The Use of Simulation with Supply Chains

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SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS**
Abstract

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Abstract

The aim of this thesis is to learn how computer simulation is being used within the area of supply chains.

The project was made available by DigiBranch. The DigiBranch project was created to learn more about simulation, virtual production, lifecycle management, manufacturability, prototyping and structural engineering

Background research was done on supply chains and then simulation. Research about supply chains included what it is and how it is managed. The simulation research was about history, what it is, and how to make a simulation model.

Then a look at how supply chains are being simulated today and a couple examples are looked at.

A case study concerning the supply chain for a virtual motorcycle factory made by Digibranch was attempted to be made as well.

The conclusion was that the use of simulation with supply chains is a useful tool. Although it can be expensive and time consuming the benefits from simulation proved worthwhile. The test case study was unable to be finished but was helpful in learning more about simulation.

Keywords
Supply Chains, Simulation

Contents

1 Introduction

With todays fast pace, global and highly competitive environment, Engineers are constantly looking for new tools and methods to increase their company's profit. With businesses being competitive and always looking for an edge, it is no longer good enough to just have the best product. Companies also need to have the most efficient supply chain. A supply chain is a system of organizations, people, info and resources involved in moving a product or service from supplier to customer. While that might sound simple it can be quit complicated. Companies nowadays normally have business extending globally and many different suppliers. With the focus on supply chains many industrial engineers are using a new powerful tool, simulation. With today's advancements in simulation software and computers, simulation is becoming a powerful tool in the workplace. Industrial engineers can use simulation to make more efficient supply chains many different ways. Some common strategies that can be tested with simulation are bull whip effect analysis, value chains, risk analysis, and new shipping strategies. With each supply chain being different from one another, each simulation project will be unique in its own way.

In 2009 the Digibranch project was started at Savonia University of Applied Science and it includes a few different areas of research such as production and productivity. The focus points for Digibranch are (13):

- Simulation
- Virtual production
- Lifecycle Management
- Manufacturability
- Prototyping
- Structural Engineering

The applied research is mainly concerned with digital production and focused specifically to the following topics (8):

- Development of virtual production assembling, and manufacturing management specifically concerning the supply chain viewpoint
- Using simulation and remote programming of production and production systems
- Planning building and testing of virtual and real prototypes including augmenting reality
- Development of process ability and productivity in the supply chain

- Personal Learning Environment (PLM) should be created using the digital production technologies and related to business processes

This thesis study is one part of the Digibranch project and the goals were to find how simulation is being used with supply chains today. The thesis will go over what makes up a supply chain and how it is managed. It is important to understand the basic strategies for improving a supply chain to be able to apply the theories to a simulation study. That is followed with a review of the basics of simulation including what it is and how it became to be what it is today.

In the end a case study was made where a supply chain was created for the virtual motorcycle factory made by the Digibranch project and an attempt to use simulation with the supply chain was done.

2 Supply Chains

2.1 What is a Supply Chain

A supply chain consists of all the stages and organizations that materials move through on their journey from the original supplier to the customer who purchases the final product (3). Figure 1 shows what goes on in a supply chain.

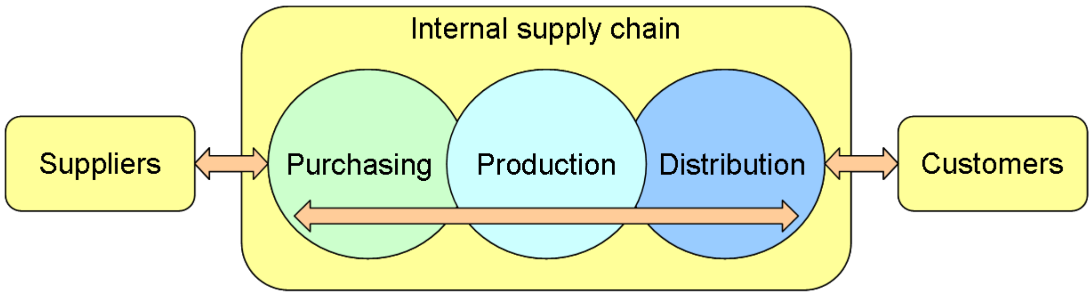


Figure 1. A Picture of what goes on in a supply chain

A Supply chain is a very complicated system and quite unique. Depending on the product being produced it can be relatively simple or quite complex. For example the supply chain of a chocolate bar company starts from ordering coco beans from a farmer in Colombia, to the final product that is bought by the consumer. A supply chain for Levi jeans started with fields of cotton and then ends when one buys them in a shop. The supply chain refers to the journey of materials as they move from "dirt to dirt." During this trip materials will move through many different places such as farmers, miners, raw materials suppliers, processors, agents, assemblers, component makers, manufacturers, packers, logistics centers, finishers, warehouses, third party operators, transport companies, wholesalers, retailers and a whole range of other operations(3). Many things can affect and change the supply chain.

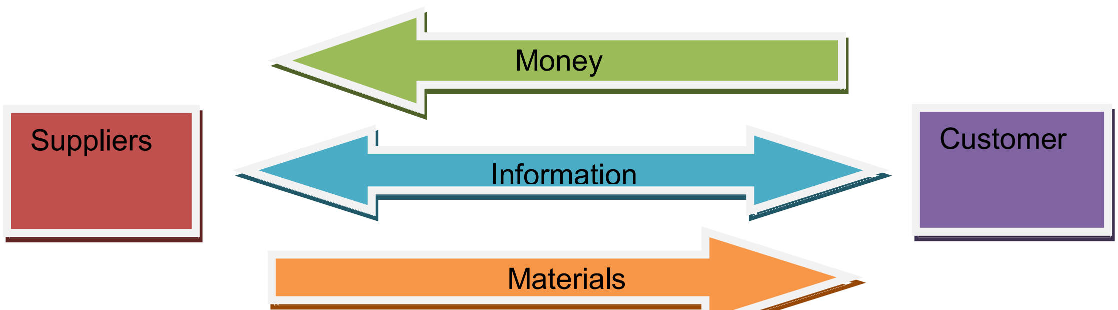


Figure 2. Shows the direction of flows in a supply chain

There are three types of flows that help make up a supply chain, those flows are material flow, information flow and cash flow. The direction of flows can be seen from figure 2. Materials for the product flow from the supplier to the manufacturer, then from the manufacturer to warehouses and retailers then finally the customers (2). The information flow includes data that's created when a change in the system occurs. Examples of information flowing in the supply chain are purchased orders or empty inventory notices. The cash flow is the flow of money in the supply chain going from the customers all the way back to the supplier.

2.2 Supply Chain Management

Supply chain management (SCM) is the term used when one is trying to manage the supply chain. SCM is the control of movements and storage of products on their journey from the original suppliers to the final customers (3). It helps to bind supplier's networks and manufacturers more tightly together. Sometimes SCM is also considered to be called logistics which is more related to transportation and distribution. All though nowadays it seems SCM is the more common term.

The goal of SCM is to overcome any kind of gap between customers and suppliers. There are five different gaps that need to be filled. The first one is space gaps, where suppliers physically separate from customers such as granite that is mined in Brazil but used by manufactures from America. The next one is a time gap, which is when there is a difference between the time a product is ready and the time when the customer wants to buy it, such as whisky that has been stored for years. Quantity gaps, between the amounts available from suppliers and the demand from customers for example how book publishers print large batches of books but customers only buy one. Next is variety gap, which is when customers want a wider variety of products than what is available from a single supplier. An example of this is how music companies have contracts with certain singers, but we buy CDs from retailers who stock a wider selection. The last one is information gap, when customers do not know about the source of a product or availability and suppliers do not know about potential customers. An example of that is how some countries have no McDonald's restaurants because the supply chains have not penetrated the markets (3). Supply chain managers want to overcome these gaps as efficiently as possible while still providing good customer service levels. Good customer service in SCM consists of fast deliveries, quick response, low costs, little waste, no damage to the products, no mistakes, good morale, etc. (3).

As SCM is a very broad task, there are many activities that make up SCM and those are (3):

- Procurement - this is what initiates the flow of materials, such as a purchase order sent to a supplier
- Inward transport - moving material from suppliers to an organizations receiving area. For this managers have to pick the right ways of transportation such as air or road etc., the best operators and route, making sure all safety and legal requirements are met, delivery times are met, low costs and so on
- Receiving - making sure the materials are the correct ones, taking receipts, unloading delivery vehicles, inspecting for damage and sorting
- Warehousing - moving the material from the receiving area into storage and making sure the materials are properly looked after, such as food needing to stay refrigerated.
- Stock control - This sets the policies for inventory, consists of overall investment, the materials to store, stock levels, customer service, order sizes, order timing and so on.
- Material handling - the movement of materials within an organization
- Order picking - finds and removes materials from stores that is needed by customers
- Packaging - wrapping materials to make sure they are protecting while they are moved to prevent damage
- Outward transport - taking the material from the departure area and delivers them to customers
- Physical distribution - the general term for activities that deliver finished goods to customers. Often it’s aligned with marketing and forms a link with downstream activities.
- Recycling returns and waste disposal - often when materials are delivered they are incorrect such as being faulty or too many etc. These products have to be returned. This also includes the packaging material such as pallets or other materials that can be recycled.
- Location - Logistic activities are usually spread to many locations. Managers have to find the best locations for the materials and number of facilities.
- Communication - with the physical floor of materials there is also the flow of information. This is what links all the parts of a supply chain

2.3 History and Importance

SCM has been around for a while now. There is no single point that marks the origin of SCM and it has been evolving ever since people have wanted to move things (3). Attention to supply chains was raised by military campaigns, a Quote by Eisenhower shows this “battles, campaigns and even wars have been won or lost primarily because of logistics.” Logistics and SCM are often words used to describe the same thing. After knowing what makes up the supply chain and what it takes to manage it, it can be seen that it is an important function in an organization. But despite this fact many managers haven’t always given it proper attention. Instead they focus on making products. In the 1920’s people began to take a closer look at supply chains. Until 1960’s their work didn’t have much of an impact on business, except in World War II which finally brought logistics to highlight. Around that time as economic pressures grew on business, and as companies expanded globally SCM become one of the most dynamic areas of business. It is constantly introducing new methods and creating the way for new types of operations.

2.4 Building effective supply chains

Building an effective supply chain is a difficult task. There are many things to consider and strategies that you can use to help optimize a supply chain.

A SCM strategy consist of all the long term goals, plans, policies, culture, resources, decisions and actions that relate to the management of an organizations supply chains (3). In figure 2 you can see how there are many different factors that will affect what kind of SCM strategy will be used.

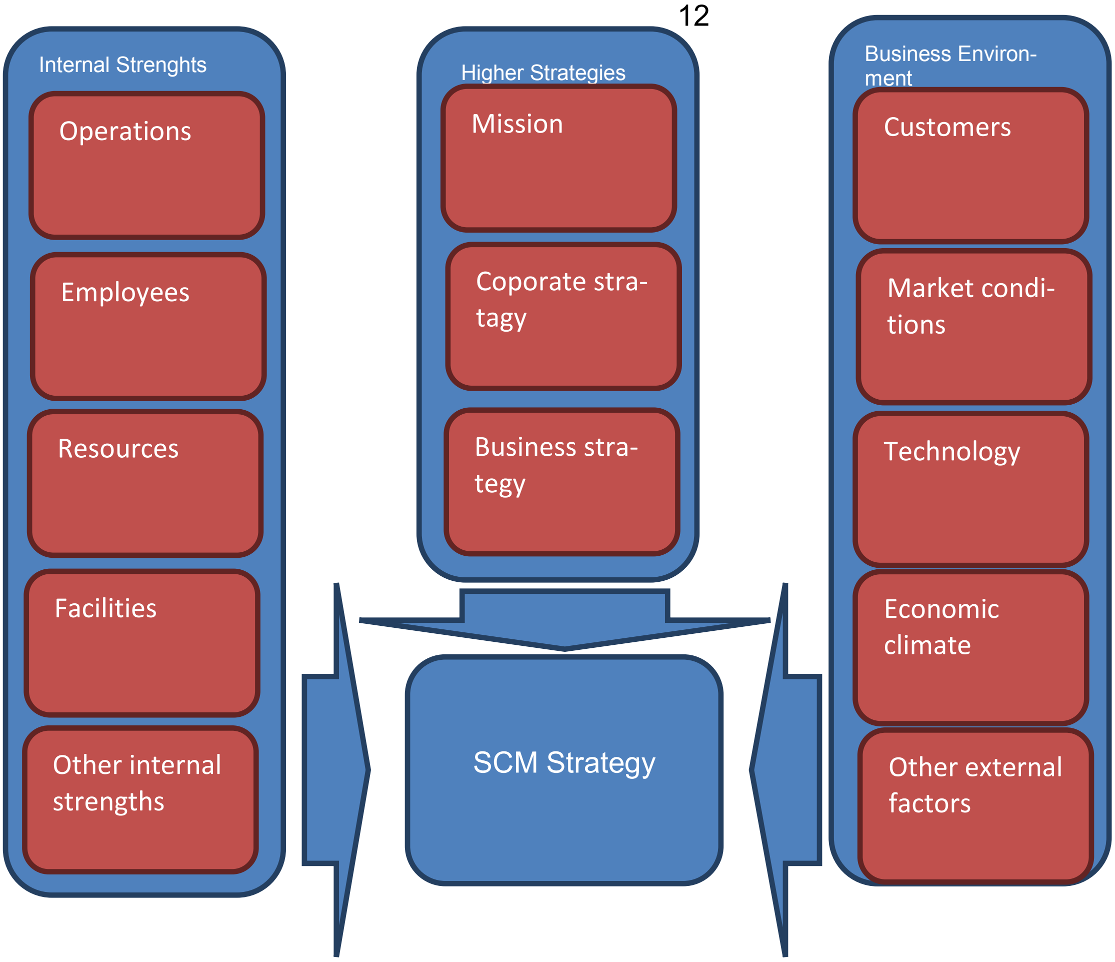


Figure 3. Shows what factors are used in designing a SCM strategy

The area of business where SCM will improve a company is with their internal strengths. The main assets that are used for that are (3):

- customers - their demands, loyalty, relationships
- suppliers - their service flexibility, partnerships
- operations - types quality, reputation, flexibility
- employees - skills, expertise, knowledge, loyalty
- facilities - types locations, capacity, age, reliability
- finances - costs, cash flow, overheads,
- technology - currently used, systems, updates, special types,
- innovation - in services, operations, systems,
- organization - structure, relationships, flexibility

2.5 SCM strategies

Although each company's supply chain is different there are a few SCM strategies that are frequently being used today with good success.

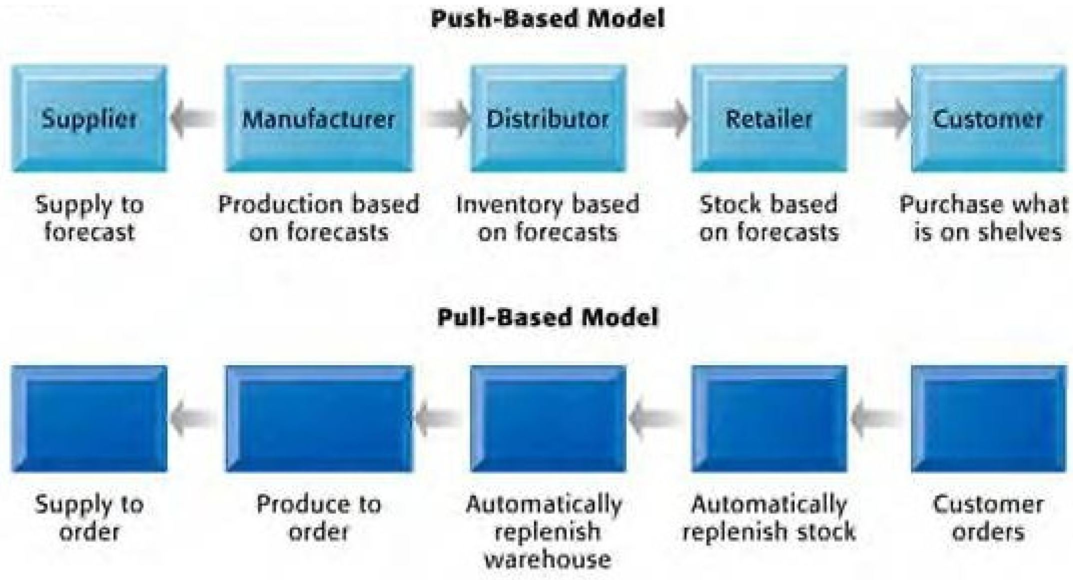


Figure 4. The differences between push and pull based models

2.5.1 Lean Manufacturing

Lean Manufacturing is a production strategy that focuses on maintaining acceptable customer service while using as few resources as possible such as people, facilities, time, stock, equipment and so on. This is accomplished is by removing waste from the supply chain. The history of lean manufacturing is quite long; however it became quite popular because of the car manufacture Toyota. Toyota initially called the strategy the Toyota Production System (TPS) where they focused on removing waste from the manufacturing processes, where the term lean production was coined up. Lean manufacturing also uses a pull system. From figure 4 you can see how a pull system works. Instead of creating a product and pushing it through the supply chain the product is pulled through the supply chain caused by a customer's order. Another part of leanness is to look at all the operations being used to deliver a final product, and then identify the operations as value adding or non-value adding, and removing the non-value adding activities. It is known that there are seven areas of waste but there can be a few more added to the list as well (3):

- Overproduction – Making units that are not needed and giving excess stocks of finished goods.
- Waiting – With resources sitting idly waiting for operations to start of finish, materials to arrive, equipment to be repaired and so on.
- Transportation – moving materials over to long distances between suppliers and customers.
- Poor process – with unnecessary, complicated, or time consuming operations.

- Work in progress – with materials held up and moving slowly through supply chains.
- Movement- with products making unnecessary, long or inconvenient movements during operations.
- Product defects – with resources wasted as poor quality units are scrapped, repaired, reworked or returned to an earlier part of the process.
- Overbuying – giving high stocks of raw materials that are not immediately needed.
- Space capacity – that lies idle and gives low utilization and productivity.
- Waste of human resources – not using people to their full potential.
- Bureaucracy – giving to many layers of management, slow decisions, inefficient flows of information, and so on.
- Excessive over heads – with various fixed costs adding an unnecessary burden to operations.

From the list above one can see that there are lots of different types of waste that can be removed. As Robert Townsend said that “All organizations are at least 50% waste – waste people, waste effort, waste space and waste time.”(3)

2.5.2 Agile strategy

Some people feel that a lean strategy only works best with large-scale mass production systems where efficiency and cost are the main factors, but the key points don’t transfer to other types of supply chains successfully. They feel that waste is important and not a key factory especially when there are variable and uncertain conditions. Then it is more important to be able to be responsive to rapid changes and maintaining customer service with customized products and short delivery times. This leads us to the agile strategy. An agile strategy is based on a push system, the opposite of a pull system, which you can see how it works from figure 4. Instead of the product being pulled through like in a leanness strategy the product is pushed through the supply chain which starts at the supplier. With volatile markets becoming the norm nowadays, an agile strategy is a key component to staying successful. An agile supply chain gives high customer service by responding quickly to changing conditions. Its key features are its flexibility and speed of response (3). In theory there are two key points with an agile strategy. First is the speed of reactions, an agile strategy keeps a close eye on the customer demand and then quickly reacts to changes. Second is the ability to tailor fit each customer’s needs, providing a unique service that fulfills the needs of each person. Organizations with an agile strategy put so much emphasis on customer satisfaction that they are said to have a customer focus, and they typically (3):

- Are sensitive to market conditions and know exactly what customers want
- Aim for customer satisfaction.
- Offer a wide range of products, which are made to order or mass customization.
- Have variable demand that is less predictable.
- Base operations on actually customer demands rather than forecasts.
- Cooperate with supply chain partners to share information and ensure that final customer demands are met.
- Ensure that all operations are flexible enough to respond quickly to changing conditions.
- Design logistics to meet, or exceed, likely demands.
- Have an open organization that allows customers easy access.
- Routinely ensure, perhaps through after sales checks, that customers remain satisfied.
- Look outwards and keep in touch with customers, potentials customers, competitors, and so on.

Leanness is mostly associated with mass production, agility is more likely in use with smaller operations with more product variety.

2.5.3 Environmental protection strategies

With todays “green power” being a huge marketing tool and concern in society, it is wise for all business to take interest. For example the store, The Body Shop, emphasis its ethical standards, and in supply chain management this means fair trade, reusable containers, recycling materials and ethical relationships with other organizations (3). With new regulations being put in place such as the European waste Electrical and Electronic Equipment Directive that became law in 2003 and implements recycling, collection, and recovery targets for all kinds of electrical goods the importance of going green can be easily seen.

Figure 5. Going “green” is a common idea today.

Also there are the ISO14000 standards that gives guidance for environmental management systems which puts emphasize on the need to reduce, reuse and recycle and businesses have to increase the amount of attention paid to their emissions of carbon dioxide and environmental impact. But quite often managers are looking at the new environmental rules and taking them as new pressures and threats instead of an opportunity for new possibilities. A strategy of environmental protection can lead to improvements in a whole range of ways, including less energy waste from better insulation of buildings, improving fuel efficiency, reducing distances travelled, lowering emissions, avoiding traffic jams, travelling outside peak hours, reusing packaging and so on(3).

2.5.4 Just In Time

Just In Time, JIT, is a strategy that helps control the flow of materials. One of the key points for JIT is to make sure that all the materials or activities that are needed will occur at the exact time that they are needed. One can see how this is important when ordering a taxi. If you order a taxi for 8:00 but the taxi comes at 8:30 you will not be happy. If the taxi comes at 7:30 you won’t be ready and the taxi waste times sitting and waiting. When the taxi comes at 8:00 it does not waste time waiting and you are happy with the service.

JIT is another strategy that became popular through Toyota. JIT operations organize materials to arrive just as they are need. By coordinating supply and demand, they eliminate stocks of raw materials and work in progress (3). Typically companies will use stocks to help cover the demand of a product between the time a new batch is coming in. But with JIT it is believed that having stocks is a waste because the products are just standing there. With a JIT approach, you look to improve problems rather than accepting current bad practice. With stocks, its argument goes as follows (3):

- Stocks are held to cover short term mismatches between supply and demand.
- These stocks serve no useful purpose, they only exist because poor coordination does not match the supply of materials to the demand
- As long as stocks are held, there are no obvious problems and no incentive for managers to improve things
- So operations continue to be poorly managed, with problems hidden by stocks.
- The real answer is to improve operations, find the reasons for differences between supply and demand, and then take whatever action is needed to overcome them.

With this reasoning being so convincing many western companies have started to use the JIT strategy in their own operations since the 1980's.

JIT uses two ideas to help manage the flow of materials. First is that it uses a pull system instead of a push system. In a traditional process, materials are pushed through to the next operation. But this ignores what the next operations are actually doing, creating large bulky stocks. JIT uses a pulling approach to pull materials through a process. When one operation is finished with its work, it passes a message back to the previous operations that it needs another unit to continue work. Meaning that earlier operations do not push the work forward but later operations will pull it through. The second key to JIT is the ability to pass a message back to the previous operations; this is done through the use of kanbans. Kanbans are cards that control the flow of materials through JIT operations. They organize the pull of materials through a process (3). There are lots of ways to use kanban cards, with paper messages from electronic ones. The traditional JIT system uses two types of kanban cards. A production kanban, which will signal for more of a product to be made and then a movement kanban, which signals the need to retrieve more stock.

JIT is a powerful tool that works by coordinating activities and eliminating waste. Which is one of the aims of a lean strategy, and JIT is one of the sources that helped create lean thinking. It can be said that JIT expanded and evolved into leanness.

2.5.5 Heijunka box

Heijunka is another tool that comes from the Toyota Production System and can be used with the JIT strategy or any other one for that matter. A heijunka box easily allows visual control of a smoothed production schedule (13). The typical heijunka box has horizontal rows for each product but in our case with supply chains instead of products, each process in the SC can be used. The vertical columns are for the time intervals of production, or the time for a process in the SC. Figure 6 shows how a typical Heijunka box can look like

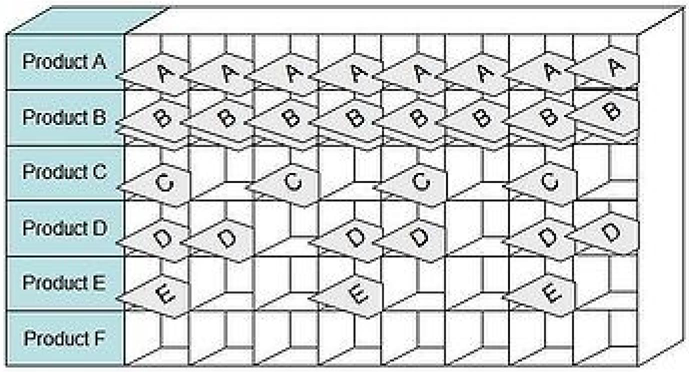


Figure 6. A typical heijunka box

Using heijunka boxes with a supply chain will help streamline things together to prevent wasted time and unnecessary work. This is because the user will be able to see what process can be mixed with other ones or where a process may not be fully utilized, an example of that could be a machine that only ran for 1 hour a day when it could be ran for 24 hours instead.

3 Simulation

Simulation today is one of the most widely techniques used for research and management techniques, if not the most widely used (4). Nowadays there are many different types of ways to use simulation ranging from spreadsheet simulation to effective over the counter simulation products such as Arena and Enterprise Dynamics. This paper will be focusing on the use of ”over the counter” simulation products and how they can be used. Simulation is used for many different reasons, a very common one is testing out “what if” situations. Consider a manufacturing company that is contemplating expanding one of its plants but is not sure if the potential gain in productivity would justify the construction cost. Building the extension first and then removing it later if it didn’t work out would not be cost effective. However, a carefully planned simulation study would be able to help the question by simulating the operation of the plant as it currently exists and then as it would be if the plant expanded (4). From this it can be seen that simulation is a powerful tool that can be very helpful by reducing the risk in investment decisions.

3.1 History of simulation

Today simulation is arguable one of the most multifaceted topics that can face an Industrial engineer in the work place. It can also be one of the most important to a corporation, regardless of the industry (5). With the advances in technology and easy to use modeling there is now low priced packages that would have been unthinkable just a few years ago. The simulation industry is coming of age and is no longer only in the field of academics.

The first case of using a computer to use simulation dates back to World War II, when two mathematicians were faced with a puzzling problem of the behavior of neutrons. With hit and trail experiments too costly and the problem too complicated for analysis they developed a simple simulation technique. By using the basic data regarding the occurrence of various events that were known, the probabilities of separate events were combined in a step by step analysis to predict the outcome of the whole sequence of events. With their amazing success their technique became quite popular and found many applications in the business and industry workplace (5).

During 1950 – 1970, which is known as the Formative period, was when simulation with computers started to come around. It was during this time that the use of simulation was starting to be realized by engineers (6). During this time computer simulation was quite difficult, taking a long time to get results and required many skilled people resulting in high costs.

Between the 1970's and 1990's expansion period came along. During this time simulation was still considered a difficult task but becoming more and more standardized. With affordable computers and development of simulation code commercially available simulation software was starting to make a big appearance.

The period that's occurring now is the Maturation period, starting from 1991 and continuing still today. The quest for making simulation languages more powerful and easy to use was and is becoming quite real (6). There are numerous simulation packages available today containing good graphics and becoming much easier to use. Simulation started to make its way into more and more industries such as healthcare and the airline industry. There are numerous textbooks on the market and highly regarded conferences that focuses on simulation such as the Winter Simulation Conference.

In the future simulation is going to become even easier and more commonly used. With computers becoming even more powerful soon ideas like real time what if analysis will be able to be used. Allowing supply chain managers to use up to date information, keeping efficiency and productivity at high levels.

3.2 What is Simulation

When you are simulating you are creating a system. A system is defined to be a collection of entities, such as people or machines, which act and interact together towards the accomplishment of some logical end (4). Other elements included in the system are attributes, activities, states and events (4):

- Attribute – A property of a system, these can be the speed, capacity, and breakdown rate of machines (entities).
- Activity – Is the time period with a specified length.
- State - Collection of variables that are needed to illustrate the system at any time, related to the goal of the study.

- Event – is defined as the exact moment that may change the state of a part or the whole of the system.

After finding the information that will make up the system, simulation can be used to create a model of what is wanted. A model is a copy of the real life or imaginary system that is being created when using simulation.

Systems can be categorized as two types, continuous and discrete. A discrete system is where the state variables change instantly at separate points of time. An example of this is the number of customers in a bank, the amount of customers change only when a customer arrives or when a customer finishes being served and departs. A continuous system is where the state variables are constantly changing with respect to time. An example of that is an airplane flying through the air (4).

3.3 Steps to making a simulation

After looking into the workings of simulation there is a need to realize that model programming is just part of the overall effort to design or analyze a complex system by simulation. From figure 4 the steps that will create a typical sound simulation study can be seen. Note that a simulation study is not a simple sequential process. As one proceeds with the study it may be necessary to go back to a previous step (4):

- Step 1 – Addressing such issues as the objectives of the study, specific questions that need to be answered, performance measures, time frame and the required resources.
- Step 2 – This step involves gathering the proper information. Info should be collected from all possible sources. This includes information from the existing systems, model parameters, input probability etc.
- Step 3 –Checking to see if the conceptual model is realistic to help ensure that the model's assumptions are correct and complete.
- Step 4 – Designing the simulation program or choose an OTC program that will fit the desired needs.
- Step 5 – Make pilot runs for validation purposes for step 6
- Step 6 - Check the pilot run results and compare them to existing systems or other performance measurements.

- Step 7 – This step involves specifying the runtime and a number of independent simulation runs using different random numbers to help create confidence intervals.

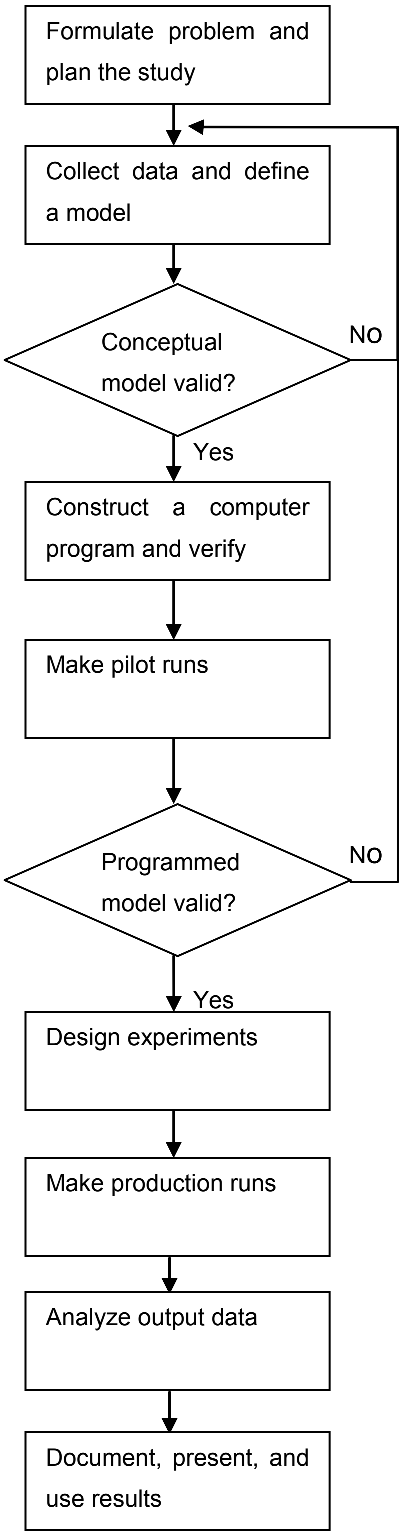


Figure 7. Steps to a sound simulation study

- Step 8 – Production runs are made for use in step 9.
- Step 9 – There are two major objectives in analyzing output data here. First determining the absolute performance of a certain system configuration. Secondly comparing alternative system configurations in a relative sense.
- Step 10 – This is the final step where assumptions are documented and results are to be studied for use in the current and future projects. The study's results are presented. The results can then be used in decision making process if they are both valid and credible.

4 Combining Supply Chains and Simulation

4.1 Introduction

With the availability of powerful simulation programs and todays focus on the importance of supply chains using the two tools together can be quite beneficial. Simulation models can be used for analyzing the efficiency and effectiveness of a supply chain system. Simulation allows users to see the whole supply chain and test numerous what if scenarios. One of the key features of simulation which naturally supports supply chain modeling is the ability to use stochastic inputs. This is good because users can easily insert random variables as inputs in the model. An example of this would be the amount of days a delivery takes, sometimes its 3 days but sometimes its 5. There are many different ways of using simulation to help improve a supply chain. Some different scenarios and examples are (7):

- Base Case – Current supply chain practices with an internal emphasis.
- Transportation – Changing from fully loaded trucks to a less loaded truck to reduce transportation lead times.
- Continuous Replenishment – A shifting of inventory management to the manufacturer or wholesaler.
- Collaborative planning – Sharing information among all participants of the supply chain.
- Combined supply chain management – A combination of all the above scenarios applied to the base case.

Results from simulation often show that there is a possibility for significant improvement in operational and financial performance for all participants in the supply chain, even the end customer.

When using simulation to help model a supply chain there are usually seven different processes that need or can be added to the model. The more detailed the model the better the results will be. But each simulation will have its own reasons for why it is being built so this can be different all the time. The seven processes are (7):

- Customer – This process represents outside customers issuing orders from the supply chain with a certain level of service for each customer. The order data is also used to aid demand forecasting and supply planning activities.

- Manufacturing – Assembles and keeps raw material and finished goods inventory as well as suppliers. During the simulations, the manufacturing process makes use of modeled information such as types of manufactured products, manufacturing time, bills of material, manufacturing and replenishment policies and so forth.
- Distribution – Models distribution centers, including finished good inventory and material handling. It can also be used to model a retail store.
- Transportation – Simulates transportation time, vehicle loading and transportation costs. Order batching policies, material handling resources and transportation resources are identified in this module.
- Inventory planning – Represents periodic setting of inventory target levels using inventory optimizer that recommends inventory levels at various locations in a supply chain.
- Forecasting – Models product forecasts including promotional and stochastic demand of future periods.
- Supply Planning – This process models the allocation of production and distribution resources to forecast demand under capacity and supply constraints.

4.2 Examples of Supply Chain Simulation

There are many different research projects being made today about the use of simulation with supply chains. It is one of the most researched topics in the academic world today. By taking a look at some examples it will help give an idea of how simulating of the supply chain actually works.

4.2.1 Simulating the Construction Supply Chain

The first example being looked at is from a research paper called Managing the Construction Supply Chain by Simulation. The project used simulation to improve the supply chain of a construction project. The study was made in order to find the quickest and cheapest way to complete the project. When the project started certain matters were fixed by the contract, such as contract duration, types and amounts of materials required at the job site and the fixed contract sum to be paid for completion of the project. The major inputs that were used in the simulation to obtain different results were:

- Timing of procurement

- Timing of the site access
- Batch size
- Refill level
- Storage capacity on site and at the factories making pre cast parts
- The number of trucks serving the site,
- Size of crews for each installation and the number of workers at each factory.

The outputs that were gathered from the simulation were an estimate of the project duration and estimated supply chain costs. The cost was calculated using material costs, transport costs, installation costs, and handling costs. Other useful outputs were resource loadings, site arrival and exit times and average inventory sizes. By analyzing these outputs they were able to change the timing and resources of the project to achieve faster completion and lower costs. They used an OTC simulation software called Simul8 to do the job. They first built the simulation then ran three different strategies that were much different from each other. Then took the one with the best results and fine-tuned it until they were happy with the results. In the end they saved 3.2% of the project costs and cut the project duration by 5%. Some key findings form their study was that simulation is educational but time consuming. They recommended that simulation should be used in repetitive projects, especially large projects where sufficient funds for planning are available. The main benefit was from better scheduling and use of resources, meaning improved control and lower inventory costs. Starting with the correct amount of resources helped to avoid crash up costs such as extra crews or equipment needed in a hurry.

Some other interesting things were the time used for analysis. Figure 8 shows how being familiar with the project can dramatically change the simulation construction time.

Stage	Novice starting from scratch	Experienced user doing a repeat project of similar style
Learning simulation methods	6-12 weeks	Updating incl. in model building
Learning the software	2 - 4 weeks	Updating incl. in model building
Collecting data	2-4 weeks	2-5 days (updating database)
Building and testing the model	2-8 weeks	2-5 days (incl. discussions with client)
Running the model and analyzing the results	1-2 weeks	2-10 days (longer if logic is faulty or data missing)
Findings & recommendations	2-3 days	1-2 days (brief action report for client)
Total cycle time	3 - 6 months	2-4 weeks

Figure 8. Estimated simulation time

Another interesting part of the paper was cost of the simulation. They mentioned that the main cost is the investment of time for learning a new methodology, and that the investment of software was small compared to that (10).

4.2.2 Simulating the Sugar Cane Supply Chain

The next example is about the use of simulation to evaluate sugarcane supply systems. In the paper they present a simulation model to evaluate the sugarcane supply system to mills. The model addresses the whole supply chain for the sugar cane which starts with harvest operations, then transportation and ends when the sugar cane is unload at the mill (11). The model created was to assess the relation of the freight, lead time, size of the truck fleet and a discounted price. The discounted price comes from how soon the sugarcane comes to the mill. If it takes more than 96 hours then the supplier of the sugarcane may be penalized because by then the quality of sugar cane is decreasing, reducing his profit. Some suppliers are located far away from the mill so there is a lot of importance on the shipping time. The simulation was built using Arena software. The researchers used the steps of simulation to help collect data, build the simulation, and to verify that the simulation was properly built to give data that is accurate.

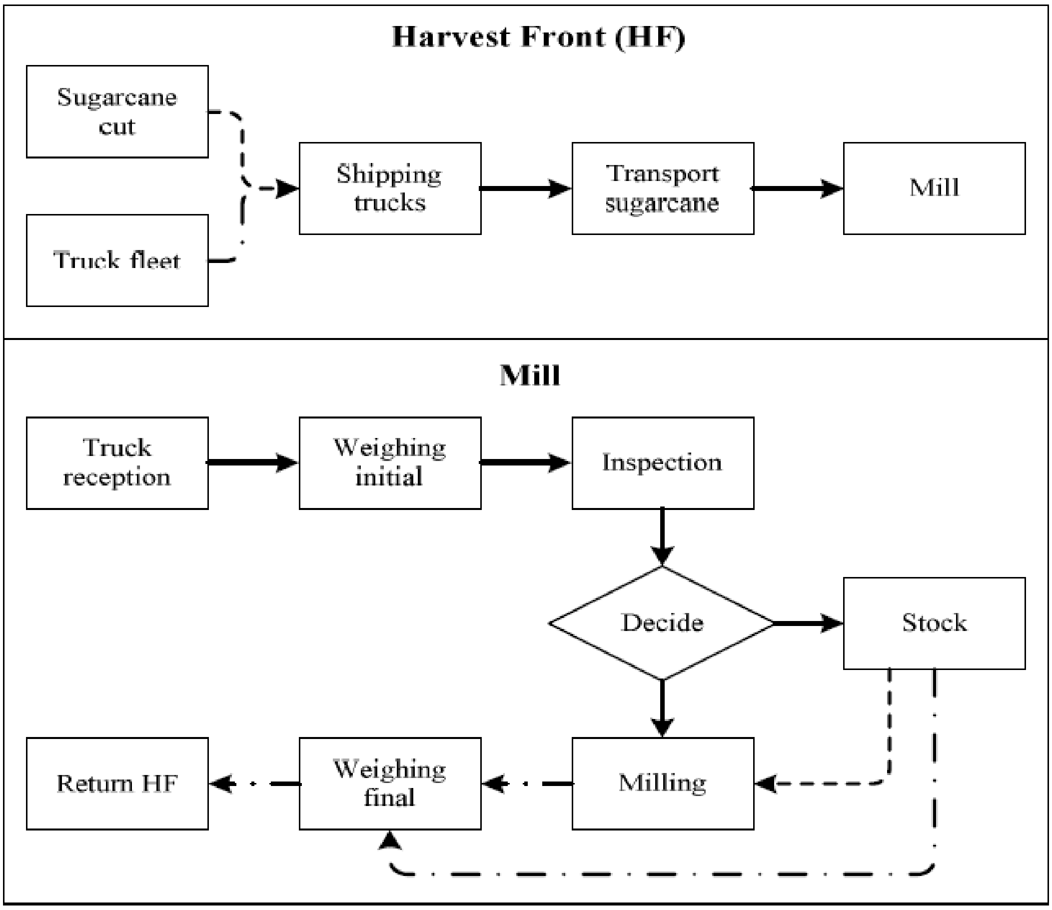


Figure 9. An overview of the supply chain to the mill and at the mill

Figure 9 shows the stages in the supply chain from the sugar cane being cut to final stage of ending up at the mill. The Bottom part of the image is the process at the mill. They do not affect the supply chain of sugar cane unless it is sent back to the supplier.

The input parameters of the model were how much sugarcane was cut per hour, how many trucks were used for shipping, how much can go in a truck, amount of time for harvest and distance from the mill.

Variables that were adjusted in the model to obtain the desired results were, Travel time, value of the freight in a truck with 40 tons of sugarcane, the amount of time to unload at the mill and the amount of trucks in a fleet with a capacity of 40 tons (11).

The experimental strategy used in the computer simulation was called the 2^K factorial project. In this strategy they input the data as it was and then changed one factor at a time. In the end the analysis of the data lead to the conclusion that the increase of fleet size benefited the supply of sugarcane with better properties, therefore improving the revenue of the load. The researchers were happy with the results because they were able to verify that increasing the fleet size related to better lead times which was what they were hoping to do.

4.3 Cons of simulating supply chains

Although simulating supply chains can have its rewards there are many difficult tasks to accomplish to build a successful supply chain simulation where the results can truly be applicable to real life. The supply chain environment is dynamic, loaded with information, geographically dispersed, and heterogeneous (9). For a supply chain simulation to be developed as a usable model, the models need to be applicable in the supply chain environment. Modeling a supply chain is very challenging. Each model has its own assumptions, scope, level of details and objectives. There are three issues that need to be taken into account when attempting to simulate a supply chain.

The first is that supply chains are never static, meaning that they are constantly changing. If the knowledge and information used to build and test a simulation model is not up to date with the supply chain, the model will be outdated, causing the results to be invalid. With this being known it can be seen that having up to date information is very important but this isn't always an easy task.

The second is that supply chains can be very large and complex. Therefore simulation models of supply chains become large scale complex models that will require large amounts of knowledge and information for modeling. Because of the complexity of large supply chains creating long cycle times that affect the time to develop a model; there is a need to reduce the amount of time needed to create a model to make simulation a responsive and applicable tool that can be used in real life.

Thirdly, businesses have invested heavily in supply chain information technology to replace the old physical inventory with information. The information technologies being used vary in scale, usage, and level of technology. These systems include Enterprise Resource Planning (ERP systems), databases, advanced planning and scheduling, information systems and supply chain management systems. Most of the supply chains information are found in these systems. Within a supply chain these systems are geographically dispersed over the supply chain network and heterogeneous, meaning they are located far away and full of different types of information in different formats etc. Because of this there are a few things that need to be done (3):

- Existing enterprise application systems need to be located.
- Find a way to remotely access the systems.
- Identify the information required for the simulation model that is being built.
- Figure out which system the information can be found in and what format.
- Identify the data of these systems and then extract the information required.

4.4 Future of supply chain simulation

All though simulation is a heavily studied topic, it is still relatively new and with the fact that supply chains are complex multi echelon systems there are still many areas that need to be studied. Firstly, extending the applications in SCM should be considered (1). Until recently, most of the uses of simulation has only been to help clients design their SCs and has created the belief that simulation is just for design, which puts a limit on the real range of applications. In the future designers might link simulation models to Manufacturing Execution Systems or Enterprise Resource Planning in SCs, enabling information to be easily shared. Another way in which applications could be extended is to integrate business process planning. With this integration, managers and engineers will be able to manage their plans and know the situations of projects, leading to the reduction of manual data entry errors (1).

Another trend coming in the future is integrating different simulation models and reusing simulation models. In a SC, different enterprises are developing their own simulation models that have been created with different commercial off the shelf simulation software. But because of this, it is difficult to exchange data in a simulation that has been created using different tools.

5 Motorcycle Shop Test Case

The second goal of this thesis is to attempt a test case by simulating a supply chain for the virtual motorbike factory that has been designed by the DigiBranch of Savonia University. The case study was to be built on the Enterprise Dynamics platform (ED). ED is a commercial over the counter simulation software that is used in many different industries. Currently there are many different simulation software products available that cater to SC simulation.

5.1 The Supply Chain

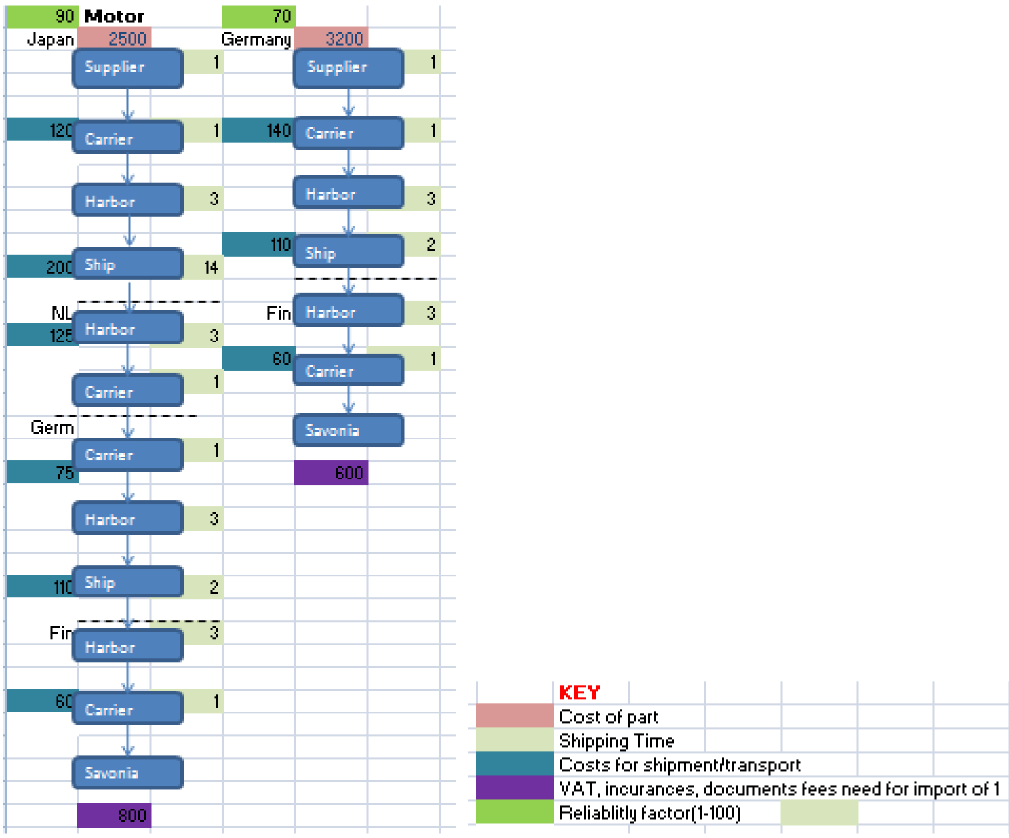


Figure 10. The supply chain for the motor.

The first step in the test case was to create an imaginary supply chain that can be put into the simulation model. The whole supply chain can be seen in appendix A. From a previous thesis done on the factory layout it was taken that there were seven different parts needed to be ordered without making the supply chain too complicated. These parts where: motor, forks, electrics/dashboard, fairings/sadal, exhaust system, lights and rims/tires. To add to the complexity of the supply chain and make it more realistic there were two different suppliers per part. Each supplier was to be from different places with different prices and reliability factor. Figure 10 shows the different suppliers created for the motor, then the different stages of shipping and the other inputs required. The reliability factor can be used to show how distribution can occur in a supply chain. For example a shipper says it's going to take 5 days to get the product, but sometimes it will take 13 days. This was to help show how simulation software can help optimize the supply chain. With the help of a masters student a supply chain was designed that took into account the shipping route, part costs, amount of days, costs for shipping, VAT, demand (how many parts needed a day), insurances and document fees which can been seen in figure 10. These are all inputs that are needed to be put into the simulation model.

5.2 The Simulation Model

The amount of bikes to be assembled a day is 8. So there will need to be a storage level built to be able to supply the parts needed.

The variables that will be able to be adjusted in the model to help optimize the supply chain will be

- Which supplier is the best, this will be decided by shipping costs, the supplier costs per part and how long the shipping takes.
- Order sizes.
- Refill level (How low does the storage go before new parts are ordered).

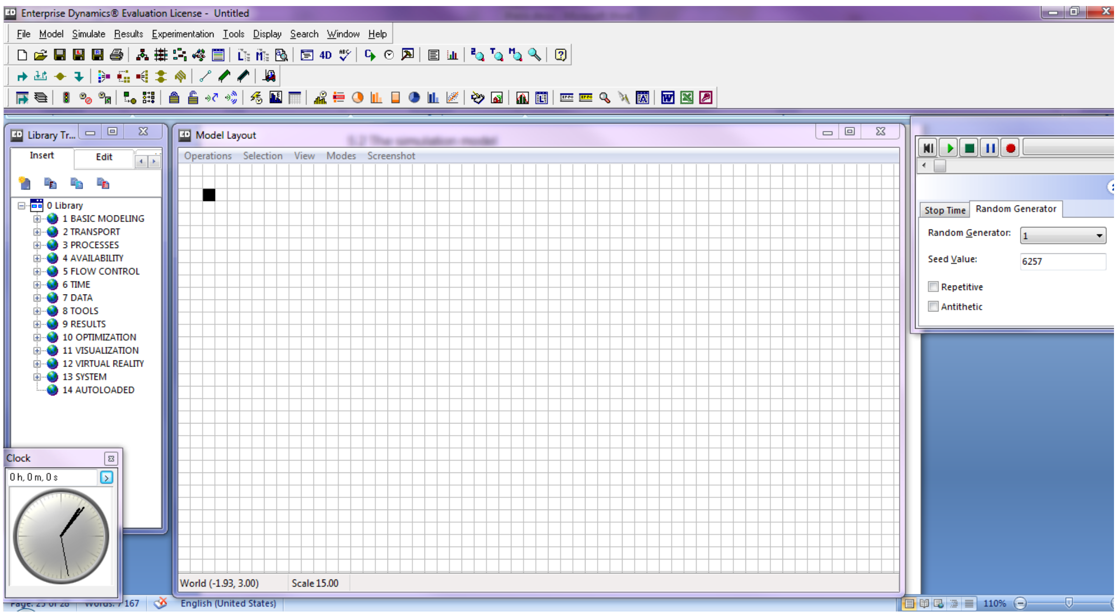


Figure 11. The layout of ED.

Figure 11 shows the basic layout for ED. There is a clock to show how long the simulation model will be ran for. When doing the simulation you have to choose how long the simulation should run for. In our situation a proper model time can be from one month to one year. The simulation platform can be quite confusing to new users and learning time quite high which is shown in the example from chapter 4.2.2.
Figure 12 shows what one part of the supply chain will look like. Form this example the first box in the upper left corner that is blue is a supplier from Japan that will provide the engine for the motor cycle. That box is called source in the ED platform. It creates the supply of parts needed at the rate decided by the simulator.

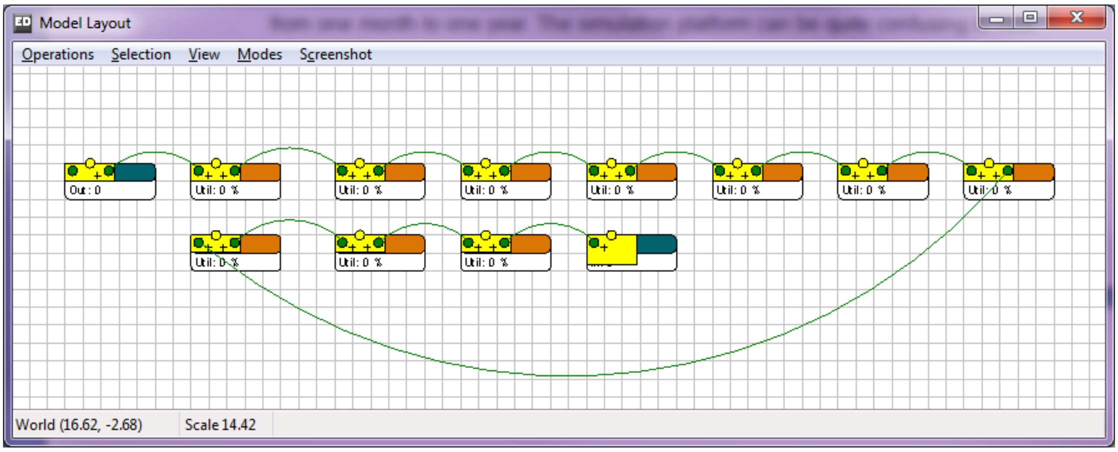


Figure 12. The model layout when using ED.

The orange boxes after that are stages in the shipping route, such as the harbor in Japan that will load the engines on to a shipping boat. The next one would be the next harbor in the Netherlands. Then after that would be the truck used to carry the goods to the motorcycle factory. The last box in the bottom right, would be the motorcycle bike factory. When the simulation is running you will be able to see how the storage levels are affected. They can be represented by small blue dots or you could use a 3D view but that isn't necessary when modeling supply chains. In each box you can set how long the part will be there for and the costs associated with that part. Also you can set the risk factor for each section. These are done by changing settings in the setup box.

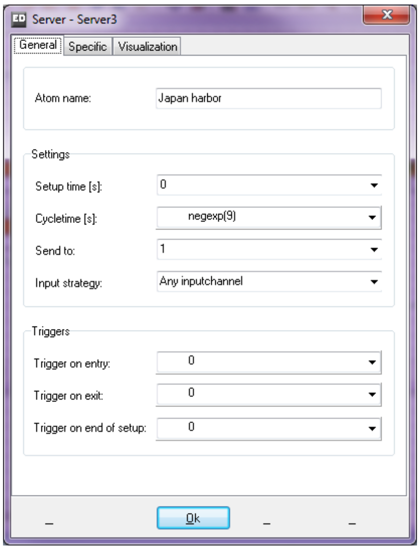


Figure 13. The setup box of a process in ED.

Figure 13 shows the box where the options are available to set for the harbor in Japan or any other stage in the supply chain. It can take a few days for the product to be sent to the harbor and then loaded onto a ship. The user can enter a certain amount of days that it takes, say 3 days. And since the model needs to be realistic a standard deviation formula will be used that will affect the days to add randomness. Depending on the variance wanted different formulas can be used too. So in the simulation it could take just one day or it could be five days. This helps to make the results more realistic.

5.3 Test Case Conclusion

Due to time constraints the complete model for the motorcycle factory supply chain was not able to be built in the simulation model. But that wouldn't make this test case a failure. Many of the key benefits of using simulation with supply chains can be seen from the test case example. The test case shows how many different scenarios can be created to help design a supply chain that would meet the demands of the motorcycle factory and do it in the best possible way. Whether that is having small or large storage levels or ordering parts in large or small shipments. For example comparing an agile strategy vs. a lean strategy and from that determine which one would meet the motorcycle factories' goals the best. Besides determine the correct amount for the variables that can be adjusted in the simulation there are many other what if scenarios that could be tested in the simulation once all the inputs have been added to the model. An example of that would be combining shipping. Some suppliers could be located close together and when the whole supply chain can be seen visually, a manager would be able to see that two different shipments could be combined into one saving costs. Also most companies offer a bulk order discount. This could be added to the simulation as well which would help give better results and efficiency.

6 Conclusion

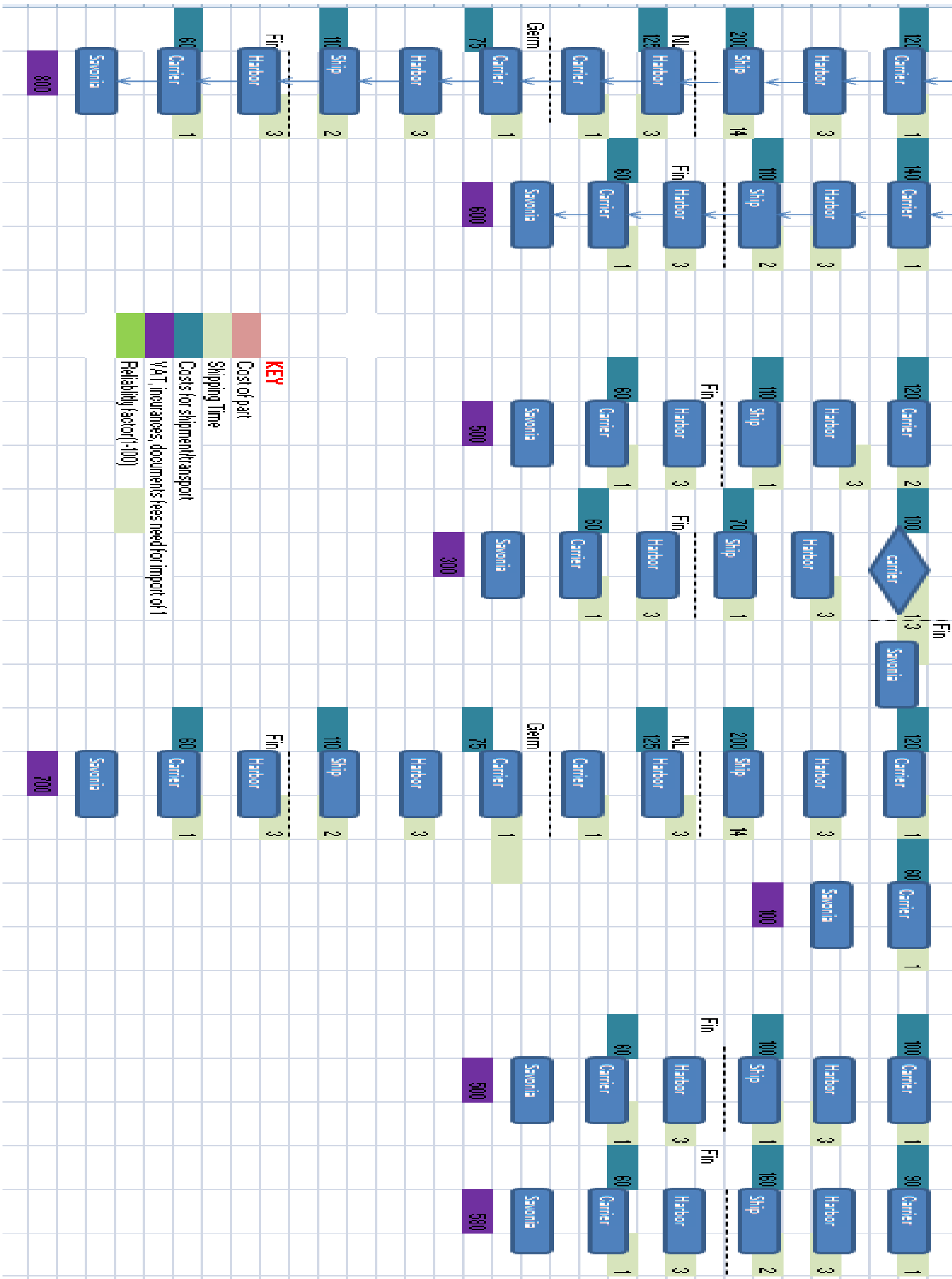
The aim of this thesis was to find out how simulation can be used with supply chains today. With enterprises focused on improving their supply chains and customer satisfaction all the while simulation becoming a relatively cheap and easy tool to use, it is easy to see how using simulation with supply chains can be quite beneficial.

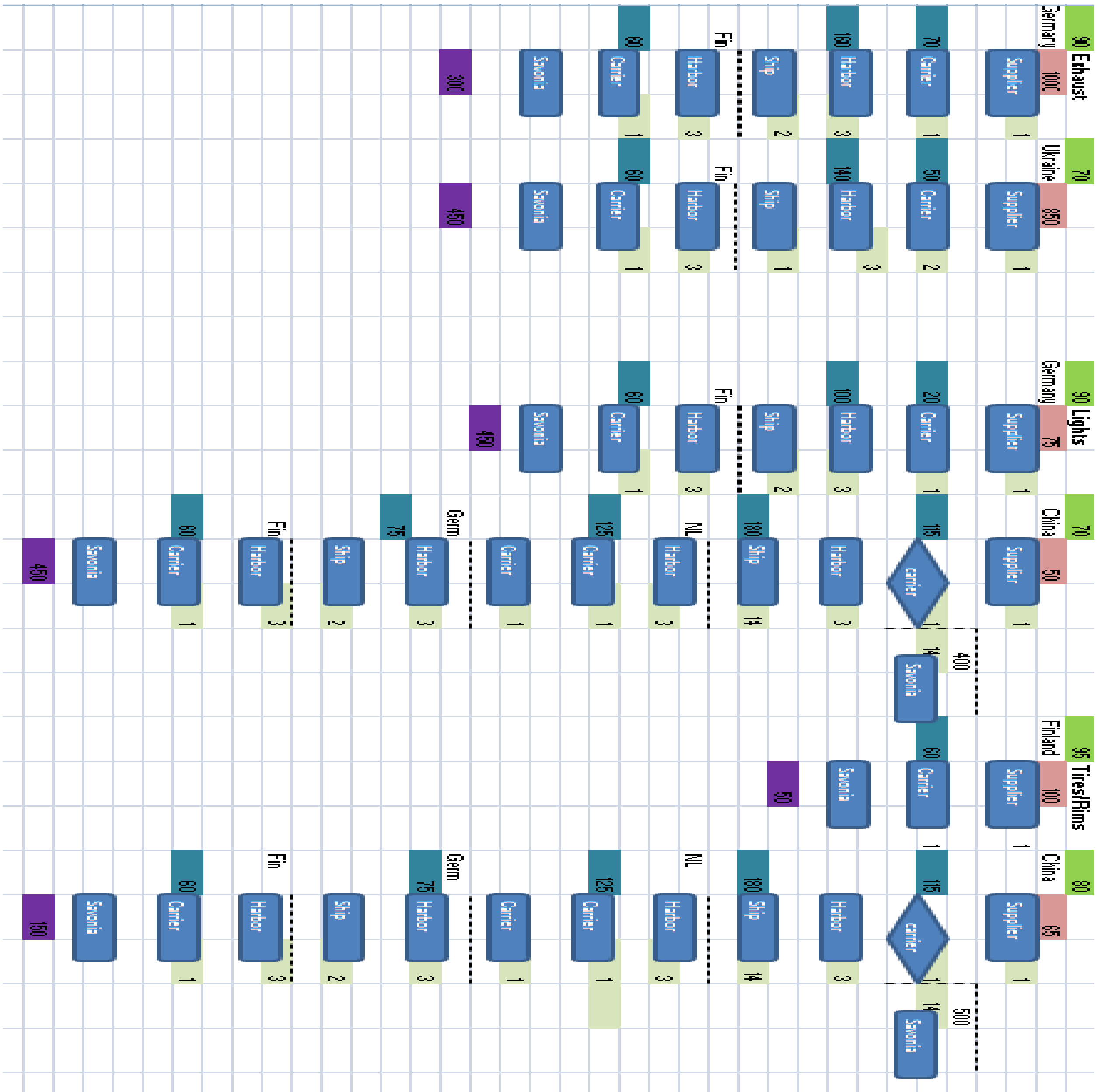
This thesis first went over what is a supply chain and supply chain management. A brief discussion of strategies that could be used was talked about. Later chapters went into how simulation is used and how it became what it is today. Then learning about how simulation can be used as a tool to improve the supply chain. Overall results found that simulation can be quite a useful tool to aid with supply chain management. Its use is growing every day. The key benefits were shorting the information gap, improving lead times, lowering costs and testing possible what if situations. But it needs to be brought to mind that although simulation is a powerful tool, it doesn't being other factors into account such as trust with suppliers.

Although the test case study was cut short, it was quite useful in finding out what inputs are needed when building a supply chain simulation and what kind of changes can be made to these inputs to improve the supply chain. In order to continue on with simulating the supply chain of the motorcycle factory a few things can be done. Data needs to be input into the simulation model and then ran with different variables to find the best results that suits the needs of the motorcycle factory. Obstacles that hindered the building of a large scale simulation was the lack of knowledge with the simulation program ED and work schedules during summer time.

Overall the goals of thesis were met. In the future it is expected that the use of simulation with supply chains will become even more popular. Soon it might be possible that the simulations will be combined with real time data keeping the supply chain flexible and up to date with the current demand, which would help give more accurate data when demand is constantly changing.

Appendix A


KEY
Cost of part
Shipping Time
Costs for shipment/transport
VAT, inusrances, documents fees need for import of 1
Reliability factor(1-100)


Exhaust
Germany
Ukraine
Lights
Germany
China
Tires/Rims
Finland
China

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