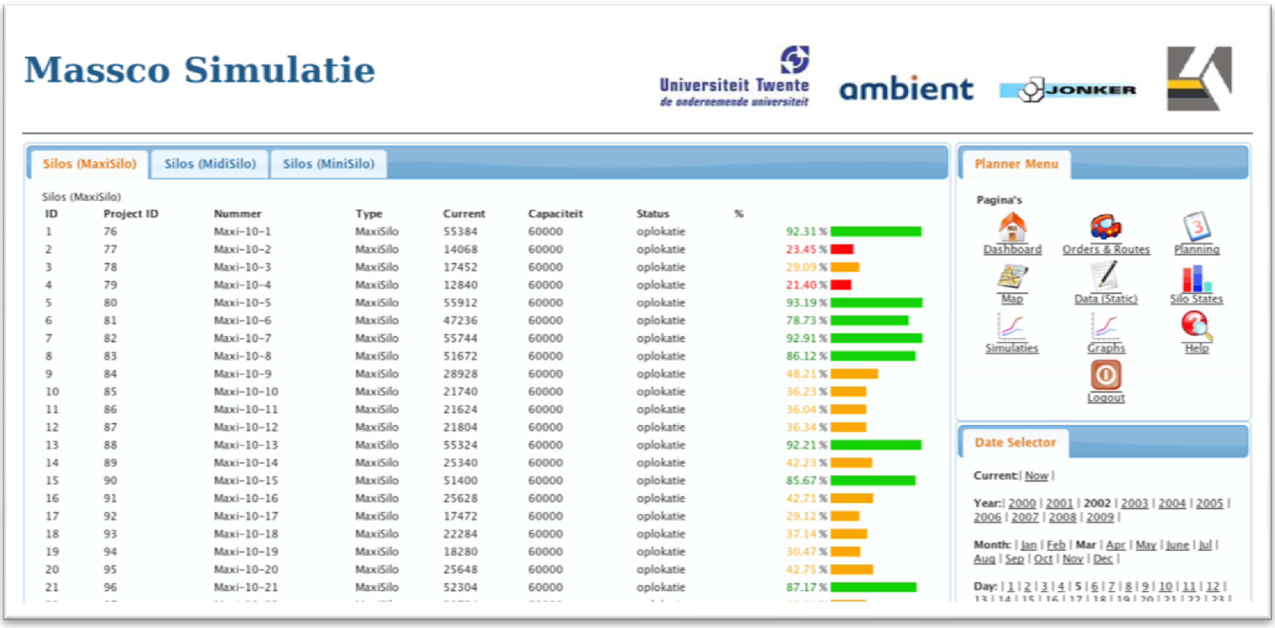


Figure 12: Silo States (Planner)

The second goal will be supported by building agents for simulating the placing and planning of orders. In order to simulate the usage of dry mortar silos are checked periodically and updated with a random decrease. The agents will be simulated using separate scripts instead of using an advanced agent platform. Collaboration between agents takes places through the database. Therefore the simulation is created as a client-server model instead of a real multi agent system.

A script is activated as a project foreman checks the silos periodically and interacts based on the silo state. When silo contents of a project run low a notice is sent to the foreman of the project. Optionally an order is automatically placed according to the total amount of raw resources ordered for the project.

Another script acts as a planner and advises the planner in assigning incoming orders to a truck. Optionally a route with travel duration close to the maximum workhours of the driver can be automatically marked as final and sent on his way.

Figure 13: Output graphs of 2 simulations

Messages between agents are stored in a central database instead of implementing it using sockets, which are needed for network communication. The interaction between parties is modeled in the diagram below. The second diagram shows the interaction between the parties using intelligent agents.

The output data of the simulation is visualized by graphs, which easily show the differences between variations. The simulation application contains an output page for the different simulation runs. Graphs are generated per month as can be seen below.

Several external data sources are used to produce as realistic results as possible. First of all the route information (distance & duration) needed to plan an order are retrieved from the ANWB route planner. This route planner estimates route duration based on normal vehicles. Therefore the duration of a route is multiplied by 1.2 to estimate the duration for a truck to drive this distance.

The location of the construction sites were created by generating a random postal code, which was validated using an external source to check if the postal code exists. Existing postal codes are needed for the route planner to work. During the creating of the simulation tool the silos were placed randomly in the Netherlands by creating a postal code between 1000 and 9999. In the final version this was changed to create postal codes between 6000 and 9999, because this resulted in a more realistic placement of the silos, because of origin the most customers of Remix are near the main production facility.

Several assumptions have been made in order to create a simulation tool to calculate or predict possible situations.

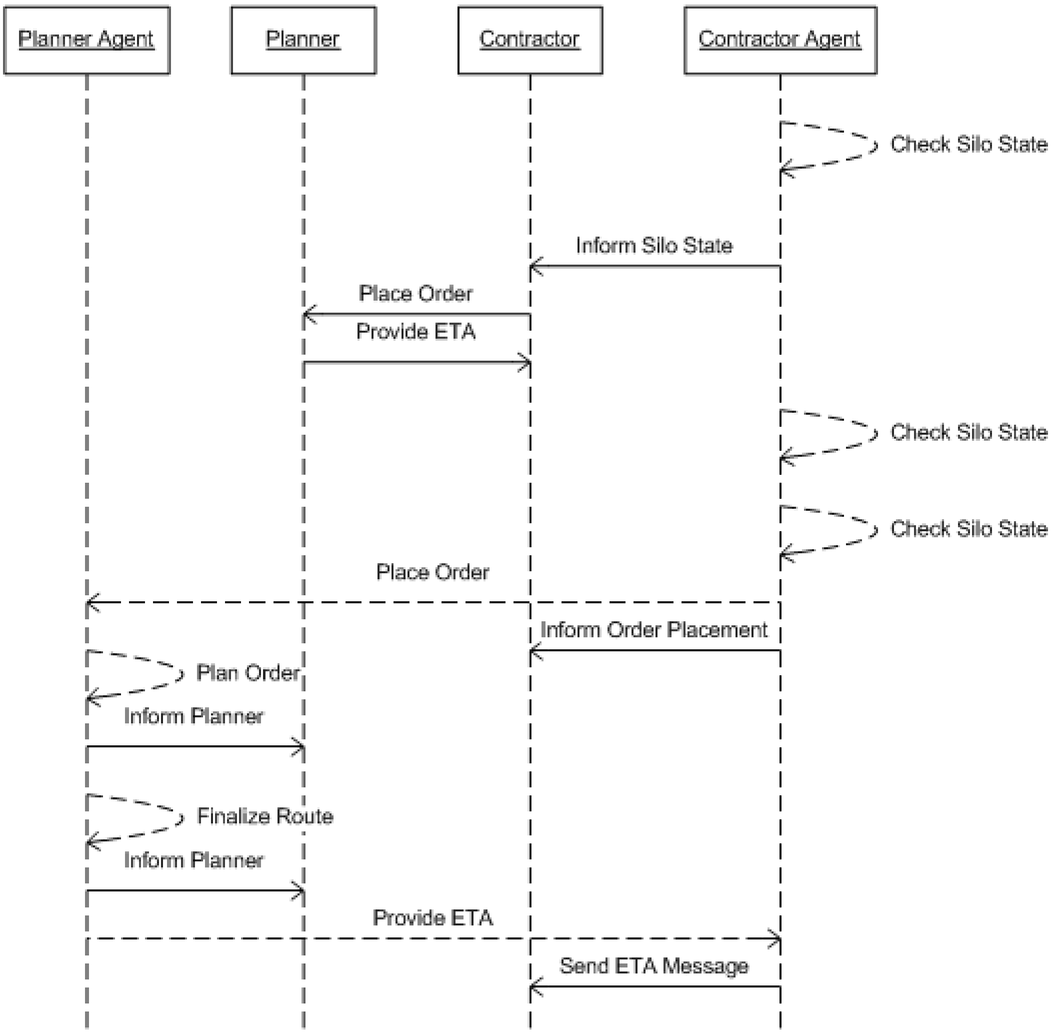


Figure 14: Agent Interaction

First of all the usage of mortar is based on the number of trucks needed per day. In contradiction to the real situation a lower number of active construction sites are used. Normally the number of active construction sites varies over time. For the simulation the number of active construction sites is held constant. Because this setting is probably lower than the real situation each construction site consumes probably more mortar than in the real situation. The total used mortar should be near realistic values.

Secondly the outcome of the simulation needs to be checked against the real situation in order to validate its outcome. Not all information needed was available to do this. The simulation does not take into account the spread of the construction sites within the Netherlands. Construction sites are generated randomly by creating a postal code between 7000 and 9999. (The production location of Remix is located at 9531.) This ensures that most construction sites are in the northern part of the Netherlands. Another test has been done where postal codes were created between 1000 and 9999. This influences the simulation because the locations were spread more evenly in the Netherlands and has a huge impact on the planning outcomes. Almost twice the amounts of trucks were needed to deliver the same amount. This is because the distances between construction sites are larger. The increased driving time also results in a lower number of possible combinations, because the truck driver has a maximum number of work hours per day.

6.5: Input Settings

The simulation program contains several input settings to tweak and vary the different simulation runs. The different settings can be categorized into four categories: Silo Alert Levels, Usage, Planning & Bulk Refill Times. The input settings are listed below with the default value.

Silo Alert Levels

The 'alert level' variable defines the range when agents are allowed to create a refill order. When the content of a silo reaches the minimum alert level an order is placed immediately.

Name	Unit	Description	Value
Minimum	kg	The minimum alert level setting defines the minimum silo level when orders are executed by an agent.	5000
Maximum	kg	The maximum alert level setting defines the maximum silo level when orders are sent by an agent.	40000

Usage

This input variable defines the minimum and maximum usage of mortar within a period.

Name	Unit	Description	Value
Minimum	kg	The minimum usage setting defines the minimum usage amount per day per silo.	100
Maximum	kg	The minimum usage setting defines the maximum usage amount per day per silo.	5000
Occurrence	Integer (min, normal , max)	The number of occurrences that a minimum, normal and maximum usage amount take place.	70,25,5

Bulk Refill Times

These variables are constants defining refill times. This information was not fully known during the research and should be verified in future research with Remix in order to get a more realistic planning.

Name	Unit	Description	Value
Connect	Seconds	The connect setting defines the amount of seconds needed to connect the truck to the silo in order to refill it.	600
Refill	kg per sec (per 10.000)	This setting defines the amount of seconds needed to refill the silo with 10.000 kg.	600
Disconnect	Seconds	The disconnect setting defines the amount of seconds needed to disconnect the truck to the silo in order to refill it.	0.03

Planning

The variables below influence the planning agent about when and how to plan new orders.

Name	Unit	Description	Value
Algorithm	Constant (nearest, farest)	This settings defines the planning algorithm used. New routes are created with selecting the nearest/farest destination first.	nearest
New route penalty	Virtual amount ~ km	This setting defines the amount of extra costs associated with creating a new route measured in a virtual amount (which is related to the amount of kilometers to the first destination).	750
Finalize Order Time Window	Seconds	This setting defines the time in seconds before finalizing (update its state to final) a route regarding its start date.	3600

6.6: Output Data

Each simulation run produces various output metrics per day. This output data can be summarized per day and month. In the table below the output data is listed.

Name	Description
Order count	The number of orders fulfilled within a certain period.
Order amount	The sum of all order amounts within a certain period.
Route count	The number of routes planned within a certain period.
Route amount	The sum of all delivered amount of dry morter within a certain period.
Route duration	The time used for executing all planned routes within a certain period.
Route kilometers	The amount of kilometers of all planned routes within a certain period.
Delivery count	The number of deliveries planned within a certain period.
Delivery amount	The average of all delivery amounts within a certain period.
Delivery duration	The average amount of time used for executing a planned delivery.=
Delivery kilometers	The average amount of kilometers of all planned deliveries with a certain period.

6.3: Hypotheses

A number of settings are implemented in the simulation program. In order to test the influence of settings regarding the results several preset simulation runs are defined.

Usage

First of all three experiments are set up for simulating the usage of dry mortar. Three maximum usage parameters are used. The parameter settings for the experiments are 2500, 5000 and 10000.

1. Increased variations of mortar usage will result in a higher variation of used trucks per day.

2. Increase variations of mortar usage will result in more kilometers.

3. A higher throughput will result in a higher silo stock-out.

Alert Level

The next three experiments test the alert level which should be used when using automatic placing of orders. This will be done according the current silo level. The parameter settings for the experiments are 2500, 5000 and 10000.

1. A higher silo state alert/order setting will result in a decrease of empty silo states
2. A lower silo state alert/order setting will result in a decrease of the ratio: kilometers driven / delivered kilogram.

Agents

One of the sub goals is to minimize the trucks needed and the amount of kilometers travelled for the deliveries. To keep the amount of trucks needed per day steady a new route penalty is implemented. Each route distance is calculated. To prevent creating a new route for each order a new route penalty is created. This penalty is a virtual cost for creating a new route. It is related to the amount of kilometers needed to drive back to the production facility. The penalty settings for the experiments are 25, 50 and 100.

The time window between the finalizing and executing of routes is varied in three experiments to see its influence. A shorter time window can lead to quicker deliveries because the time in which orders can be planned is bigger. The parameter settings for the experiments are 12 hours, 24 hours and 48 hours.

1. A higher ‘new route penalty’ will result in a decrease in the variation of number of routes per day.
2. Increasing the time window will decrease the ratio: kilometers driver / delivered kilograms

Plan Algorithm

A basic planning algorithm is implemented in the simulation. The algorithm chooses a start city for a route and then selects the nearest city to add to the route. In this experiment the selection of the first destination is test. The parameter value 'nearest' will select the nearest destination to start a new route with. The parameter value 'farest' will select the ‘farest’ destination to start a new route with. This experiment tests the influence of this parameter.

1. The ‘nearest’ plan algorithm will result in increase of the ratio: kilometers driven / delivered kilogram.

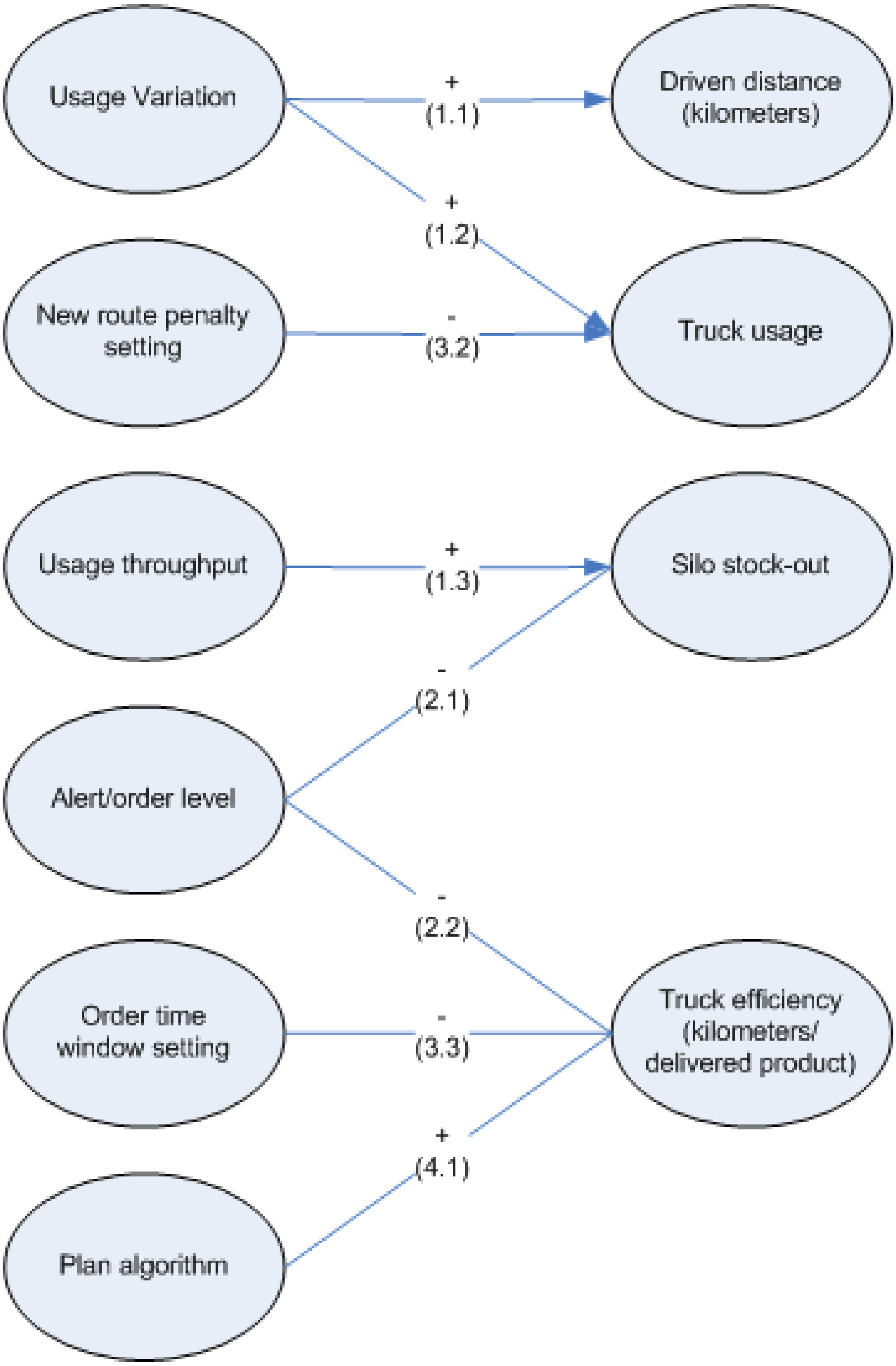


Figure 17: Hypotheses

PART IV: EVALUATION

7: Results

7.1: Experiment results

In the table below the results of the simulation runs are shown. The numbers are the total sum within a time period of 6 months. The abbreviations used in the simulation out data are respectively order count (OC), order amount (OA), route count (RC), route duration (RT), driven kilometers (KM), silo stock out (SO), and truck minimal and maximum usage (TMM) and finally the order count/route count ratio (OC/RC). The columns in red indicate the data is used for the hypotheses.

7.1.1: Usage Level

Name	Input Variable	OC	OA	RC	RT	KM	SO	KM/OA	TMM	OC/RC
Usage1	Usage level 1: (1000-2500)	546	17423	186	24622	40414	0	2.32	3-5	2.93
Usage2	Usage level 2: (500-5000)	509	15527	166	24780	35326	3	2.27	2-6	3.06
Usage3	Usage level 1: (100-10000)	436	12762	144	23396	26565	15	2.08	0-8	3.02

HP 1.1: Increase variations of mortar usage will result in a higher variation of used trucks per day.

In the first simulation experiment a minimum of 3 and a maximum of 5 trucks per day were needed. The following two simulation experiments the variation of mortar usage was increased. As expected the output data clearly shows that increasing the variation of mortar usage will result is more variations in truck usage (TMM).

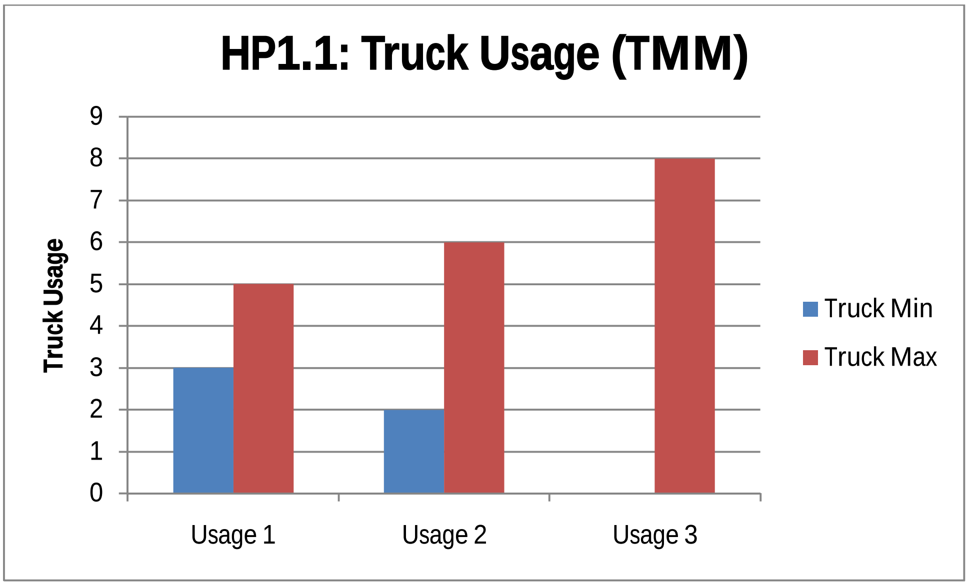


Figure 15: HP1.1: Truck Usage (TMM)

HP 1.2: Increase variations of mortar usage will result in more kilometers.

The measurement of hypothesis 1.2 is done by analyzing the driven distance (KM) indicator. The data shows that the driven distance is decreasing for each experiment in which the variation of mortar usage increases. The amount of orders (OC) also decreases and thus the ordered amount of mortar (OA). However the duration of the deliveries is almost the same for each experiment. A possible explanation for this would be if the construction sites with a lot of mortar usage (allocated randomly) are located far from the production facility. Another remark is that the OC/RC indicator (Order count divided by Route Count) remains almost the same (approximately 3 deliveries per route). Therefore hypothesis 1.2 cannot be confirmed by the output data of the simulation.

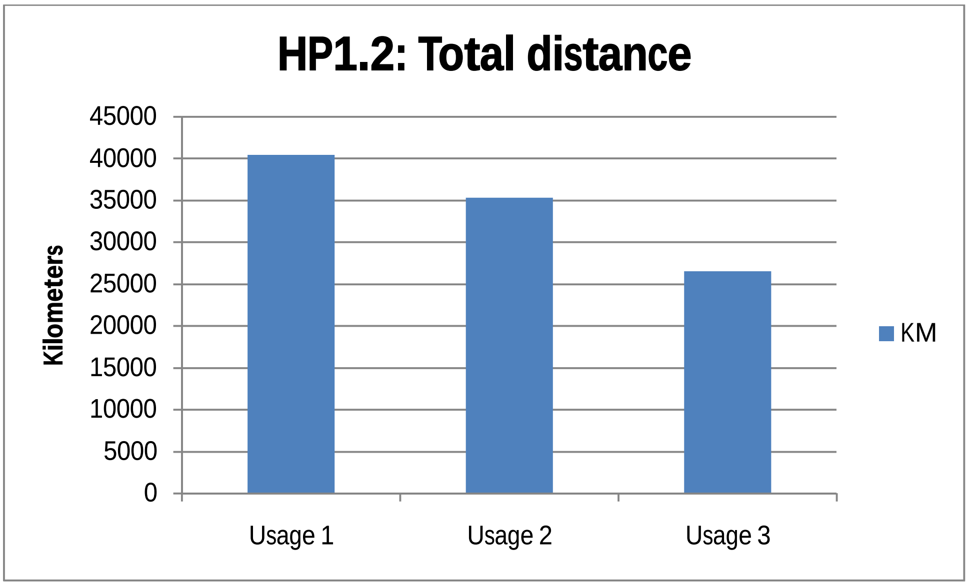


Figure 16: HP1.2: Total Distance (KM)

HP 1.3: A higher throughput will result in a higher silo stock-out.

The third hypothesis states a higher throughput of mortar will result in a higher stock out. According to the output data this is not the case, but a remark should be made that the simulation experiment varies in usage variation and not in throughput. Overall the throughput is less when a higher variation is used. The experiments have simulated 6 months. A possible explanation for this behavior could be a longer startup phase than normal because of the higher variations in mortar usage. In this case the amount of stock out increase while throughput decreases.

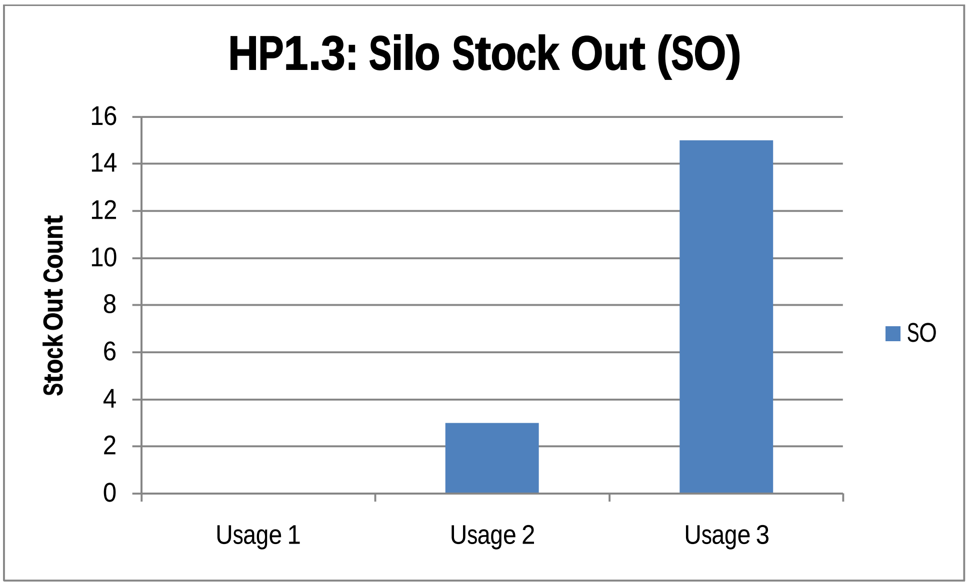


Figure 17: HP1.3: Silo Stock Out (SO)

7.1.2: Alert Level

Name	Input Variable	OC	OA	RC	RT	KM	SO	KM/OA	TMM	OC/RC
Alert1	Alert level 1: (5000-30000)	467	15508	167	23543	32558	5	2.10	2-6	2.80
Alert2	Alert level 1: (10000-30000)	561	14559	156	26946	38115	0	2.61	3-6	3.59
Alert3	Alert level 1: (20000-30000)	829	13696	150	36442	50971	0	3.72	4-6	5.53

HP 2.1: A higher silo state alert/order setting will result in a decrease of empty silo states

This experiment tests the alert level versus the amount of silo stock outs. As shown the only time stock-outs occur are at the minimum setting of 5000 kilograms of mortar. In the other two cases no stock outs occur.

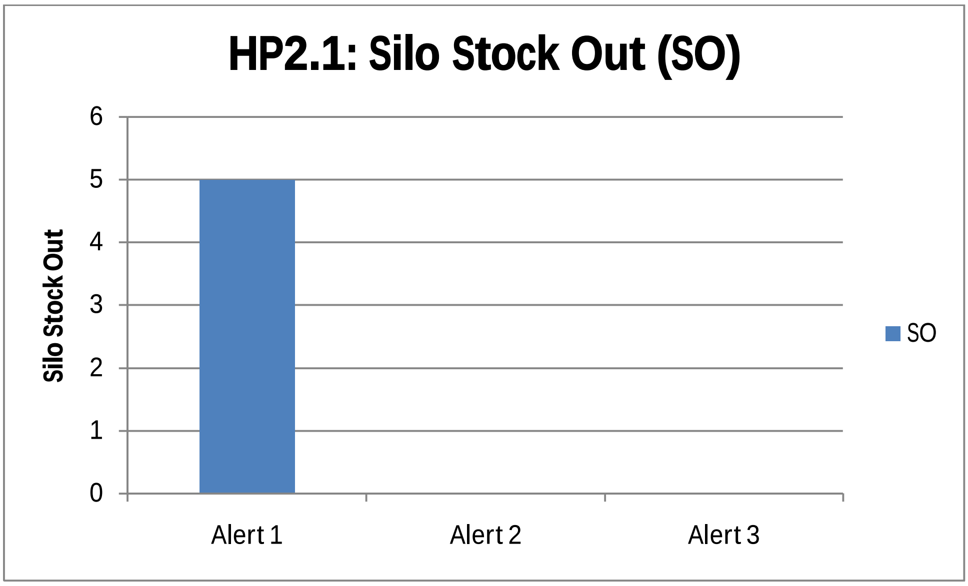


Figure 18: HP2.1: Silo Stock Out (SO)

HP 2.2: A lower silo state alert/order setting will result in a decrease of the ratio: kilometers driven / delivered kilogram.

The second hypothesis for this experiment states that the ratio of driven distance divided by the amount of mortar ordered decreases when the alert level is lower. The ordered amount of mortar is almost the same, but the total distance increases; possibly because the amount per order decreases. The output data clearly shows that the ratio is increasing when the alert level increases, so the hypothesis is true.

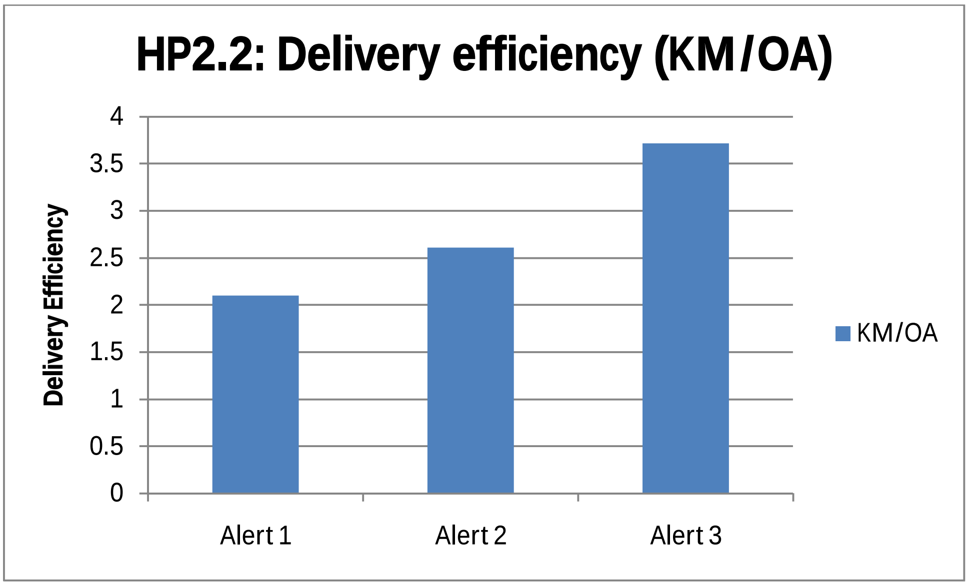


Figure 19: HP 2.2: Delivery Efficiency (KM/OA)

7.1.3: Agents

Name	Input Variable	OC	OA	RC	RT	KM	SO	KM/OA	TMM	OC/RC

Penalty1	Penalty level 1: (500)	367	10427	118	22141	22109	1	2.12	2-7	3.11
Penalty2	Penalty level 1: (750)	324	8993	108	22060	20384	2	2.26	3-7	3.00
Penalty3	Penalty level 1: (1000)	241	6355	83	17942	15045	1	2.37	4-6	2.90

Name	Input Variable	OC	OA	RC	RT	KM	SO	KM/OA	TMM	OC/RC
Window1	Time Window level 1: (2h)	523	17635	195	26112	26146	0	1.48	3-6	2.68
Window2	Time Window level 1: (12h)	498	16987	162	24781	23458	0	1.38	3-6	3.07
Window3	Time Window level 1: (48h)	582	17751	203	22651	20145	2	1.13	4-6	2.86

HP 3.1: A higher 'new route penalty' will result in decrease the variations of number of routes per day.

The variation of trucks needed per day (measures by the minimal and maximal number of trucks needed per day) is steadier with a higher new route penalty. This is logical because the new route penalty setting is implemented to prevent creating a new route for each order.

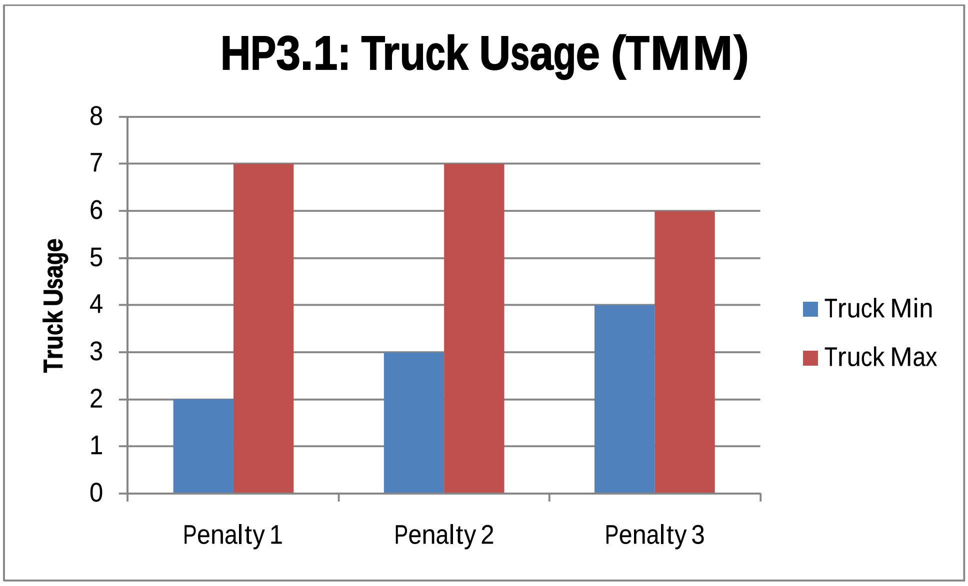


Figure 20: HP3.1: Truck Usage (TMM)

HP 3.2: Increasing the time window will decrease the ration: kilometers driver / delivered kilograms

Increasing the time window in which orders can be planned before they need to be made final, results in more efficient planning because more mortar is delivered with less mileage. Therefore this hypothesis is true.

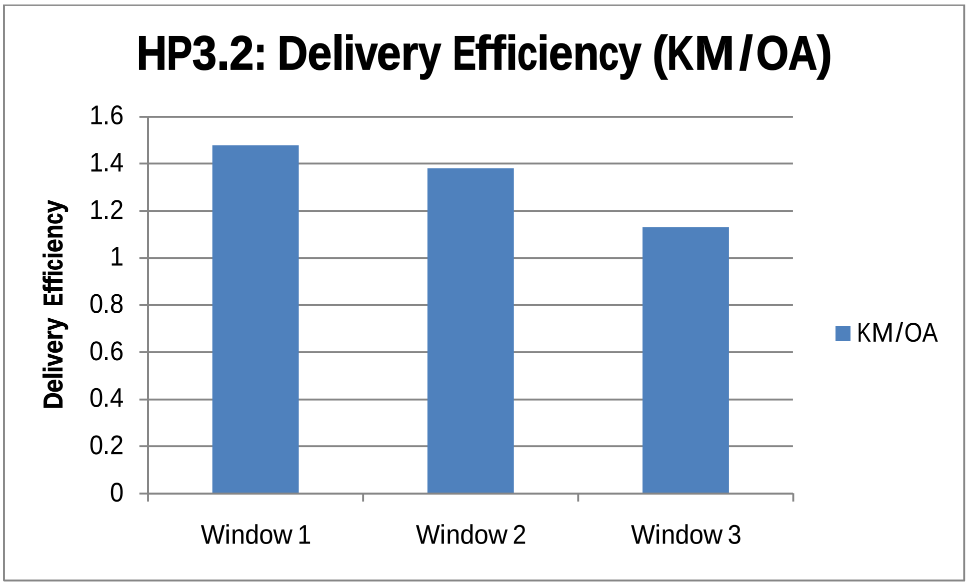


Figure 21: HP3.2: Delivery Efficiency (KM/OA)

7.1.4: Plan Algorithm

Name	Input Variable	OC	OA	RC	RT	KM	SO	KM/OA	TMM	OC/RC
Plan1	Plan level 1: (nearest)	529	16024	179	23246	21632	0	1.34	3-7	2.95
Plan2	Plan level 1: (farest)	492	14983	158	22458	21861	2	1.45	3-7	3.11

HP 4.1: The 'nearest' plan algorithm will result in increase of the ratio: kilometers driven / delivered kilogram.

The last hypothesis tests two different plan algorithms and will be evaluated according to the KM/OA indicator. The output data shows a slight decrease in efficiency when using planning algorithm 2 (farest destinations first).

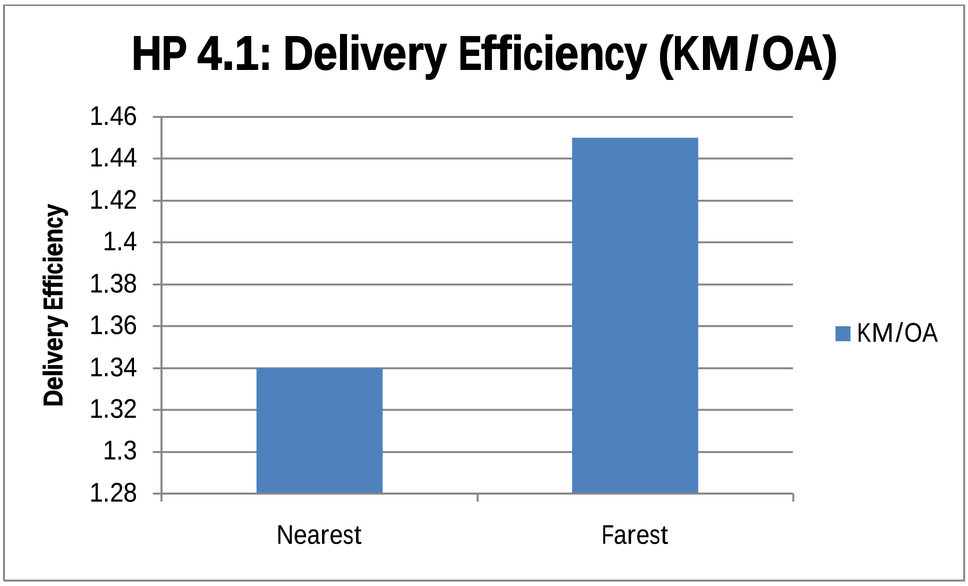


Figure 22: HP4.1: Delivery Efficiency (KM/OA)

7.2: Conclusion

The results of all hypotheses are shown in the table below. The simulation tool uses several information source on the internet for creating a simulation are realistic as possible. However many data sources are used, some assumptions had to be made. The outcome of the simulation tool is also based on these assumptions. Therefore it is important to know what assumptions are made and how they influence the outcome of the simulation.

Hypotheses	True / False
1.1: Increase variations of mortar usage will result in a higher variation of used trucks per day.	True
1.2: Increase variations of mortar usage will result in more kilometers.	False
1.3: A higher throughput will result in a higher silo stock-out.	False?
2.1: A higher silo state alert/order setting will result in a decrease of silo stock outs	True
2.2: A lower silo state alert/order setting will result in a decrease of the ratio: kilometers driven / delivered kilogram.	True
3.1: A higher 'new route penalty' will result in decrease the variations of number of routes per day.	True
3.2: Increasing the time window will decrease the ration: kilometers driver / delivered kilograms	True
4.1: The 'nearest' plan algorithm will result in increase of the ratio: kilometers driven / delivered kilogram.	True

8: Conclusion

8.1: Answers to research questions

The research questions as described in chapter 1 form the structure of this research. The first question is answered in chapter 4, where the supply chain is modeled using the SCOR model. The SCOR model provides a set of diagrams for providing a clear view of the supply chain and its processes.

The second question is answered in chapter 4. A Wireless Sensor Network is a network consisting of a very large number of small-size, low-power, wireless devices widely distributed and deeply embedded in our physical environment. Wireless Sensor Networks can be used to measure the contents of the silo placed at construction sites. This information is useful to forecast orders, notice the planning in advance and to prevent urgent orders. Chapter 4 also covers some design decision of how to implement Wireless Sensor Network for planning purposes.

The third question is answered in chapter 5 in which Multi Agent Systems are explained. A multi agent system is a system that is composed of several independent programs called agents: "An agent can be a physical or a virtual entity that can act, perceive its environment (in a partial way) and communicate with other agents, is autonomous and has skills to achieve its goals and tendencies.

The main question is answered by the prototype application itself and the performance results of the simulation experiments. The prototype application shows the usefulness of the silo information gathered by wireless sensor networks. The prototype is developed as a web application which supports also the foremen of the construction sites. Foremen can view their silo statuses online and optionally place orders. Sharing the information between both parties reduces the change of placing orders (too) late.

8.2: Future Research

The focus of this research was on the producer of mortar, who has to cope with planning the orders of the construction yards. The research proposed a system composed of Wireless Sensor Networks and Multi Agent Systems in order improve the logistic planning. The research shows that it is possible to support the business process with these technologies and how a simulation could be used to measure its performance. The outcomes of the simulation experiments do not provide any valuable information about the increased performance of such system, because these experiments are heavily dependent on the accuracy of its input. It does however give an impression how such system could be used to simulate and improve the logistic planning using intelligent agents.

On the other side the construction yards have to manage to order multiple types of building resources on time. Also many times the available space on a construction site is limited. This space is used for storing building resources but also loading and unloading it. The limited space available makes the planning problem more complex. Deliveries have to be managed by the minute to maintain construction speed. Delivery delays can create even bigger problems at the construction site. For example: When no mortar is delivered at a building site, which has limited space. It is of no use to deliver the prefabricated windows, even if they were ordered before according to planning. In such case current orders have to be postponed and communicated with the producer. Future research with the focus on the construction site is needed to further improve the logistic planning using multi agent systems.

8.3: Recommendations

Based on this research several recommendations can be given to the partners of this project. The recommendations are listed per partner.

8.3.1: Recommendations for Remix

- First of all the simulation application shows how Wireless Sensor Network helps the planner by providing valuable silo information. The WSN makes it possible to display up-to-date silo information. Sharing this valuable data with customers improves the customer service and also decreases the amount of urgent last-minute orders.
- Secondly the simulation application shows the use of creating an online ordering platform. The implementation of such system will result in an increased efficiency because fewer calls have to be made. Also the service can be improved by sharing customer related information, such as historic data and product information.
- Checking the silos on a daily basis can easily be done manually for small construction sites. The system described in this thesis can help managing the supply of mortar for larger construction sites. For smaller construction sites the costs can be too high compared to the benefits. Larger construction sites have more benefits of such system, which can exceed the costs easily on the longer term.
- Remix can create extra revenue by selling the online ordering system, wireless sensor network and possible supporting agent system as separate services to the bigger clients.

8.3.2: Recommendations for Jonker

- The recommendations above are also important for Jonker, because they do the IT implementation of the business process of Remix and others. Developing an online ordering system which is connected to the current TClick application would be of high value to Remix and its competitors and customers.
- The database of the TClick application contains a lot of historical data. Using this data in the simulation tool will result in better simulation results. The results can be validated using existing historical data.
- The application shows the use of a simulation tool for analyzing agent behavior. The demo and outcome of the simulation tool can help selling MAS to Remix and its competitors.

8.3.3: Recommendations for Ambient Systems

- Ambient Systems has created a useful system, which can be extended with new sensors. The standard node only consists of a temperature sensor. Extra sensors are currently built on demand, but are currently not available as standard add-ons. Developing a set of standard add-ons for the Ambient sensor node will speed up the implementation time and also improves the applicability of the standard product of Ambient.
- As mentioned in the section ‘future research’ more research is needed for examining the possibilities of a WSN with the focus on the construction industry. This creates an interesting opportunity of joining a possible follow-up research program, where wireless sensor networks can track and trace other building materials located on a construction site.

PART V: APPENDIX

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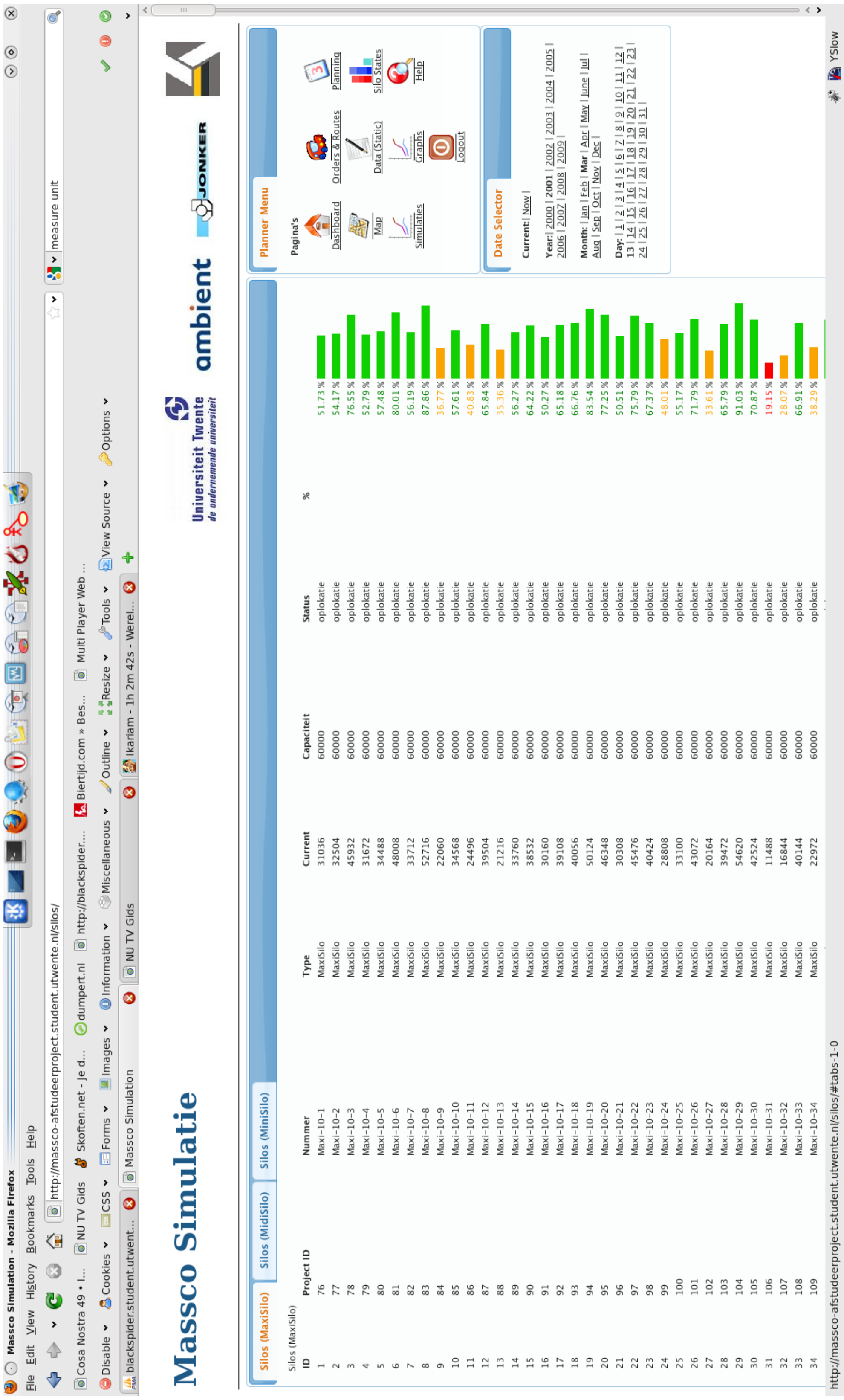
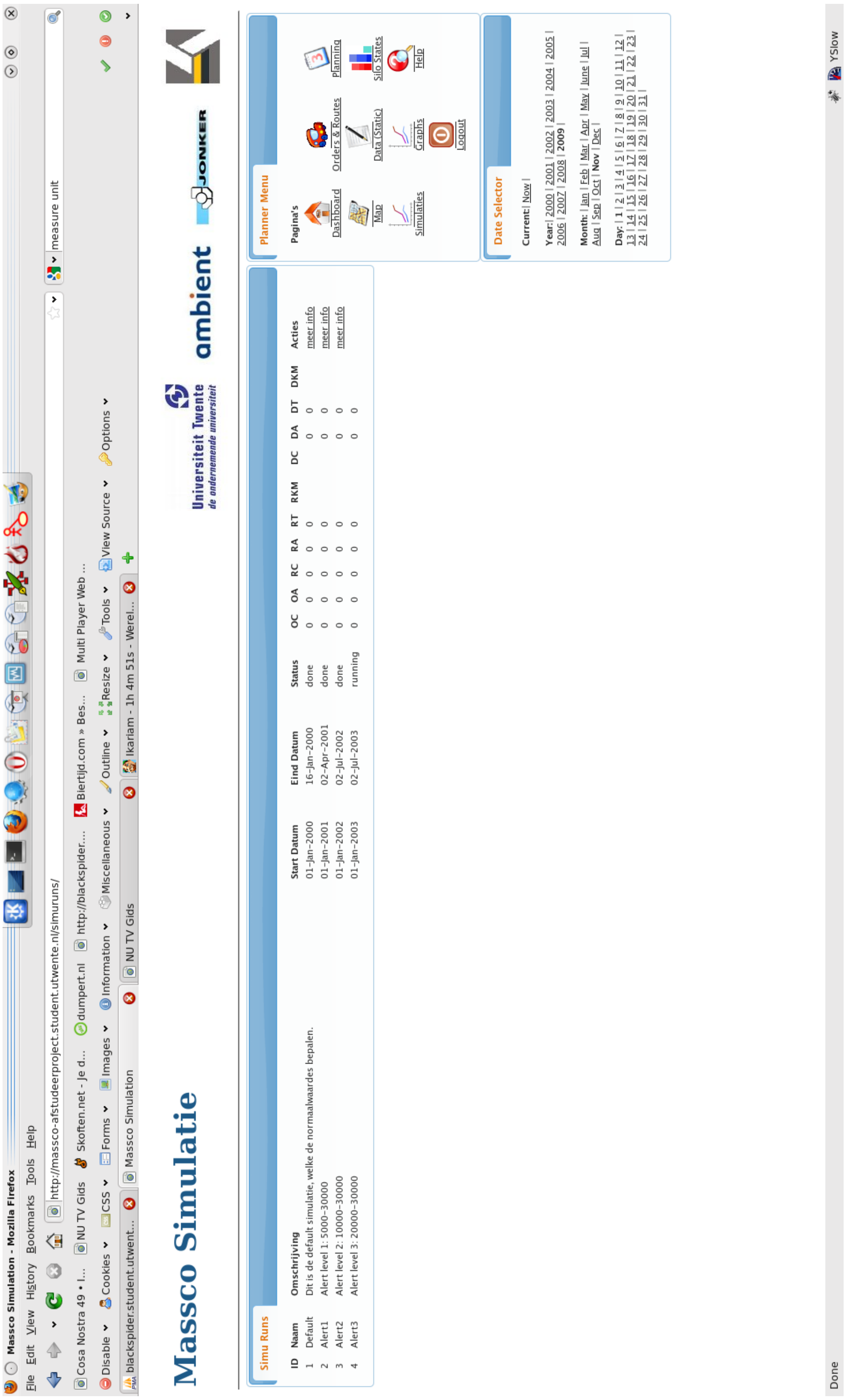
Appendix A: Screenshots

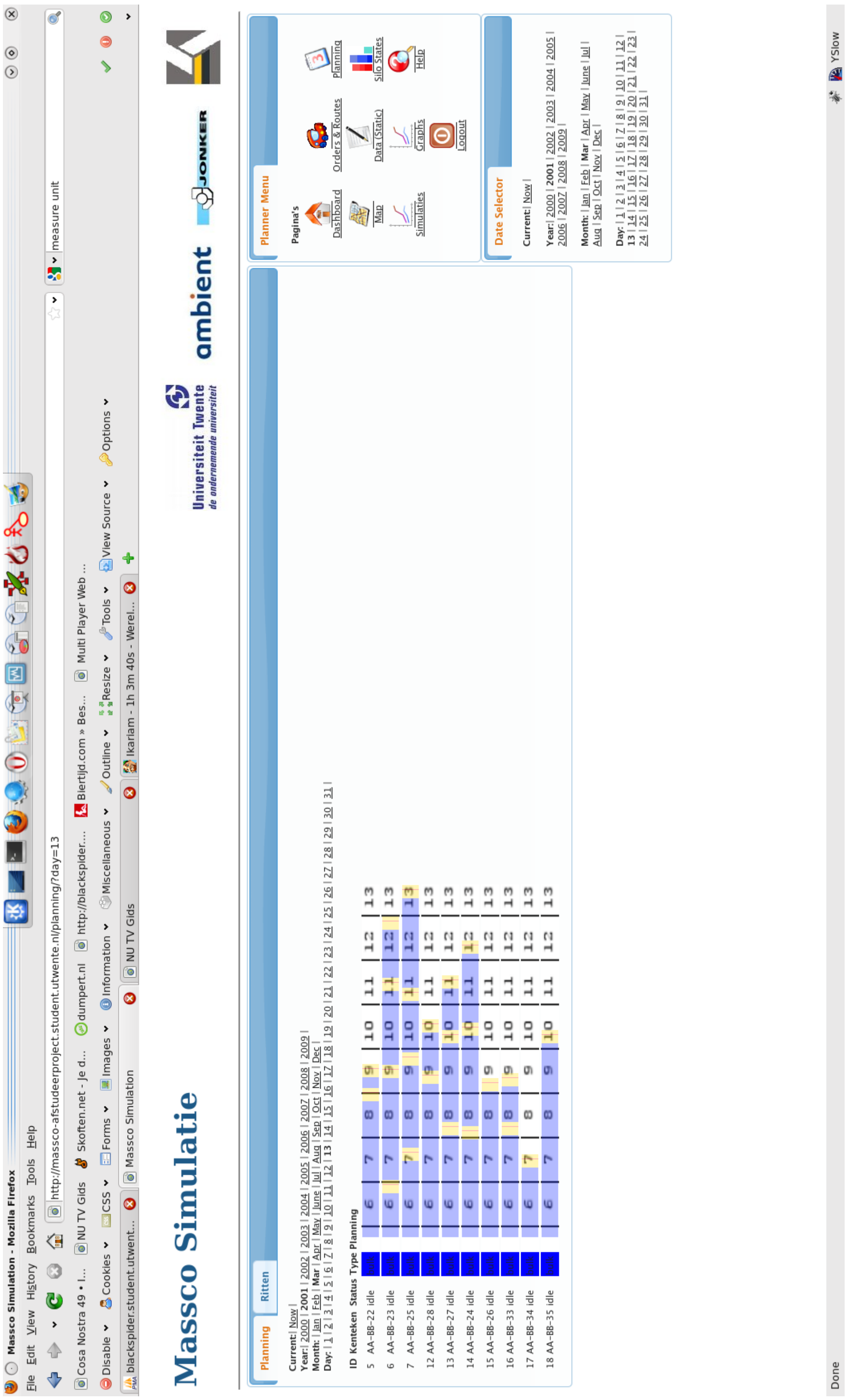
Appendix A1: Silo States



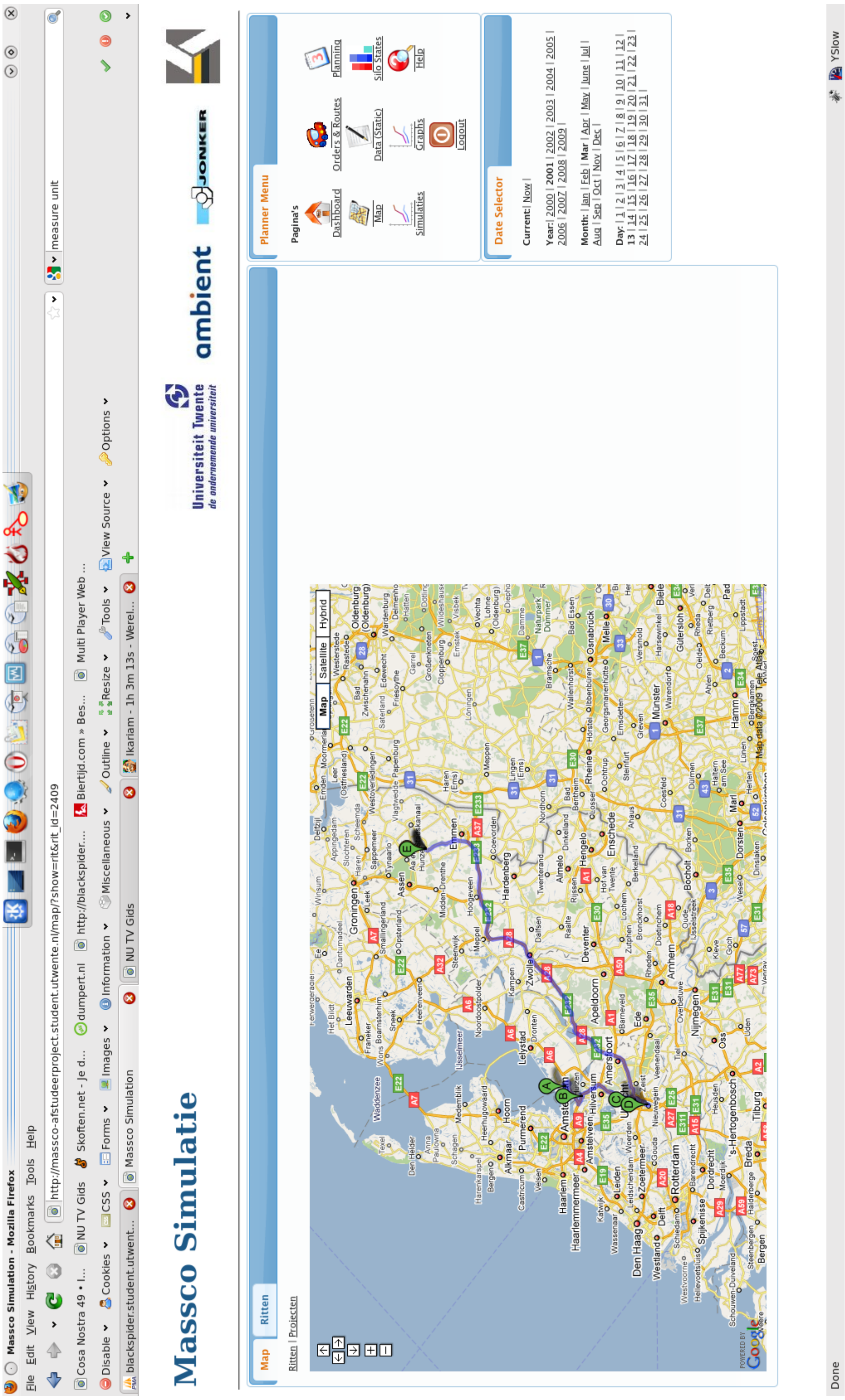
Appendix A2: Dashboard



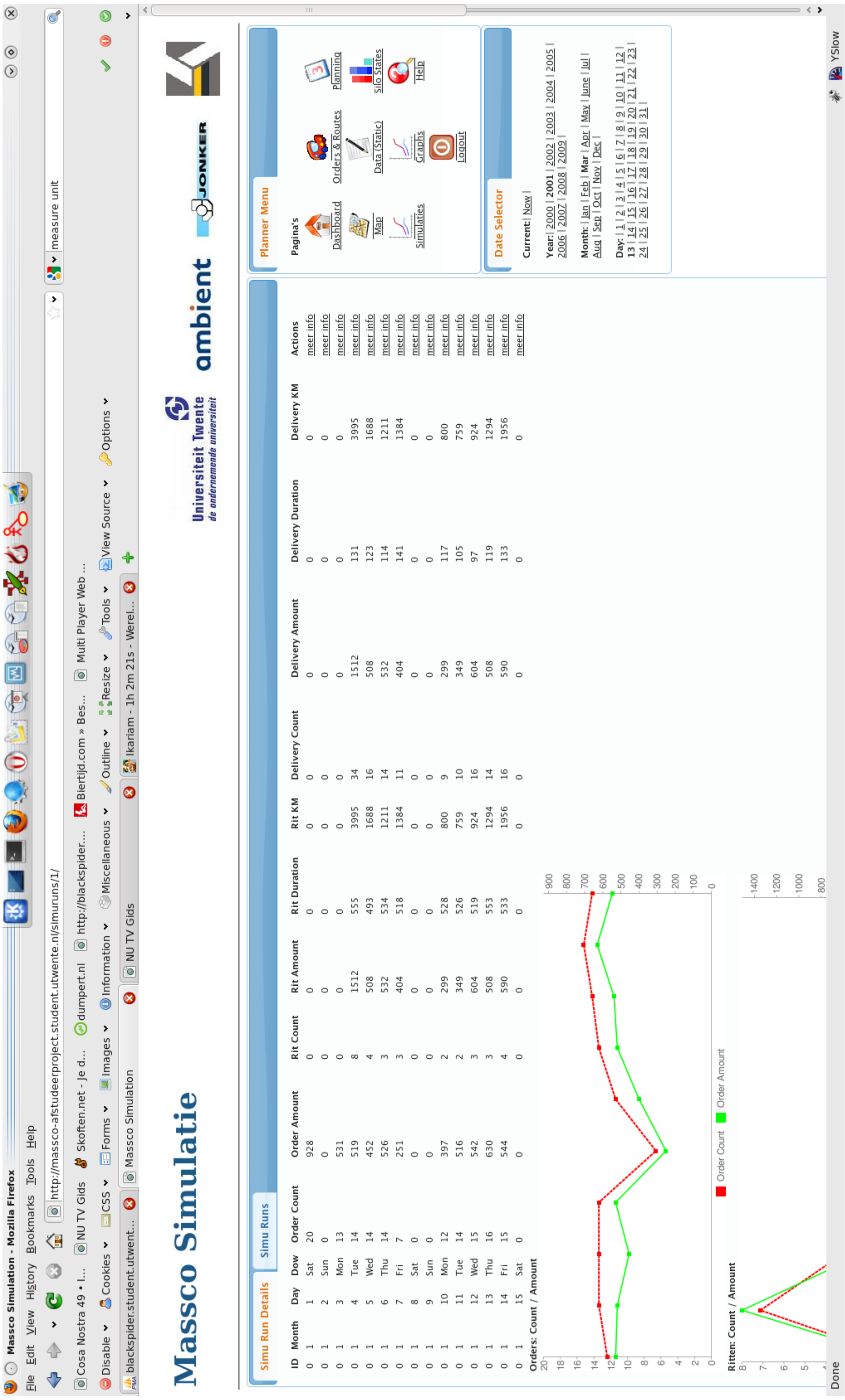
Appendix A3: Planning



Appendix A4: Map route



Appendix A5: Simulation run



Appendix B: Default Run

Appendix B1: Default Run Routes

Day	Dow	OC	OA	RC	RA	RT	RKM
1	Thu	22	944	8	688	302	2117
2	Fri	12	528	10	779	264	2306
5	Mon	18	678	7	676	304	1633
6	Tue	16	609	8	700	252	1527
7	Wed	17	700	6	618	393	2114
8	Thu	21	741	7	687	328	1928
9	Fri	14	629	8	708	282	1635
12	Mon	13	448	7	664	320	1916
13	Tue	17	617	5	492	388	1686
14	Wed	27	1036	6	624	359	1763
15	Thu	21	740	10	774	282	2677
16	Fri	20	667	11	958	314	2869
19	Mon	14	544	6	626	373	2083
20	Tue	18	713	6	606	336	1536
21	Wed	20	776	8	678	333	2624
22	Thu	17	518	9	777	301	2533
23	Fri	14	597	5	509	379	1602
26	Mon	19	613	6	592	283	1318
27	Tue	17	571	6	585	370	1929
28	Wed	17	698	6	584	329	1379
29	Thu	15	522	8	713	283	1664
30	Fri	14	485	6	572	318	1488

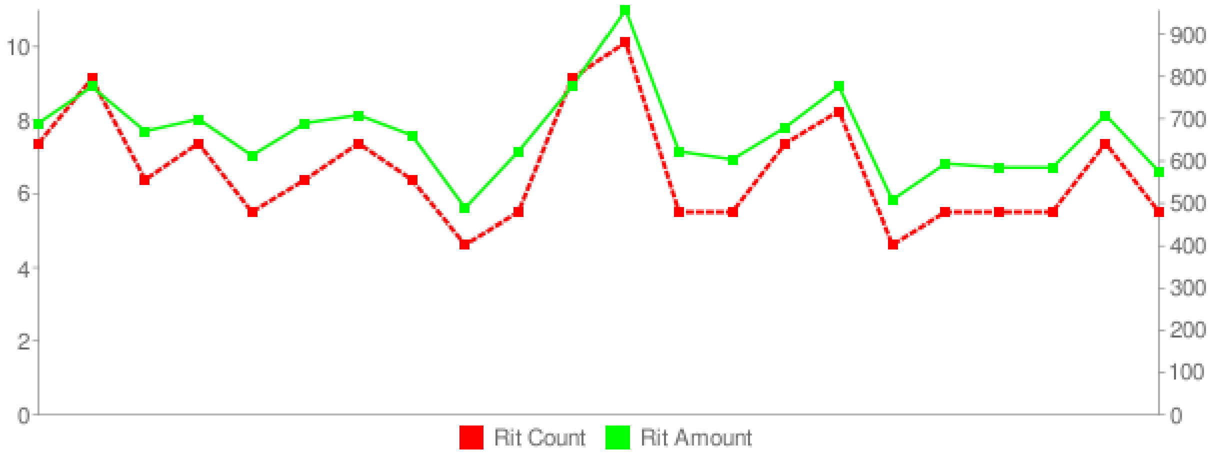
Appendix B2: Default Run Deliveries

Day	Dow	OC	OA	RC	RA	RT	RKM
1	Thu	22	944	19	688	127	2117
2	Fri	12	528	17	779	155	2306
3	Sat	0	0	0	0	0	0
4	Sun	0	0	0	0	0	0
5	Mon	18	678	17	676	125	1633
6	Tue	16	609	17	700	118	1527
7	Wed	17	700	18	618	131	2114
8	Thu	21	741	16	687	143	1928
9	Fri	14	629	20	708	113	1635
10	Sat	0	0	0	0	0	0
11	Sun	0	0	0	0	0	0
12	Mon	13	448	15	664	149	1916
13	Tue	17	617	15	492	129	1686
14	Wed	27	1036	16	624	135	1763
15	Thu	21	740	22	774	128	2677
16	Fri	20	667	27	958	128	2869
17	Sat	0	0	0	0	0	0
18	Sun	0	0	0	0	0	0
19	Mon	14	544	17	626	131	2083
20	Tue	18	713	16	606	126	1536
21	Wed	20	776	18	678	148	2624
22	Thu	17	518	20	777	136	2533
23	Fri	14	597	15	509	126	1602
24	Sat	0	0	0	0	0	0
25	Sun	0	0	0	0	0	0
26	Mon	19	613	15	592	113	1318
27	Tue	17	571	17	585	131	1929
28	Wed	17	698	18	584	110	1379
29	Thu	15	522	18	713	126	1664
30	Fri	14	485	16	572	119	1488
31	Sat	0	0	0	0	0	0

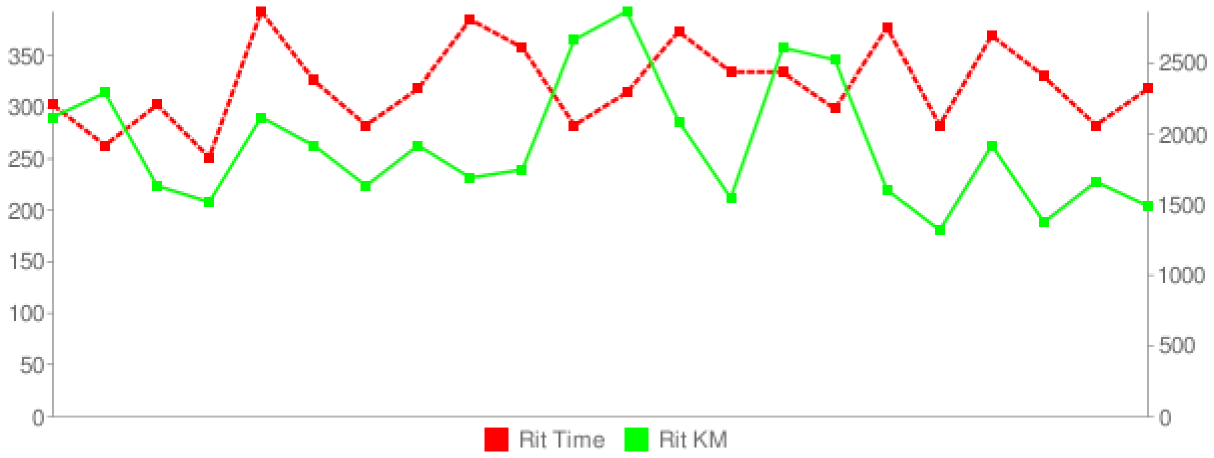
Appendix B3: Default Run Graphs

Orders: Count / Amount

Ritten: Count / Amount



Ritten: Time / KM



Deliveries: Count / Amount

Deliveries: Time / KM