

Master Thesis  
Mechanical Engineering

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# **Production Scheduling, Developing an Economic Decision-Making, Cost Model for Supply Chain Management–**

Developing an economic- decision-making, cost model for outsourcing of manufacturing to alternate Bindomatic low-cost country (LCC) production plant to reduce overall system cost.

**JAMES EMMANUEL ROBINSON**

**BINDOMATIC<sup>®</sup>**  
A professional impression.

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This thesis is submitted to the Department of Production Engineering and Management, School of Industrial Engineering and Management at Royal Institute of Technology in partial fulfilment of the requirements for the degree of Master of Science in Computer Science. The thesis is equivalent to 30 weeks of full-time studies.

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# Summary

**Title:** Production Economics, developing an economic decision-making, cost model for supply chain management  
-Developing an economic decision-making, cost model for outsourcing of manufacturing to alternate Bindomatic low-cost country (LCC) production plant to reduce overall system cost.

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**Problem analysis:** Many incredibly fortunate companies have experienced the desired increased profit that is a by product of greater demands for their products, however they are unable to track the unforeseen costs that also accumulates. In order to stay competitive, they somehow must manage their production cost, evaluate the currency exchange rate and supply chain in a growing market. It can also be challenging to calculate transportation costs when the manufacturing operations have been tied to two plants in two different countries. An example of this described situation is when Bindomatic AB has outsourced a large portion of production from their North Carolina manufacturing plant to its Portugal plant. The company experiences a number of problems concerning increase volume demands in the United States. The US plant can not handle the increase demand because the facility has a low capacity and is not as flexible as the superior Portugal plant. Bindomatic AB lacks the experience of formulating an economic decision-making model regarding supply chain management, currency exchange rates and production. In the master thesis, I will investigate all the costs involved and create a model which has variables that Bindomatic can manipulate in route to increase savings. The solution recommended to Bindomatic must also fit the company's overall strategies.

**Purpose:**

- To investigate how Bindomatic, a company that has a problem with an increased demand in its United States plant (also known as Coverbind), can forecast the best period to outsource production to Bindomatic's Portugal plant for manufacturing

**Method:** To analyze and formulate an effective economic model requires a complete perspective instead of the separation of parts. Bindomatic and its production plants of binders have been analyzed with a system approach. A mix of quantitative and qualitative data has been gathered in interviews and by extracting statistics from different production systems. A

literature study within the relevant fields has been performed. I have also studied research done in this area from three other companies facing partly similar challenges to broaden the perspective.

**Key Words:** Production scheduling, decision-making, optimization, supply chain, logistics, outsourcing, multi-location supply chain

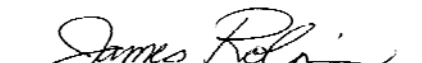
# Preface

This master thesis has been written during the summer/fall of 2007 as the final part of my Masters of Mechanical Engineering Degree. I am a student who studies Production Engineering and Management at the Department of Production Engineering and Management at The Royal Institute of Technology (KTH) in Stockholm, Sweden. The thesis has been conducted at Bindomatic AB in cooperation with the Department of Production Engineering and Management.

There are a number of persons we would like to thank. I would like to thank my supervisor for this project, Ove Bayard from KTH, who has given me great support and good advice. I would like to thank my girlfriend, Elina Svenborn for giving me the support and inspiration to finish this work. I am grateful to be blessed by my family that gives Trans-Atlantic love to me. I am also grateful to all persons that have given information and shared their knowledge during meetings, visits and numerous interviews. This goes to people within Bindomatic AB and Bindomatic PT.

Friends and family have of course also had to put up with long expositions about my master thesis. Thanks for everything!

Stockholm 2008-03-25

  
**James Emmanuel Robinson**

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# Introduction

*In the area of this master thesis, supply chain management, there have an enormous amount of change. The fundamental reason is that companies have painfully realized that mastering there SCM is as much a beneficial business strategy as good marketing is. As a result companies constantly face new challenges and have to take actions to stay competitive. Bindomatic AB has supplier network that shall best support their multinational production of binders.*

## 1.1 Background

In the recent years there have been several forces that have increased the competition between companies. Such forces are for example: improved transport facilities, trade regions and information technology. Those forces have enabled the increased globalization, which has increased the competition.<sup>1</sup>

These quality improvements have forced company to focus on the efficient reduction of cost wherever possible. As a result, many companies have outsourced manufacturing activities to low-cost manufacturing countries, which means that the supply chain management has became a new frontier in the business strategy. The best known method of cost estimation of a product is effectively and correctly modelling the activities.

However, outsourcing manufacturing activities elsewhere can be two-fold. On one hand, there can be positive gains such as increased profits from the relocation. On the other hand, unforeseen or indirect cost can suddenly appear and create investment problems. The term that best describes this situation in a company is supply chain strategy. Supply chain strategy is sometimes confused with supply chain management, which are supply chain operations controlled to reduce costs. Although, this is somewhat true, supply chain strategy is broader, and it illustrates how the supply chain should operate in order to compete. Supply chain strategy is an iterative process that evaluates the cost benefit trade-offs of operational components.<sup>2</sup>

It is necessary that the person managing the supply chain must possess a thorough knowledge of the logistics, production and foreign currency exchange market. Many companies have experienced problems to manage the complex and growing supply chain. Companies have experienced problems regarding, for example how to manage and control: quality, lead-time and delivery reliability.<sup>3</sup>

An example of this described situation is when Bindomatic AB has outsourced a large portion of production from their North Carolina manufacturing plant to its Portugal plant. The company experiences a number of problems concerning increase volume demands in the US. The US plant can not handle the increase demand because the facility has a low capacity and is not as flexible as the superior Portugal plant. Bindomatic AB lacks the experience of formulating an economic decision-making model regarding supply chain management, currency exchange rates and production. There are approximately 2 component suppliers in the USA and an approximately of the supply chain as illustrated in Figure 1.1



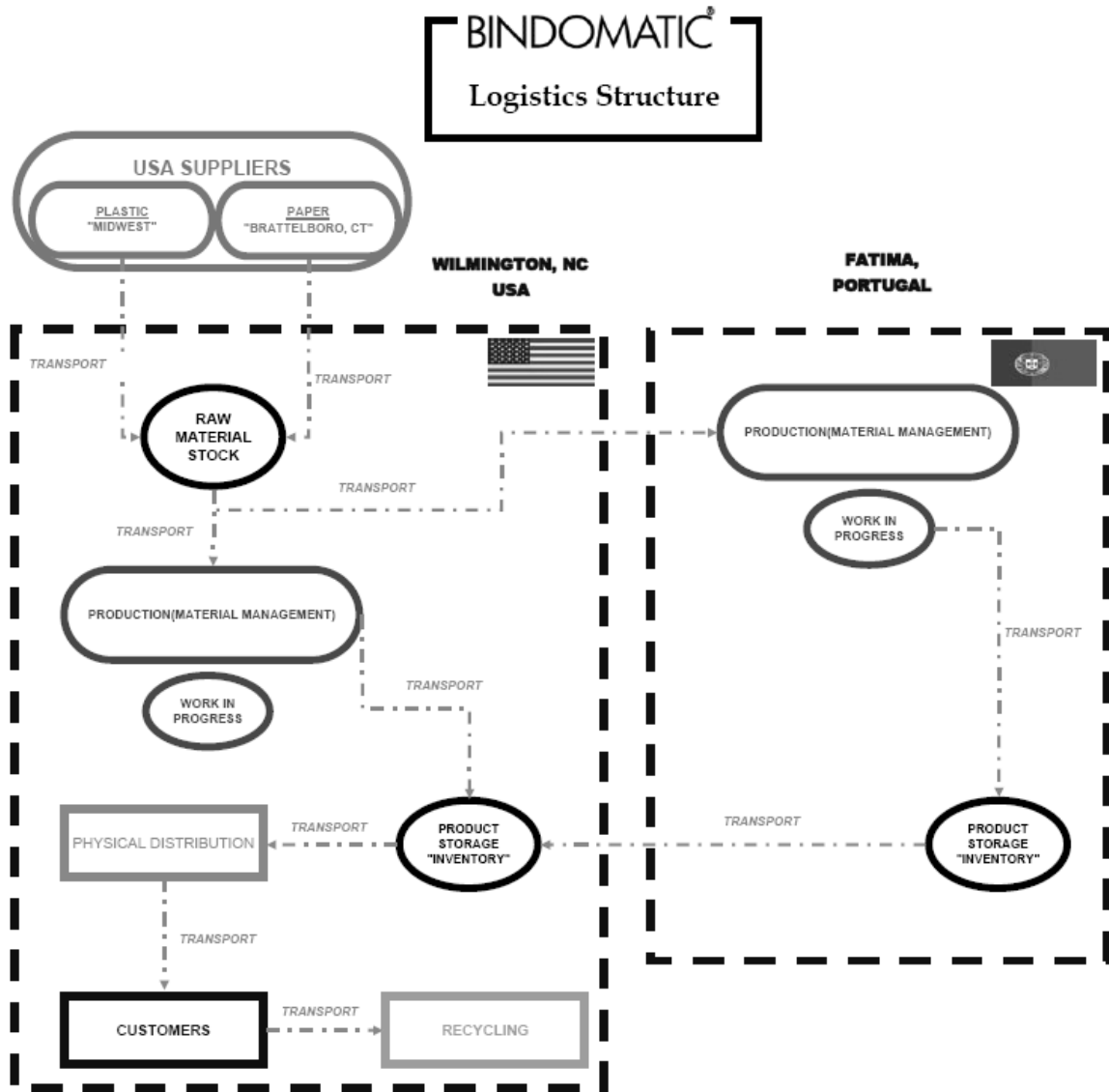


Figure 1.1

### 1.1.1 Problem Analysis

Bindomatic AB is an example of a company that has outsourced a large portion of its US production to its European market production (Portugal) plant and faces challenges in controlling cost and utilizing possible improvements in their unharmonic supply chain. This manipulation of the supply chain creates the following main problems:

- Bindomatic experiences a lack of control:
  - Regarding the volume of US market production that should be bought the Portugal plant.
  - Regarding which suppliers that are used
- Bindomatic lacks an appropriate cost model:
  - Track costs throughout the supply chain
  - Track the unit cost of one product

Those were the problems that Bindomatic explained to me as the fundamentals of my master thesis. If time permits, they would also what to know if the how much savings of the entire distribution system can profit if all production was completed in Portugal.

The problems with developing an alternative supply chain and an efficient economic cost model were created by the technical director and chief financial officer at Bindomatic AB. I was granted the assignment to create a cost model for Bindomatic in order to track logistics cost, the Forex Exchange market, and labor cost. This model will help predict whether or not to move more or less production from USA to Portugal. In some cases, costs that creates a minor affect and are not really considered is in this project are machine downtime for maintenance and training cost for new employees when demand increases.

### **1.1.2 Purpose**

- To investigate how Bindomatic, a company that has a problem with an increased demand in its US plant can forecast the best time to outsource production to its Portugal plant for manufacturing

### **1.1.3 Focus and Delimitations**

This master thesis focuses on the costs involved in the supply chain for one product, the Classic Antique Covers, which is produced in United States for the United States market specifically. Recently, Bindomatic has a drastic raise in demand in the US market.

The raw material used to produce this brand of product only known to be available in the US. These classic covers, with a clear, non glare front, come in a large variety of rich colors as well as white. These covers quietly project your professionalism and good taste. Below is a list of technical data for the classic covers:

## **1.2 Company Description**

### **1.2.1 The History of Bindomatic AB<sup>4</sup>**

The Bindomatic homepage states:

Bindomatic – making a professional impression since 1974.

Since its start-up in 1974, Bindomatic has been providing companies and organisations with the right tools to make a professional impression. At the heart of this concept is the production of perfect bound attractive covers, in which documents are bound using technically advanced binders.

Bindomatic head office is located in Stockholm, Sweden, with subsidiaries in Germany, USA and Portugal. Sales and distribution in the rest of the world, is managed by independent distributors in around 40 different countries. In addition, Bindomatic has OEM agreements with Xerox, Océ and others.

Bindomatic covers are made from paper produced from sustainable forests – biological diversity and ecological land use being a prime focus in their

management. Bindomatic use unbleached paper pulp, and prefer the use of PET plastic for the fronts of our covers. When it comes to printing, Bindomatic mostly use offset ink derived from vegetable oils. Bindomatic covers are as recyclable to the fullest extent possible, and we consistently aim to use the most energy-efficient transport.

The Coverbind Corporation is the brand name for Bindomatic in the US and is a wholly owned subsidiary of Bindomatic A.B. Coverbind has been providing our patented covers and binding machines to customers in North and South America for over twenty years. During those 20 years Coverbind have continuously developed product enhancements that allow them to provide quality covers and improve productivity for their clients. Coverbind Corporation is headquartered in Wilmington, NC. They have a 44,000 square foot building housing their corporate offices, production facilities and warehouse space.

Bindomatic suggests that their covers are a well-informed choice

Starting with the innovative thinking of our founder, Sture Wiholm, and continuing today with a team of research and technological experts, Coverbind has developed proprietary and patented processes for producing the highest quality covers and binding machines. This continued emphasis on quality and productivity enables Coverbind to bring to the marketplace new and timely products. This enables our customers to improve both quality and productivity in their binding operations.

Coverbind is a quality company determined to delight our customers with our products and services.

### 1.2.2 Bindomatic Binders

The Classic Antique Covers:

Binding:

Durable EVA adhesive and embedded book binding fabric, specially designed by Coverbind.

Spine Size:

Spine sizes from 1/16" up to 2"

Number of Sheets per Cover: Between 1 and 500 sheets

Standard Size Cover:

8 1/2" x 11"

Other sizes can be custom manufactured

#### AVAILABLE COLORS:

White

Black

Navy

Burgundy

Green

Red

Royal Blue



### 1.3 Target groups for the thesis

This thesis is targeted towards managers and employees at Bindomatic and Coverbind working with production and supply chain structure. The other target group is students and other people within the academic world with an interest in logistics, purchasing and supply chain management.

### 1.4 Definitions

- **Lead Time:** is the period of time between the initiation of any process of production and the completion of that process, including delivery. Thus the lead time associated with ordering a new car from a manufacturer may be anywhere from 2 weeks to 6 months. In industry, lead time reduction is an important part of lean manufacturing.
- **Production (Cycle) Time:** The time it takes for one product to go from initial setup to completion.
- **Inventory Level:** The amount of goods and materials, or those goods and materials themselves, held available in stock by a company.
- **Safety Stock:** Safety stock is a term used to describe a level of stock that is maintained below the cycle stock to buffer against stock-outs. Safety stock is defined as extra units of inventory carried as protection against possible stock outs. It is held when an organization cannot accurately predict demand and/or lead time for the product.
- **Low-cost country sourcing (LCCS)** is a procurement strategy in which a company sources materials from countries with lower labor and production costs in order to cut operating expenses. LCCS falls under a broad category of procurement efforts called Global Sourcing.

The primary principle behind LCCS is to obtain sourcing efficiencies through identifying and exploiting cost arbitrage between geographies.

- **Fixed Cost:** Fixed costs are expenses that do not change in proportion to the activity of a business, within the relevant period or scale of production.
- **Labor Cost:** Labor costs are variable cost. Variable costs are expenses that change in proportion to the activity of a business. In other words, variable cost is the sum of marginal costs. Along with fixed costs, variable costs make up the two components of total cost. Direct costs can be associated with a particular cost object. Not all variable costs are direct, for example, variable manufacturing overhead costs are not direct, but indirect costs
- **Variable Cost:** Variable costs are sometimes called unit-level costs as they vary with the number of units produced.
- **Direct raw material costs** -- costs of raw materials used to make a specific product.

- **Direct labor costs** -- costs of labor used to make a specific product.
- **Overheads** -- costs that cannot be charged directly to a specific product.
- **Fixed overheads** -- stable costs that occur regardless of whether or not goods are being produced (i.e. rent of factory). These are allocated according to the number of machine hours.
- **Variable overheads** -- changeable overhead costs that vary according to the number of goods produced (i.e. water and lights). These are allocated according to the number of labor hours.
- **Indirect raw material costs** -- costs of raw materials whose role in the manufacturing of a product cannot be easily determined (i.e. glue).
- **Indirect labor costs** -- costs of labor that cannot be charged to a particular product (i.e. the floor sweeper in a factory).
- Primary production costs = direct labor + direct raw materials
- Overhead expenses = fixed overheads + variable overheads
- Total production costs = primary production costs + overhead expenses
- **Production Rate:** the number of units manufactured in a given period of time or the time required producing a single article.
- **Plant Capacity:** the manufacturing plant's maximum production possible.
- **Production Accessibility:** is the difference of production capacity and production level. This will give the user the amount of how many additional products that can be produced.

## 1.5 The disposition of the report

The traditional disposition has been used for this master thesis. Mostly the disposition follows my work method. The disposition of the master thesis can be divided into three main parts, as can be seen in Figure 1.2.

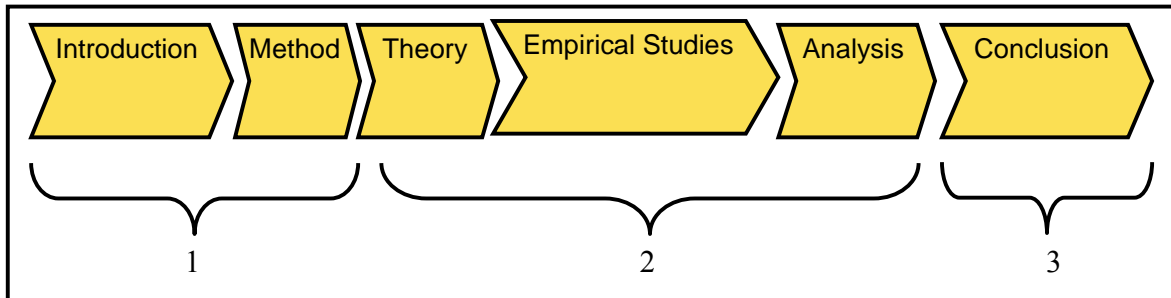


Figure 1.2

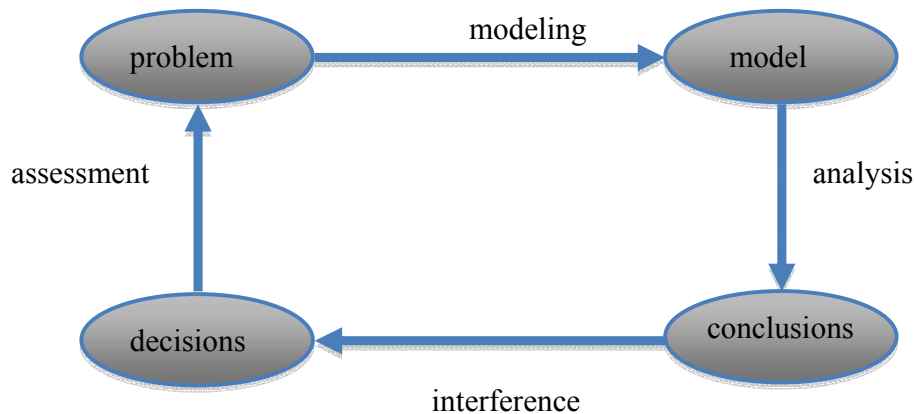
Introduction and Method are connected since they together create the base to the report. In the introduction a background to my assignment is presented as well as general information about Bindomatic and Coverbind. In the introduction a background to our assignment is presented as well as general information about the company Bindomatic AB.

The Method chapter explains different methodological techniques that can be used and which ones we have chosen for our purpose i.e. how our research has been performed. This chapter is meant to give the reader a possibility to further evaluate the credibility of the findings of this master thesis. After having read the first part the reader should be informed and understand the problem, the purpose and also how our work has been performed to fulfil the purpose.

The latter part of the master thesis is the main part and starts with a chapter with the theoretical framework addressing the areas of interest for this master thesis, for example outsourcing and synergies in the supply chain, and after that a presentation of the empirical data that we have collected. The analysis is then based on the theories and the empirical data. The conclusion is presented at the end of the report where I make our recommendations and generalizations.

## 2 Method

This research was created with the steps of the Operations Research cycle approach, created by Ronald L. Rardin. This cycle, shown below in Figure 1.3, is initialized with the formulation of the problem. A rough modeling of the problem along the available information follows. The different relationships in the system and the different parameters are quantified. The suggested decision-making model is implemented to obtain conclusions. These conclusions are derived from the model but not from the present, realistic situation. The conclusions are validated with a person who possesses expert knowledge of the actual problem. The next step is the detection of advantages and disadvantages in the model. Finally, translation of all the collected information is integrated into changes in the model to obtain more effective usability.<sup>5</sup> The path of the loop is run repeatedly several times.



**Figure 1.3**

## **2.1 Scientific approach**

My thesis required an abductive approach. This approach means that the researcher goes from empirical data and theories back and forth. The abductive approach starts with a phenomena, the researcher tries to find the forces behind this phenomena by excluding forces and conducting tests. There is a problem with the abductive method since it is not a schematic method; it requires extensive experience of similar cases.<sup>6</sup> The instrument I used to formulate this cost model was Microsoft's Excel software program.

As explained earlier, the purpose of this research is analyze and formulate an effective economic model requires an all wide and entire perspective. Bindomatic and its production plants of binders have been analyzed with a system approach. I utilized qualitative data collected in meetings with Bindomatic management and by extracting statistics from information gathered. A literature study within the relevant fields has been performed. I also study research done in thesis areas from three other companies facing partly similar challenges to broaden the perspective.

## **2.2 Choice of Research Method**

### **2.2.2 Qualitative versus quantitative**

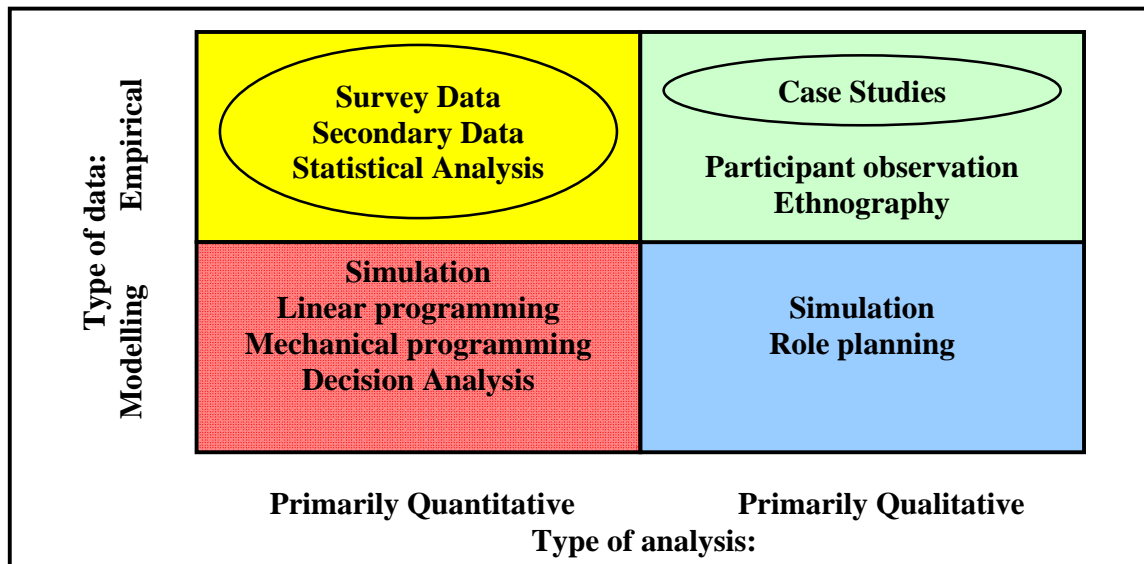
Two typical research methods are the qualitative and the quantitative method. In my thesis I use a mix of these two methods.

Qualitative research work is being performed when data that is not expressed in numbers is gathered, interpreted and analyzed. The opposite is true for the quantitative method, i.e. the study consists of information that can be measured or quantified. The qualitative method shall be used when one strives for a deeper understanding in a specific subject or situation. The purpose of the study shall decide which method to use.<sup>7</sup>

I want to understand what a change in the production amount and currency rate would do to the cost. To understanding this, it is necessary to perform a qualitative investigation by interviewing production personnel. In contrast, I need to calculate if the alternative supply chain structure shall be recommended from a financial point of view. This area of work needs a quantitative method, which is the collection statistical data from Bindomatic production systems. I began with a qualitative method in order to grasp the problem and develop new knowledge in the subject. After the initial phase quantitative methods were used in combination with further qualitative studies, an approach called method triangulation. In triangulation different methods are used to add different perspectives of a subject.<sup>8</sup>

### 2.2.3 Research Design

Figure 2.1 presents a sample of techniques. Data collection was from an analysis from the real world, i.e. empirical data. I used both qualitative and quantitative methods. My work actually is represented in the top two boxes in the table.



**Figure 2.1 Different research designs<sup>9</sup>**

As explained, I used a systems' approach in the master thesis and a natural choice of method is then a case study.<sup>10</sup> In a way of not using large samples and following a strict procedure to examine a limited number of variables, case study methods involve an in-depth, longitudinal examination of a single event. Survey data or secondary data is collected and possibly processed by people other than the researcher in question. Concerning my thesis problem analysis, I used a little bit of both survey and case study approach. I needed to cover many factors of a complex system and I realized that using both was preferable.



## **2.3 Data collection**

A formal data collection process is necessary as it ensures that data gathered is both defined and accurate and that subsequent decisions based on arguments embodied in the findings are valid.<sup>11</sup> The process provides both a baseline from which to measure from and in certain cases a target on what to improve.

In this master thesis, I used two kinds of data. The first one is primary data, which is the data that I have collected directly from Bindomatic. The secondary data emerged from material that I have collected previously from my literature studies.

I gathered the primary data in from meetings, interviews and emails primarily between Bindomatic and myself. I wanted the company to be personally involved in every aspect of this research. I used phone calls and emailed questions mostly to keep a clear and responsive flow of information.

### **2.3.1 Interviews**

The interviews were used as meetings with relevant personnel at Bindomatic. They were quantitative meetings, usually for statistical purposes. This process was a bit behind because of the timeline of the research. I began my thesis during the summer and it was quite difficult to obtain information from the company. After several weeks, I received an important email concerning a rough draft of a proposed model.

Before scheduling meetings with the company, I proposed an agenda regarding relevant concerns. I emailed questions and other important factors that I needed to address. In return, the company was able to keep track of my process and setbacks.

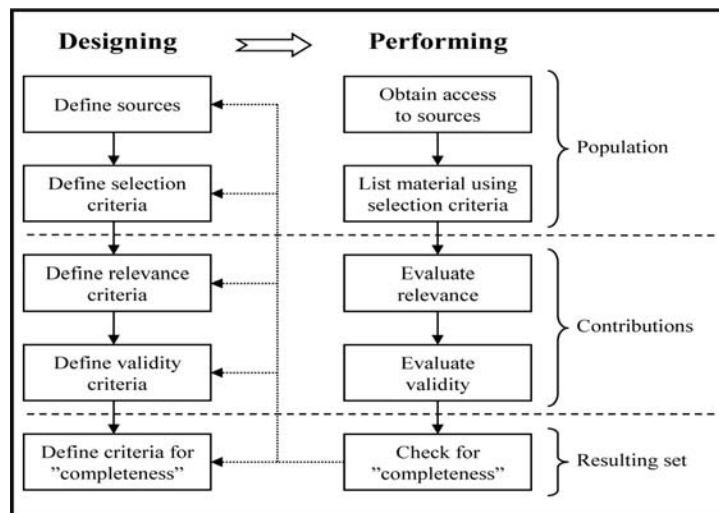
### **2.3.2 Existing statistics**

Bindomatic presented existing financial statistics after my literature studies. I was able to map the current supply chain structure as a foundation for the calculations. The technical department previously tracked the production of their binders at both facilities, which is how they were aware of the problem of not having an effective production schedule. I collected all of this information input it in my calculations.

### **2.3.3 Literature studies**

The initial step in doing a literature study is to identify the purpose of the study. Literature studies are not considered the main bulk of the research but are typical secondary data. Usually there are many risks in using these studies because the information may not be totally objective amongst other risks. The advantages of literature studies are that a foundation of theoretical knowledge is obtained rather quickly.

Figure 2.3 below illustrates the process of defining and performing a literature study.<sup>12</sup>



**Figure 2.3: The process of defining and performing a literature study**

In this master thesis, I used literature studies to gain knowledge concerning supply chain management, production economics & scheduling, logistics, and methods. The sources of this information are presented in APPENDIX B.

### 3 Theoretical frame of reference

#### 3.1.1 Problem Description

*Methodologies, theories and procedures designed by the production department have been changed in recent years reflecting trends towards globalization, increased competition and outsourcing. Information has become the most important factor because indirect conditions are changing in a faster rate than ever. The question that every production department must face is whether to meet the future challenges with a centralized or decentralized organization.*

#### 3.1.1 Introduction

*"They have realized that the real competition is not company against company but rather supply chain against supply chain."*<sup>13</sup>

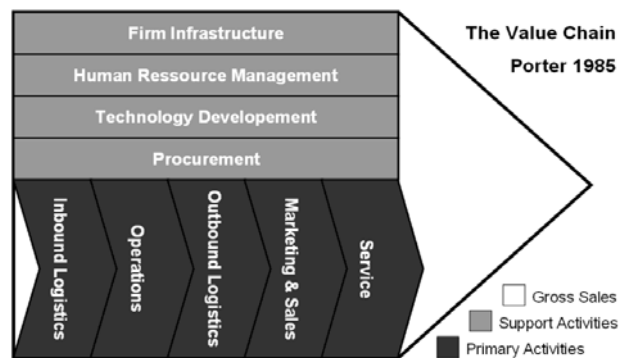
In order to better understand production planning and create the most efficient model, supply chain management must be addressed. Supply chain management (SCM), traditionally called logistics, is the process of planning, implementing, and controlling the operations of the supply chain. The main goal of SCM is to satisfy customer requirements as efficiently as possible. Fundamentally, a supply chain is the entire network related to the activities of a firm that links, supplier, factories, warehouses, stores, and customers.<sup>14</sup> SCM also involves the supervision of all movements of goods, money and information from point-to-point. In 1982, Keith Oliver of Booz Allen Hamilton was the first to employ the word supply chain management.

During course lectures, I have learned that SCM involves also involves Demand Chain, Value Chain and Demand Management. Demand Chain Management is the management of upstream

and downstream relationships between suppliers and customers to deliver the best value to the customer at the least cost to the demand chain as a whole. The term demand chain management is used to denote the same concept commonly referred to as supply chain management. The organization's supply chain processes are managed to deliver best value according to the demand, created by marketing programs. For this reason, while supply chain is now widely used, the philosophy behind it is really demand chain management.<sup>15</sup>

### 3.2.2 Value Chain Management

**Value Chain Management** categorizes the generic value-adding activities of an organization. The "primary activities" include: inbound logistics, operations (production), outbound logistics, marketing and sales, and services (maintenance). The "support activities" include: administrative infrastructure management, human resource management, R&D, and procurement. The costs and value drivers are identified for each value activity. The value chain framework quickly made its way to the forefront of management thought as a powerful analysis tool for strategic planning. Its ultimate goal is to maximize value creation while minimizing costs.<sup>16</sup> Figure 3.1 below, illustrates the structure of a Value Chain.



**Figure 3.1**

The primary activities of value chains are, Inbound logistics, Operations, Outbound logistics, Marketing and sales and Services.

Value chain analysis is a technique used to identify and evaluate a company's resource and capabilities. The primary activities include the major product life cycle activities from product creation distribution to after-sales services. Support activities provide the infrastructural activities to enable the primary activities to take place.

In Economics, demand management is the art or science of controlling economic demand to avoid a recession. The term is also used to refer to management of the distribution of, and access to goods and services on the basis of needs. An example is social security and welfare services. Rather than increasing budgets for these things, governments may develop policies that allocate existing resources according a hierarchy of neediness.<sup>17</sup>

### 3.2.3 Methods of Supply Chain Management!

In order to get effective results, management has to use various methods of forecasting. I have listed a few below:

**Just-In-Time (JIT)** is a philosophy, developed by Toyota, which grew from the **Kanban System**. The Kanban system is a type of card system that was used in early systems to signal to upstream supply point that a certain quantity of material could be released. Kanban is a pull system, which is driven by the demand that demand is at the lowest point in the chain. The main purpose of JIT is the elimination of waste. Systems are designed to reduce material flow to small batches to avoid bottlenecks of work-in-process.

In JIT, no product must be made; no component should be ordered, until there is a downstream requirement. JIT minimizes large inventory, which hides a lot of problems due to inaccurate forecasts, unreliable suppliers, quality problems, and bottlenecks.

JIT solution may not always be appropriate or justified. It is not so much a question of the volume of requirements which justifies JIT– indeed on high volume and hence predictable demand items it will be most cost effective to work on the basis of classic economic batch quantities – the variables which really effect the viability of JIT logistic are the variety of opinions within a category (e.g. different style, shape, and colure of seats in Toyota Camry).

Kanban scheduling does not replace material planning, but rather takes the material planning information and uses it to create the Kanban.<sup>18</sup>

What Kanban replaces is:

- The daily scheduling activities necessary to operate the production process
- The need for production planners and supervisors to continuously monitor schedule status to determine the next item to run and when to change over

In many production processes, control of production quantities can be haphazard which can lead to overproduction of parts, i.e., one of the seven wastes identified in the Toyota Production System (TPS). The Kanban prevents overproduction by specifying the production container sizes and the maximum number of containers to be produced.<sup>18</sup> In conclusion, Kanban scheduling makes controlling much easier, without expensive or labor-intensive inspections.

**Material Requirements Planning (MRP)**, is a dependent demand technique that uses bill-of-materials, inventory, expected receipts, and a master production schedule to determine material requirements. The typical components of the MRP technique are:

- Customer Order
- Master Production Schedule
- Forecast Demand
- Bill of Material (BOM)
- Inventory Records
- Purchase orders
- Material plans
- Work orders

MRP used although with the Kanban system is an excellent execution tool. When planning, MRP systems are better with translating production forecast into a series of component forecasts by using bills-of-materials (BOM) and routers. BOM represents products in terms of its assemblies, sub-assemblies, and basic parts in a hierarchical way. MRP systems also use data on lead times and safety stocks to develop production schedules and raw material requirements. Some important shortcomings of MRP are forecast error, labor intensive, systems intensive, and resistant to change.

**Enterprise Resource Planning (ERP)** systems can be described as “configurable information systems packages” which integrate information and processes across organizational functional areas.<sup>19</sup> ERPs are software systems for business management including modules which support planning, manufacturing, sales, marketing, distribution, accounting, financial, human resource management, project management, inventory management, service and maintenance, transportation and e-business. The built in architecture of the software facilitates transparent integration of modules providing flow of information between all functions within the enterprise in a consistently visible manner. Therefore, ERP systems enable people in these very different parts of business to communicate with each other. In an ideal case of moving information across the supply chain, sale representatives enter customer orders directly into company’s ERP. The sale reps access the sales order planning and master production schedule. Once the orders are input in the system, the sale reps can provide an “available-to-promise” report and can inform customer when they can expect order delivery. The master production schedule drives the material requirement system, which automatically generates purchase orders to ensure that suppliers deliver parts, components, and services in time to produce customer order.<sup>20</sup>

The material requirement planning module converts material requirements into purchase requisitions that purchasing places with selected suppliers. When the supplier delivers the components, this information is passed through to the scheduling system that ensures that the components are linked to the specific production order on the shop floor. Once the production begins, the sales person in the field also knows that the order will soon be delivered to the customer. Once delivered customer billing and payment also automatically generated by ERP system.<sup>21</sup>

During course work, our class learned about the method of **Kaizen (改善)**. Kaizen, Japanese for "change for the better" or "improvement"; the English translation is "continuous improvement" or "continual improvement"). In the context of this article, Kaizen refers to a workplace 'quality' strategy and is often associated with the Toyota Production System and related to various quality-control systems, including methods of W. Edwards Deming.

Kaizen aims to eliminate waste (defined as "activities that add cost but do not add value"). It is often the case that this means, "to take it apart and put back together in a better way." This is then followed by standardization of this 'better way' with others, through standardized work

Kaizen is a daily activity whose purpose goes beyond improvement. It is also a process that, when done correctly, humanizes the workplace, eliminates overly hard work (both mental and physical), and teaches people how to perform experiments using the scientific method and how to learn to spot and eliminate waste in business processes.

Kaizen must operate with three principles in place: process and results (not results-only); systemic thinking (i.e. big picture, not solely the narrow view); and non-judgmental, non-blaming (because blaming is wasteful).

There are three different levels of Kaizen.

- Top management – problems with business idea – long term
- Middle management – problems with investments, middle term
- Floor management – everybody is managing, in teams or individually

## SUPPLY CHAIN MANAGEMENT PROBLEMS

Supply chain management must address the following problems:

- Distribution Network Configuration: Number and location of suppliers, production facilities, distribution centers, warehouses and customers.
- Distribution Strategy: Centralized versus decentralized, direct shipment, cross docking, pull or push strategies, third party logistics.
- Information: Integrate systems and processes through the supply chain to share valuable information, including demand signals, forecasts, inventory and transportation etc.
- Inventory Management: Quantity and location of inventory including raw materials, work-in-process and finished goods.

The **Bullwhip Effect**<sup>22</sup> (or *Whiplash Effect*) is an observed phenomenon in forecast-driven distribution channels. The concept has its roots in J Forrester's *Industrial Dynamics* (1961). Because customer demand is rarely perfectly stable, businesses must forecast demand in order to properly position inventory and other resources. Forecasts are based on statistics, and they are rarely perfectly accurate. Because forecast errors are a given, companies often carry an inventory buffer called "safety stock". Moving up the supply chain from end-consumer to raw materials supplier, each supply chain participant has greater observed variation in demand and thus greater need for safety stock. In periods of rising demand, down-stream participants will increase their orders. In periods of falling demand, orders will fall or stop in order to reduce inventory. The effect is that variations are amplified as one move upstream in the supply chain (further from the customer).

Bullwhip effect is also attributed to the separate ownership of different stages of the supply chain. Each stage in such a structured supply chain tries to amplify the profit of the respective stages, thereby decreasing the overall profitability of the supply chain.

Supply chain experts have recognized that the Bullwhip Effect is a problem in forecast-driven supply chains, and careful management of the effect is an important goal for Supply Chain Managers. The alternative is to establish a demand-driven supply chain, which reacts to actual customer orders. This is the Kanban system. This model has been most successfully implemented in Wal-Mart's distribution system.

Factors contributing to the Bullwhip Effect:

- Forecast Errors

- Lead Time Variability
- Batch Ordering
- Price Fluctuations
- Product Promotions
- Inflated Orders

Methods intended to reduce uncertainty, variability, and lead time:

- Vendor Managed Inventory (VMI)
- Just In Time replenishment (JIT)
- Strategic partnership

Supply chain execution is managing and coordinating the movement of materials information and funds across the supply chain. The flow is bi-directional.

### **3.2.4 Additional Research Information**

The SCM management components are the third element of the four-square circulation framework. The level of integration and management of a business process link is a function of the number and level, ranging from low to high, of components added to the link (Ellram and Cooper, 1990; Houlihan, 1985). Consequently, adding more management components or increasing the level of each component can increase the level of integration of the business process link. The literature on business process reengineering,<sup>23</sup> buyer-supplier relationships,<sup>24</sup> and SCM suggests various possible components that must receive managerial attention when managing supply relationships. Lambert and Cooper (2000) identified the following components, which are:

- Planning and control
- Work structure
- Organization structure
- Product flow facility structure
- Information flow facility structure
- Management methods
- Power and leadership structure
- Risk and reward structure
- Culture and attitude

However, a more careful examination of the existing literature<sup>25</sup> will lead us to a more comprehensive structure of what should be the key critical supply chain components, the "branches" of the previous identified supply chain business processes, that is what kind of relationship the components may have that are related with suppliers and customers accordingly. Bowersox and Closs state that the emphasis on cooperation represents the synergism leading to the highest level of joint achievement (Bowersox and Closs, 1996). A primary level channel participant is a business that is willing to participate in the inventory ownership responsibility or assume other aspects financial risk, thus including primary level components (Bowersox and Closs, 1996). A secondary level participant (specialized) is a business that participates in channel

relationships by performing essential services for primary participants, thus including secondary level components, which are supporting the primary ones. Also, third level channel participants and components may be included, that will support the primary level channel participants, and which are the fundamental branches of the secondary level components.

Consequently, Lambert and Cooper's framework of supply chain components, does not lead us to the conclusion about what are the primary or secondary (specialized) level supply chain components (see Bowersox and Closs, 1996, p.g. 93), that is what supply chain components should be viewed as primary or secondary, and how should these components be structured in order to have a more comprehensive supply chain structure and to examine the supply chain as an integrative one.

Baziotopoulos reviewed the literature to identify supply chain components.<sup>[26][27][28][29][30][31][32][33]</sup> Based on this study, Baziotopoulos (2004) suggests the following supply chain components:

1. For **customer service management**: Includes the primary level component of customer relationship management, and secondary level components such as benchmarking and order fulfillment.
2. For **product development and commercialization**: Includes the primary level component of Product Data Management (PDM), and secondary level components such as market share, customer satisfaction, profit margins, and returns to stakeholders.
3. For **physical distribution, Manufacturing support and Procurement**: Includes the primary level component of enterprise resource planning (ERP), with secondary level components such as warehouse management, material management, manufacturing planning, personnel management, and postponement (order management).
4. For **performance measurement**: This includes the primary level component of logistics performance measurement, which is correlated with the information flow facility structure within the organization. Secondary level components may include four types of measurement such as: variation, direction, decision and policy measurements. More specifically, in accordance with these secondary level components total cost analysis (TCA), customer profitability analysis (CPA), and Asset management could be concerned as well. In general, information flow facility structure is regarded by two important requirements, which are a) planning and Coordination flows, and b) operational requirements.
5. For **outsourcing**: This includes the primary level component of management methods and the company's cutting-edge strategy and its vital strategic objectives that the company will identify and adopt for particular strategic initiatives in key the areas of technology information, operations, manufacturing capabilities, and logistics (secondary level components).



## **4 Empirical Studies**

### **Bindomatic**

*Bindomatic AB has a complex supplier structure. This supplier structure has evolved over time and Bindomatic uses strategies in terms of quality, relations, and agreements etc. in order to control it. Still they have a problem with efficient production scheduling that will minimize cost in the supply chain structure.*

#### **4.1 Supply Structure**

For detailed information concerning Bindomatic's supply structure, **SEE APPENDIX C.**

#### **4.2 Components**

For detailed information concerning Bindomatic's components, **SEE APPENDIX D.**

#### **4.3 Transport**

For detailed information concerning Bindomatic's transport, **SEE APPENDIX E.**

#### **4.4 Purchasing**

For detailed information concerning Bindomatic's purchasing, **SEE APPENDIX F.**

#### **4.5 Cost Agreements**

For detailed information concerning Bindomatic's cost agreements, **SEE APPENDIX G.**

## 5 Analysis

Using the appropriate view or perspective is very difficult when applying a production schedule. Each perspective has a distinctive scope; its own set of assumptions, and various ideas for improving production scheduling. The three most important perspectives are the problem-solving perspective, the decision-making perspective, and the organizational perspective. I have chosen the decision-making perspective for my thesis.

The decision-making model perspective is a process of gathering information, evaluating alternatives, deciding on one, and implementing it. The production scheduler must perform a variety of tasks and use both formal and informal information to make decisions. Provided below is an excellent discussion of the decision-making perspective, starting with the task that schedulers perform each day.<sup>34</sup>

1. Situation assessment: what is where;
2. Crisis identification: what needs immediate attention;
3. Immediate resequencing and task reallocation: reactive decisions;
4. Complete scenario update: mapping the future;
5. Future problem identification: what problems can be foreseen;
6. Constraint relaxation and future problem resolution: discounting future problems; and
7. Scheduling by rote: dealing with the rest of the problem;

There are two very important points in this list. One, in this perspective, the production scheduling objective is to see to it that future troubles are discounted.”<sup>34</sup> There are many types of disorder that can disturb a production schedule, including machine failures, processing time delays, rush orders, quality problems, and unavailable material. The disruptions can be caused by disorder outside of the shop floor, such as labor agreements and the weather. Computers will never completely replace human schedulers because it is unlikely that such a wide variety of possible problems can ever be considered automatically. Moreover, improving production scheduling requires that the schedulers manage bottleneck resources effectively, understand the problems that occur (whether caused by others or by themselves), and take steps to handle future uncertainty.<sup>34</sup>

Using scheduling decision support systems can be valuable. As suggested by McKay and Wiers<sup>36</sup> and Wiers<sup>37</sup>, the design of a scheduling decision support tool should be guided by the following concepts: (1) the ability of the scheduler to directly control the schedule (called “transparency”), (2) the amount of uncertainty in the manufacturing system, (3) the complexity of the scheduling decision, and (4) how well-defined the scheduling decision is. (An ill-defined scheduling decision is characterized by incompleteness, ambiguity, errors, inaccuracy, and possibly missing information).<sup>36</sup>

There is also a place for problem-solving in this perspective. “The scheduling by rote task requires creating a schedule for the work that is not in process, assigning work to resources, and sequencing the operations subject to the constraints that the scheduler imposes to avoid future problems. Schedule generation algorithms can be useful in this step to reduce the workload of the scheduler and find solutions that are better than those a human can find (due to the size or complexity of the problem).”<sup>38</sup>

Herman<sup>38</sup> suggest an integrative strategy including all three perspectives for improving production scheduling.

1. Study the production scheduling system. Create a model (using swimlines, GRAI working techniques, or some other method) of the persons in the production scheduling system, their tasks and decisions, and the information flow between them.
2. Analyze this model and determine if changes to the information flow, task assignments, or decision-making responsibilities are desirable and feasible. For instance, it may be useful to restrict persons (other than the scheduler) from updating the schedule. If changes are needed, go to Step 6.
3. Given that the patterns of information flow are satisfactory, consider the decision-making process that the scheduler uses. Determine if the scheduler is able to manage bottleneck resources effectively, understand the problems that occur (whether caused by others or by themselves), and take steps to handle future uncertainty. If not, changes in these areas are suggested, go to Step 6.
4. Consider dividing the workload between the human scheduler and a decision support tool. If a new or improved decision support tool is needed, go to Step 6.
5. Finally, consider improving production scheduling problem-solving by developing a more appropriate problem formulation or installing more powerful algorithms that can find better solutions faster. Consult the enormous literature on scheduling problems for different approaches to these challenges.
6. Implement the changes that were selected.
7. Assess the impact of the implemented changes and repeat the above steps as necessary.

The steps in this strategy are precise and the ability to use this strategy requires a wide range of skills that go far beyond useful talents in analyzing optimization problems and programming decision support tools.

#### Benefits of Production Scheduling

There are many goals and benefits for way companies use production scheduling.

A production schedule can determine whether delivery promises can be met and identify time periods available for preventative maintenance. Efficient schedules give the shop floor personnel an explicit statement of what should be done so that supervisors and managers can measure their performance, which can illustrate:

- Minimize WIP inventory
- Minimize average flow time through the system
- Maximize machine and/or work utilization
- Minimize setup times

A production schedule can identify resources conflicts, control the release of jobs to the shop, and ensure that raw materials are ordered in time.  
Better coordination to increase productivity and minimizing operating costs.

#### The Gap between Theory and Practice

Applications of computer-based schedules are very scarce.<sup>39</sup>

Although, recently many companies have invested large amounts of money to research and development as well as in the implementation of scheduling systems, very few systems appear to be used on a regular basis. After these systems as been implemented, they used for a short period of time and for some reason changed or completely ignored.

The real world is different than idealized computer models; consequently, there are some unclear constraints, lack of accurate information and, sudden changes. Berlung stated, “Outcome of the scheduling process is influenced by the scheduler adding human capabilities that cannot be automated, problem-solving when the technical system fails, and negotiating between groups of employees to handle incompatible goals.”<sup>40</sup>

### 5.1 Using the RE Model

RE stands for ”Robinson Elina”. It is a modelling name I used to develop and apply to this economic, decision-making programmable model. I used my last name and the fist name of the person most helpful to complete this thesis project.

Implementation in RE is an ideal step once the mathematical model is formulated. It is possible to obtain information on the correctness, solvability, usability, and computability of the developed model. The personnel responsible for updating the model should make sure that the cost, exchange rate and production amounts are accurate.

Although, the RE Model is very accurate, there are a few constraints that is mostly linked to user error. User must be aware that if they receive an Overload in a production facility, they will have to adjust production levels in order to allow schedule production accordingly. The terms Overload and Feasible are discussed later in this section.

#### Re Model Explanation

In this Cost Model, the information that is outlined in red can be change or manipulate to simulate total production cost:

#### Example

<b>Blocks to Change or Manipulate</b>
---------------------------------------

1. *How many USA products do you want to produce?*

Enter the number of products that you would like to produce for the USA market.

## *2. Production Amount!*

This will schedule USA market production mainly cost effectively between the USA and Portugal production facilities. Also, it will calculate based on production capacity, foreign currency exchange rate and production cost. Cost will be calculated based on regular and extra work production. The total production costs are a yearly calculation. When the production is within the capacity of the two facilities a “Feasible” notice will appear. Feasible means that the production schedule is realistic. If a facility is requested to produce more than its capacity, an “Overload” warning will appear. Overload means that one or more production facilities have surpassed its production capacity. When there is an “Overload”, the production engineer must increase the production capacity in one or both facilities to compensate. Also, all the production costs have to be adjusted to reflect this update.

## *3. What is the current currency exchange rate?*

In the block, the user will enter exchange rates that you would like to simulate for this model. You have three choices, US Dollars, Euro and Swedish Kronor (SEK). Only change the first two blocks.

## *4. What is the current cost of production?*

Annual fixed and labor costs of USA and Portugal production facilities in their local currencies are calculated here. Fixed costs are expenses that do not change in proportion to the activity of a business, within the relevant period or scale of production. Labor costs are variable cost. Variable costs are expenses that change in proportion to the activity of a business. In other words, variable cost is the sum of marginal costs. Along with fixed costs, variable costs make up the two components of total cost. Direct costs can be associated with a particular cost object. Not all variable costs are direct, for example, variable manufacturing overhead costs are not direct, but indirect costs. Variable costs are sometimes called unit-level costs as they vary with the number of units produced.

The sums of these costs are presented in SEK. The sums of both facilities are calculated in the Group block.

## *5. What is the current production rate?*

Enter current annual production rates of both facilities and the Group amount will be also calculated.

## *6. What is the current production plant capacity?*

Enter current annual production capacities of both facilities and the Group amount will be also calculated.

Production Accessibility is the difference of production capacity and production level. This will give the user the amount of how many additional products that can be produced.

## *7. Which country has the lowest production cost in SEK?*

As in #4, the fixed and labor costs are presented in local currencies and calculated per cover. The amounts are formulated from current cost of production and number of covers needed to be produced in regular production. The model illustrates the total production cost of both facilities per cover.

8. *What is the difference in production cost between USA and Portugal in SEK?*

The differences in production cost per cover are shown here for comparison.

9. *What is the current, extra cost of production?*

Annual, extra fixed and labor costs of USA and Portugal production facilities in there local currencies are calculated here.

10. *What is the difference in extra production cost between USA and Portugal in SEK?*

The differences in extra production cost per cover are shown here for comparison.

11. *What is the cost of extra production?*

Annual, extra fixed and labor costs of USA and Portugal, production facilities in there local currencies are calculated here.

12. *Comparison Estimates.*

13. *Coverbind's price per cover estimates.*

## 5.2 Representation of Solution

### RE MODEL EXAMPLE

#### RESULTS

Enter Number Here		COST	ANNUAL TOTAL PRODUCTION COST
1. How many USA products do you want to produce?	8 500 000		
2. You should produce!			
	PORTUGAL	7 000 000 FEASIBLE	1 215 060,93 kr
	USA	1 500 000 FEASIBLE	831 578,95 kr
	TOTAL		2 046 639,88 kr
			10 779 739,88 kr

\*FEASIBLE = Means that the production schedule is realistic.  
 \*OVERLOAD = Means that one or more production facilities has surpassed it's production capacity.

#### DATA INPUTS

**BINDOMATIC®**  
 A professional impression.

REGULAR WORK			
3. What is the current currency exchange rates?		1 USD =	10,000 SEK
		1 EUR =	9,3328 SEK
		1 EUR =	0,9333 USD
4. What is the current cost of production?		USA	Portugal
	Fixed Cost in Local Currency	\$400 000	€300 000,00
	Labor Cost in Local Currency	\$100 000	€100 000,00
	Total	5 000 000 kr	3 733 100 kr
		Group	6 799 825 kr
			1 933 275 kr
			8 733 100 kr
5. What is the current production rate?		USA	Portugal
		7 500 000	18 000 000
6. What is the current production plant capacity?		10 000 000	25 000 000
	Production Accessibility	2 500 000	7 000 000
			9 500 000
7. Which country has the lowest production cost in SEK?		USA	Portugal
	Regular production Fixed Cost per product	0,5333 kr	0,1555 kr
	Regular production Labor Cost per product	0,1333 kr	0,0518 kr
	Total	0,6667 kr	0,2074 kr
			0,8741 kr
8. What is the difference in production cost between USA and Portugal in SEK?			0,4593 kr
EXTRA WORK			
9. What is the current extra work production rate?		USA	Portugal
		2 000 000	5 000 000
			7 000 000
	Extra Work production Fixed Cost per product	0,4211 kr	0,1217 kr
	Extra Workproduction Labor Cost per product	0,1333 kr	0,0518 kr
	Total	0,5544 kr	0,1736 kr
			0,7280 kr
10. What is the difference in extra work production cost between USA and Portugal in SEK?			0,3808 kr
11. What is the cost of extra work production?		USA	Portugal
	Extra labor cost	266 667 kr	259 243 kr
	Freight to Coverbind		1 000 000 kr
	Extra service cost	200 000 kr	93 328 kr
	Material cost	3 474 000 kr	5 851 634 kr
	Totally extra	3 940 667 kr	7 204 205 kr
			11 144 871 kr
12. Comparison estimates.		Comparison	
	All new covers produced at Coverbind		10 054 268 kr
	Delta (+ is lower cost for the group)		-1 090 604 kr
13. Coverbind's price per cover estimates.		Total UMC per cover Coverbind	
	Transfer price from Portugal to Coverbind	2,2914 kr	1,6094 kr
	Total UMC per cover if all produced at Coverbind		1,7375 kr
	Apparent UMC delta (+ means lower for Coverbind)		0,1330 kr
			-8%

Figure 5.1 RE Model

### 5.2.1 The Evaluation Function

I was not able to use heuristic optimizations in this thesis. I was not blessed with this information which considers the additional costs that are currently not included in the mathematical model. The cost for late or early production is taken in account in the solution included in the mathematical model. Also the cost associated to production on a particular production line. It is possible to expand the mathematical model in various ways. This mathematical model is a general representation of the minimization production costs in the sequenced production planning of product orders in two different production plants.

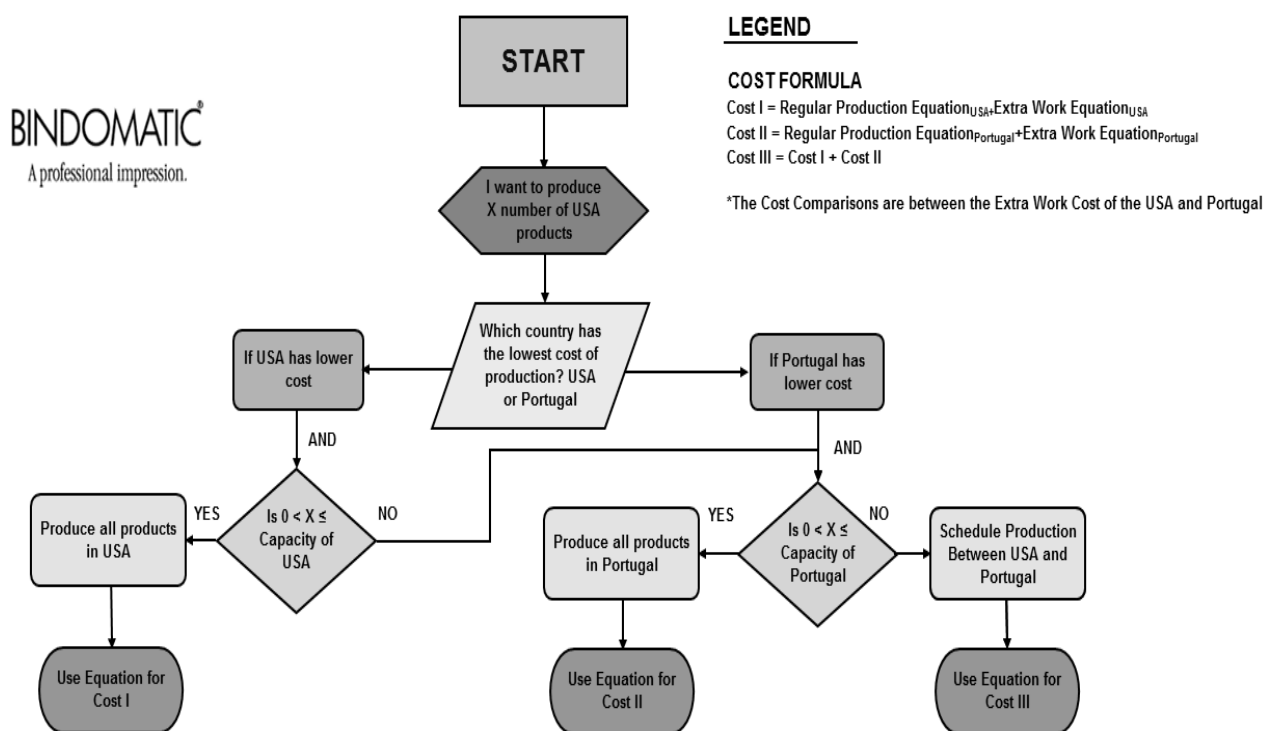


Figure 5.2.1 Decision-Making Flowchart

### 5.3 Generic Equation

I used the following variables for sets:

Set x = number produced in USA

Set y = number produced in Portugal

Set f(x) = total cost of producing x

Set g(y) = total cost of production y

Set b = capacity of Portugal facility



$$\min f(x) + g(y)$$

Minimizing the cost

$$\text{Subject to } x + y = \text{demand} \quad (2.1)$$

$$\min f(x) + g(\text{demand} - x) \quad (2.2)$$

$$f'(x) - g'(\text{demand} - x) = 0 \quad (2.3)$$

$$f'(x) = g'(y) \quad (2.4)$$

### WITH CAPACITY FACTOR IN EQUATIONS

Minimizing the cost

$$\min f(x) + g(y) \quad (2.5)$$

$$\text{Subject to } x + y = \text{demand} \quad (2.6)$$

$$Y \leq b \quad (2.7)$$

$$\min f(x) + g(\text{demand} - x) \quad (2.8)$$

Demand Constraint

$$\text{Subject to } \text{demand} - x \leq b \quad (2.9)$$

$$\leq \text{ or } \geq \quad (2.10)$$

$$x \geq \text{demand} - b \quad (2.11)$$

#### 5.3.1 Specification

The used RE Model implementation is built on formulas based in the Microsoft Excel 2003-2007 software program. The representation used for the generic equation is also suitable RE Model. The same evaluation function and parameters can be used, which is very convenient for benchmarking the equation. The excel file, along with the formula will be attached to the **APPENDIX H**.

Constraints

Equation 2.1 is calculates total demand of both production facilities. Equation 2.2 is a minimizing cost function and evaluates the US demand. Equation 2.5-2.8 is also a minimizing function that includes production capacities at the US and Portugal production plants. These set of equations assess the capacity of the production plants and scheduling production with regard to minimizing costs. Equation 2.9-2.11 further minimizes the previous function relative to demand.

## **6 Conclusions and Recommendations**

As stated in the problem analysis, we should investigate different aspects of the

- To investigate how Bindomatic, a company that has a problem with an increased demand in its United States plant (also known as Coverbind), can forecast the best period to outsource production to Bindomatic's Portugal plant for manufacturing

### **6.1 Conclusions**

The thesis introduced a decision-making model and identified, implemented and demonstrated useful optimization techniques for the complex scheduling problem.

The model can be refined. The Operation Research cycle could be iterated a number of times with as input feedback from Bindomatic AB. Not all research questions are treated in the research, but a build-up towards them has been created.

Some opportunities to lower costs; increase productivity have been suggested during in the Recommendations.

Reasonably good results have been obtained in the final stage. The suggested combination is fast and can handle different types of costs. This is promising regarding the support of decomposition.

#### **6.1.1 Future Work**

Future work could possibly include:

- Add production times to the model.
- Explore the validity and tractability of the presented model further and adapt it consequently.
- The decision-making model could become the core of an interactive Decision Support System or an Expert System.
- The above mentioned system themselves can be part of a greater supply chain management system (considering actors up and down stream), such as an enterprise resource planning (ERP) system. This system could control the whole chain and all complex interactions from raw material purchase to end-customer delivery; considering the "greater picture".
- Customize to better assist the planner; such as answering available-to-promise questions to customers.
- Research the applicability of a similar approach to other industries
- Add functionality to measure the performance with respect to usage of resources (inventory, machine utilization, etc.)

### **6.2 Recommendations**

In order to summarize the issues and the important topics that we discovered in the empiric study, a list was made:

**Issues:**

- Unpredictable increase in demand
- Low capacity in US plant
- Little purchasing involvement in the design
- Unknown lead-times
- Conservative purchasing
- Inventory at the system supplier
- Transport costs
- Administrative costs
- Handling cost
- Statistical Study not found

**To be considered:**

- Increased responsibilities of the system suppliers
- Forecasting US demand
- Moving all sourcing and production activities to Europe
- Outsource Supply Chain Management to Specialist
- Orders are placed very conservative today and not Just-In-Time
- The rate production at Bindomatic
- Simulation software program
- HTML format version of Model with blank cells
- Statistical Study
- Aggregated Planning

These issues and aspects to consider in Bindomatic form the overall understanding of the situation and will be the platform from which alternative solutions will be discussed and analyzed later in the master thesis.

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## **APPENDIX A**

### ***PowerPoint Presentation***

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## APPENDIX B

### *Literature Reference*

# **Improving Production Scheduling: Integrating Organizational, Decision-Making, and Problem-Solving Perspectives**

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#### **Abstract**

Production scheduling activities are common but complex. This leads to many different views and perspectives of production scheduling. Each perspective has a particular scope, its own set of assumptions, and a different approach to improving production scheduling. This paper covers three important perspectives (the problem-solving perspective, the decision-making perspective, and the organizational perspective) and discusses the methodologies that these perspectives use. Finally, this paper presents an integrative strategy that can be used to select, in a particular setting, an approach for improving production scheduling.

KEYWORDS: Production scheduling, decision-making, optimization

### **1. Introduction**

Many manufacturing facilities generate and update production schedules, which are plans that state when certain controllable activities (e.g., processing of jobs by resources) should take place. In manufacturing systems with a wide variety of products, processes, and production levels, production schedules can enable better coordination to increase productivity and minimize operating costs. A production schedule can identify resource conflicts, control the release of jobs to the shop, and ensure that required raw materials are ordered in time. A production schedule can determine whether delivery promises can be met and identify time periods available for preventive maintenance. A production schedule gives shop floor personnel an explicit statement of what should be done so that supervisors and managers can measure their performance.

Production scheduling can be difficult and time-consuming. In dynamic, stochastic manufacturing environments, managers, production planners, and supervisors must not only generate high-quality schedules but also react quickly to unexpected events and revise schedules in a cost-effective manner. These events, generally difficult to take into consideration while generating a schedule, disturb the system, generating considerable differences between the predetermined schedule and its actual realization on the shop floor. Rescheduling is then practically mandatory in order to minimize the effect of such disturbances in the performance of the system.

Because production scheduling activities are common but complex, there exist many different views and perspectives of production scheduling. Each perspective has a particular scope and its own set of assumptions. Different perspectives lead naturally to different approaches to improving production scheduling. Three important perspectives are the problem-solving perspective, the decision-making perspective, and the organizational perspective.

The problem-solving perspective is the view that scheduling is an optimization problem that must be solved. A great deal of research effort has been spent developing methods to generate optimal production schedules, and countless papers discussing this topic have appeared in scholarly journals. Typically, such papers formulate scheduling as a combinatorial optimization problem isolated from the manufacturing planning and control system in place. Schedule generation methods include most of the literature in the area of scheduling. Interested readers should see Pinedo and Chao [1], Pinedo [2], or similar introductory texts on production scheduling. Researchers will find references such as Leung [3] and Brucker [4] useful for more detailed information about problem formulation and solution techniques.

The decision-making perspective is the view that scheduling is a decision that a human must make. Schedulers perform a variety of tasks and use both formal and informal information to accomplish these. Schedulers must address uncertainty, manage bottlenecks, and anticipate the problems that people cause [5].

The organizational perspective is a systems-level view that scheduling is part of the complex flow of information and decision-making that forms the manufacturing planning and control system [6, 7]. Such systems are typically divided into modules that perform different functions such as aggregate planning and material requirements planning [8, 9]. In this paper, production scheduling refers to the low-level, shop floor control function.

The paper will discuss the methodologies that these perspectives use and show the relationships between them. In addition, the paper will present an integrative strategy that can be used to select, in a particular setting, an approach for improving production scheduling. The remainder of this paper is organized as follows: Section 2 discusses the problem-solving perspective. Section 3 describes the decision-making perspective. Section 4 addresses the organizational perspective. Section 5 discusses an integrative strategy for improving production scheduling. Section 6 concludes the paper.

## **2. Problem-solving: Finding Optimal Schedules**

When viewed from the problem-solving perspective, production scheduling is a fascinating puzzle to be solved by moving tasks around a Gantt chart, searching for the optimal solution. MacNiece [10] gives a beautiful example of using a Gantt chart to solve a scheduling problem. The problem is to determine if an order for an assembly can be completed in 20 weeks. The Gantt chart has a row for each machine group and bars representing already planned work to which he adds the operations needed to complete the order. He argues that using a Gantt chart is a much quicker way to answer the question. More generally, the ability to formulate the problem rigorously and to analyze it to find properties of optimal solutions has attracted a great deal of research effort. In addition to exact techniques [4], there are a variety of heuristics and search algorithms used to find near-optimal solutions to these problems. Although there exists a significant gap between scheduling theory and practice, some researchers have improved real-world production scheduling through better problem-solving (see, for instance, Dawande et al. [11]).

However, the optimization approach relies upon the ability to formulate the problem. Its feasibility depends upon the ability to collect the data needed to specify the problem instance. More importantly, its relevance depends upon whether or not someone will use the schedule that is generated. The relevance problem is not new and predates the academic research on scheduling. Reacting to situations that he observed ninety years ago, Gantt [12] warned that the most elegant schedules created by planning offices are useless if they are ignored.

## **3. Decision-making: Planning for Trouble**

Decision-making is a slightly broader perspective on production scheduling. Decision-making is, in general, a process of gathering information, evaluating alternatives, selecting one, and implementing it. Schedulers must perform a variety of tasks and use both formal and informal information to make scheduling decisions. A number of authors have documented the activities that schedulers must perform, including [13, 14]. McKay and Wiers [5] provide an excellent discussion of the decision-making perspective, starting with the tasks that schedulers perform each day:

1. Situation assessment: what is where;
2. Crisis identification: what needs immediate attention;
3. Immediate resequencing and task reallocation: reactive decisions;
4. Complete scenario update: remapping the future;
5. Future problem identification: what problems can be foreseen;
6. Constraint relaxation and future problem resolution: discounting future problems; and
7. Scheduling by rote: dealing with the rest of the problem.

Two important points should be highlighted. One, in this perspective, the production scheduling objective is “to see to it that future troubles are discounted” [15]. There are many types of disturbances that can upset a production schedule, including machine failures, processing time delays, rush orders, quality problems, and unavailable material. Problems can be caused by sources outside the shop floor, including labor agreements and the weather. It is unlikely that such a wide variety of possible problems can ever be considered automatically, implying that computers will never completely replace human schedulers. Moreover, improving production scheduling requires

that the schedulers manage bottleneck resources effectively, understand the problems that occur (whether caused by others or by themselves), and take steps to handle future uncertainty [5].



Scheduling decision support systems can be useful as well. As suggested by McKay and Wiers [16] and Wiers [17], the design of a scheduling decision support tool should be guided by the following concepts: (1) the ability of the scheduler to directly control the schedule (called “transparency”), (2) the amount of uncertainty in the manufacturing system, (3) the complexity of the scheduling decision, and (4) how well-defined the scheduling decision is. (An ill-defined scheduling decision is characterized by incompleteness, ambiguity, errors, inaccuracy, and possibly missing information [16].)

The second point is that there is a place for problem-solving. The scheduling by rote task requires creating a schedule for the work that is not in process, assigning work to resources, and sequencing the operations subject to the constraints that the scheduler imposes to avoid future problems. Schedule generation algorithms can be useful in this step to reduce the workload of the scheduler and find solutions that are better than those a human can find (due to the size or complexity of the problem).

#### **4. The Organizational Perspective: Sharing Information**

The organizational perspective, which is the most complete, views production scheduling as a system of decision-makers that transforms information about the manufacturing system into a plan (the production schedule) [6].

In a manufacturing facility, the production scheduling system is a dynamic network of persons who share information about the manufacturing facility and collaborate to make decisions about which jobs should be done when. The information shared includes the status of jobs (also known as work orders), manufacturing resources (people, equipment, and production lines), inventory (raw materials and work-in-process), tooling, and many other concerns.

The persons in the production scheduling system may be managers, production planners, supervisors, operators, engineers, and sales personnel. They will use a variety of forms, reports, databases, and software to gather and distribute information, and they will use tacit knowledge that is stored in their memory.

The following are among the key decisions in a production scheduling system:

- releasing jobs for production,
- prioritizing jobs that require the same resources,
- assigning resources (people, equipment, or production lines) to jobs,
- reassigning resources from one job to another,
- determining when jobs should be started, and
- interrupting jobs that should be halted.

The production scheduling system is a control system that is part of a larger, more complex manufacturing planning and control system. The production scheduling system includes but is more than a schedule generation process (be it manual or automated). The production scheduling system is not a database or a piece of software. The production scheduling system interacts with but is not the system that collects data about the status of open work orders (often called a manufacturing execution system). The production scheduling system is not an optimization procedure. The production scheduling system provides information that other managers need for other planning and supervisory functions.

Representing decision-making systems is a difficult task. Herrmann and Schmidt [18] describe decision-making systems in product development. The most typical representation is an organization chart, which lists the employees of a firm, their positions, and the reporting relationships. However, this chart does not explicitly describe the decisions that these persons are making or the information that they are sharing. Another representation is a flowchart that describes the lifecycle of an entity by diagramming how some information (such as a customer order, for example) is transformed via a sequence of activities into some other information or entity (such as a shipment of finished goods). Swimlanes [19] are a special type of flowchart that adds more detail about who does which activities, a key component of a decision-making system. Herrmann [6] uses swimlanes to represent a production scheduling system since the swimlanes model yields a structured model that describes the decision-making and

information flow most efficiently and clearly shows the actions and decisions that each participant performs. One limitation is that the model does not show the structure of the organization. Also, representing a larger, more complex system would require swimlanes models at different levels of abstraction to avoid confusion. Swimlanes are not the only possibility. Work by Guinery and MacCarthy [20] on improving production scheduling systems used modified GRAI modeling techniques [21] for representing decision centers.

A scheduler is only one node in the production scheduling system network. The scheduler's tasks (listed in Section 3) describe the activity within that node. The information that the scheduler needs arrives from other nodes, and the schedules that are created go to other nodes in the network.

## 5. An Integrative Strategy

Based on the above discussion, it is clear that these three perspectives form a hierarchy, with the the problem-solving perspective at the lowest level, the decision-making perspective in the middle, and the organizational perspective at the highest level. Figure 1 illustrates this relationship in a conceptual way. Moving among these three perspectives corresponds to shifting one's focus from the production planning organization to one person to one task. Thus, this hierarchy of perspectives does not correspond to a temporal or spatial decomposition. Instead, it is related to a task-based decomposition of the production scheduling system.

### Perspectives on Production Scheduling

This hierarchy suggests the following integrative strategy for improving production scheduling.

1. Study the production scheduling system. Create a model (using swimlanes, GRAI modeling techniques, or some other method) of the persons in the production scheduling system, their tasks and decisions, and the information flow between them.
2. Analyze this model and determine if changes to the information flow, task assignments, or decision-making responsibilities are desirable and feasible. For instance, it may be useful to restrict persons (other than the scheduler) from updating the schedule. If changes are needed, go to Step 6.
3. Given that the patterns of information flow are satisfactory, consider the decision-making process that the scheduler uses. Determine if the scheduler is able to manage bottleneck resources effectively, understand the problems that occur (whether caused by others or by themselves), and take steps to handle future uncertainty. If not, changes in these areas are suggested. If changes are needed, go to Step 6.
4. Consider dividing the workload between the human scheduler and a decision support tool. If a new or improved decision support tool is needed, go to Step 6.
5. Finally, consider improving production scheduling problem-solving by developing a more appropriate problem formulation or installing more powerful algorithms that can find better solutions faster. Consult the enormous literature on scheduling problems for different approaches to these challenges.
6. Implement the changes that were selected.
7. Assess the impact of the implemented changes and repeat the above steps as necessary.

The steps of this strategy are straightforward, though the references cited in the previous sections provide more information about the techniques and give examples. It is clear that the ability to use this strategy requires a wide range of skills that go beyond useful talents in analyzing optimization problems and programming decision support tools.

## 6. Summary and Conclusions

The three production scheduling perspectives discussed here are distinct but related. Moreover, an analysis of these perspectives suggests that they form a hierarchy. This, in turn, motivates an integrative strategy for improving production scheduling that begins with considering the production scheduling system, then looking at the scheduler's decision-making process, and finally addressing the problem-solving algorithm.

Discussing the location of this integrative approach in the context of the wide variety of systems approaches [22], especially those that mix methodologies [23], is beyond the scope of this paper. This paper introduces a pragmatic strategy that stresses the need to be familiar with and consider a set of approaches to improving production scheduling. A complete theoretical analysis of the methodology remains to be done.

In practice, production scheduling is a complex system of information flow, decision-making, and problem-solving. It is not simply an optimization problem. It is hoped that the strategy presented here will help engineers, analysts, and managers recognize and understand this complexity and successfully improve their production scheduling systems.

### Acknowledgements

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## **APPENDIX C**

### ***PowerPoint Presentation***

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## **APPENDIX D**

### ***Components***

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## **APPENDIX E**

### ***Transport***

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### ***Purchasing***

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### ***Cost Agreements***

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## **APPENDIX H**

### ***RE Model Excel File***

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