IMPROVING THE MATERIAL AND INFORMATION FLOW FROM SUBASSEMBLY SHOP TO MULTIPLE FINAL ASSEMBLY LINES

Master of Science Thesis in the Master Degree Programme, Production Engineering

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Cover:
Assembly line image at Volvo Powertrain

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Abstract

This thesis work is carried out at Volvo Powertrain, Skövde and its main focus is to streamline the material and information flow between subassembly workshop and multiple final engine assembly lines. The company lacks detailed knowledge about the efficiency of product flows that exists between subassembly workshop and the assembly lines. So, the company is interested in investigating these product flows in order to assess the improvement potential of the current state.

Two product families called Slang and Startelement is chosen for the investigation. A hybrid mapping methodology that encompasses both the value stream mapping and material flow mapping features is used to map the current state flows. This current state maps are analyzed to identify the improvement potentials. The suggestions for improvements are presented as potential future states where the flows are better aligned towards minimizing the material handling, transportation activities and lean production philosophies in general.

Four potential future states are arrived at based on the analysis of the current states and these future states are evaluated with due consideration of practical implementation feasibilities and particular product family context. This evaluation led to the finalizing of different future states for the two product families under study. A horizontally integrated hybrid push/pull production system (HIHPS) is proposed for slang product family and a pure pull system for startelement family.

Activity-based costing model is developed to identify the cost of flowing an item from subassembly to the final assembly lines for the current states and evaluated future states. With this a basis, the financial appraisal of these evaluated future states are carried out using a tool called Benefit-Cost analysis and the theoretical ratio is achieved as 4.55. A pilot run of the evaluated future state is carried out for start element product family to investigate that the perceived benefits are realized. The evaluated future state proposal for the slang family is accepted by the company and it will be implemented in the near future. Finally, these two future state material flows are standardized and a future state deployment model is developed to cascade the same to other product families in the facility.

Keywords: Value stream mapping, Hybrid production system, Material flow, Information flow, Push/pull system, Activity based costing.

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Table of Contents

Terms and Abbreviations

Terms and Abbreviations	Descriptions
HBS	High Bay Storage. This is also called as Warehouse, which is an automatic storage and retrieval system to store raw materials received from the suppliers and also semi-finished components before being delivered to the assembly lines.
Subassembly shop	Assembly area where components are preassembled before it is delivered to the final assembly lines.
FA	Final assembly lines where the complete assembly of the engines takes place. There are four different assembly lines differentiated based on the model variants.
Station/Subassembly cell	It is a segment of an assembly line where a number of assembly process are carried out. It can be either completely automated or manual process.
Kitting	It is a principle where different parts that are required for a particular assembly variant at a station are collected and delivered in one single box called kits. This collecting/picking takes place at a different area called kitting storage area in order to make work easy for the assembly operator.
Emballages	These are nothing but boxes or bins used to store components. There are different standard sizes of emballages used in a company according to the component sizes.
Flow racks	These are racks with different levels to store components. These racks have a certain height standards in order for the operator to handle components in and out of the racks ergonomically.
Supermarket	It is an area to store the finished or semi-finished components in downsized/minimum quantities with clear visibility and ease to store and retrieve. Most common method of storing components will be using the emballages in flow racks.
Drop station	It is a junction point or drop point between the Warehouse/HBS and other parts in the production plant. This acts as a gate to the Warehouse.
FIFO	First In First Out.
WIP	Work In Progress.
Minimum quantity	It is the minimum number of emballages that are to be stored in the racks all the time.
Replenishment quantity	It is the number of emballages that are to be refilled in the racks. Nothing but the maximum minus the minimum quantity.

1. Introduction

This dissertation work is carried out at Volvo Powertrain, Skövde (for simplicity referred to as Volvo PT throughout this report) as a curriculum of Master of Science program at Chalmers University of Techqnology, Sweden.

This chapter briefly describes about the case company Volvo PT and the background to the problem that this project work addresses. This is followed by purpose and problem analysis illustration. This problem analysis resulted in three research questions which serve as a backbone for this project work. Then, this chapter is concluded with presentation of scope and thesis outline.

1.1 Company Profile

Volvo PT, Skövde is a manufacturer of heavy duty diesel engines for both automotive and other industrial applications. This Volvo PT production facility situated in Skövde encompasses casting, machining and assembly plants, this enables them to produce finished engines right from the molten metal.

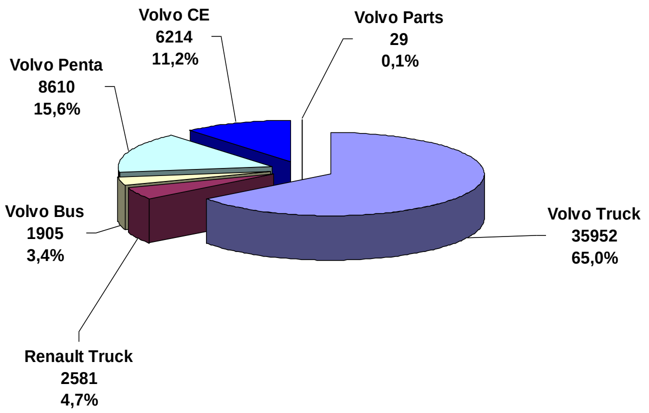


Figure 1: Sales during the year 2011

Volvo PT F-plant (assembly plant) manufactures 13 liter and 16 liter engines and serves for its own parent organization called Volvo Groups. It supplies engines to subsidiary companies like Volvo Penta, Volvo Construction Equipment, Volvo Buses, Renault Trucks, Volvo Trucks within Volvo Groups. This plant exports engines to its customers present in Brazil, France, Japan & USA apart from Sweden. Figure 1 shows sales for the year 2011 by various customer segments.

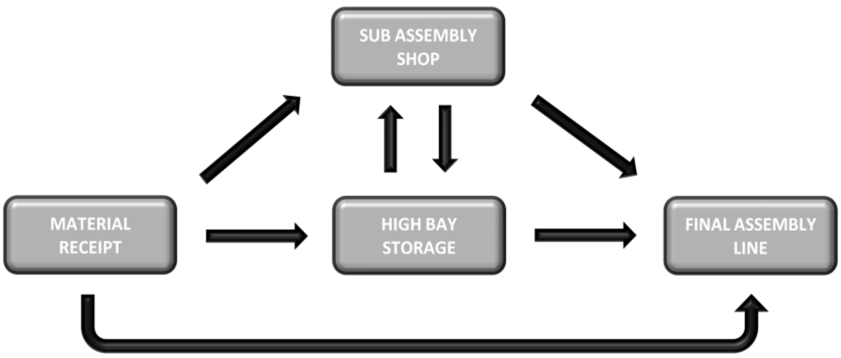


Figure 2: Material Flow in F-plant

This F-plant was built in 1974 and has almost 900 employees working in this facility. This plant manufactures both general purpose and custom made engines to meet its customer requirements. This assembly plant performs both sub-assembly and final assembly operations for manufacturing of various engine product families. Most of the materials that are received from the suppliers pass through either the subassembly functional department or warehouse (will be mentioned as High Bay Storage throughout this report) or both before being delivered to the final engine assembly line and while the rest only few items are delivered directly to the line. Figure 2 shows overall material flow within the F-plant.

Figure 3 shows a schematic representation of F-plant layout and describes how material flows within the plant. This plant comprises two 13 liter main assembly lines, one 16 liter line, one 13 liter variant line, one completely built-up line and five conversion lines. Blue arrow represents the flow of raw materials from the high bay storage to the subassembly workshop and the green arrow depicts the material flow from subassembly workshop to the assembly lines via the high bay storage.

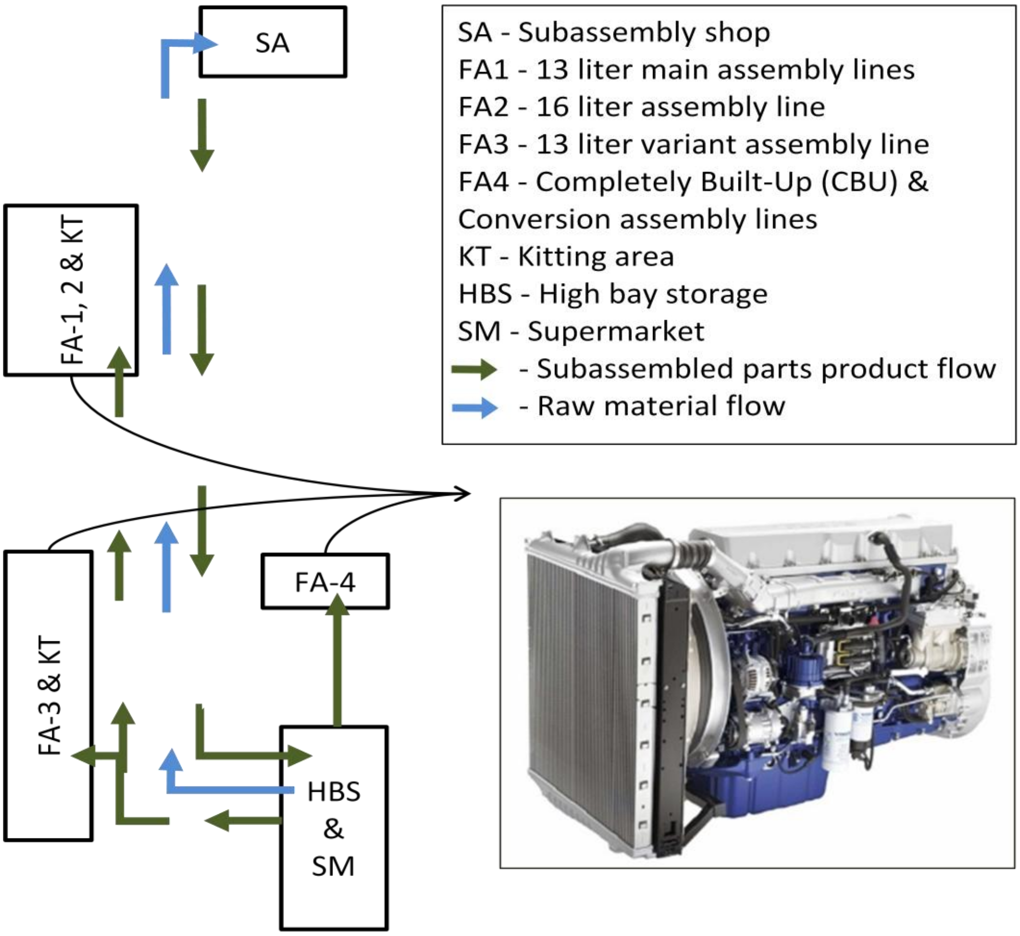


Figure 3: Schematic layout of F-plant

1.2 Background

Now-a-days, manufacturing industries face a fierce competition in this global market that is volatile, diverse and wide spread. So, the companies have been emphasizing lean principles and practices as a means to cope up with this competition. In regards to this, companies are often too focused on improving only the value adding activities or processes in the production flow from the lean perspective but the internal material handling and transport activities are relatively left untouched, despite their close connection to the production. Moreover, the material handling and transport activities constitute a significant portion of the total lead time, it becomes essential to lean these activities with due consideration of various downstream value adding activities' demands in the supply chain. So it is evident that the type of production system (either a push or pull) and material handling system are important for improving the overall material flow, considering/depending on the manufacturing environmental aspects like demand, unleveled production, resource constraints, and product mix.

For the past couple of years, Volvo PT has improved its assembly line efficiency significantly by implementing the lean principles and practices but its sub-assembly operations and material flow to the final assembly line is left untouched. Now, the company is striving to improve its material flow (material handling and transport) from this sub-assembly shop to the final assembly line.

1.3 Purpose

The main purpose of this thesis is to investigate the current flow, propose and implement future state solutions with improved flow of components from subassembly shop to multiple final assembly lines. In order to achieve this purpose there are several objectives that are to be fulfilled:

- To investigate and map the subassembly product flows and to identify and quantify the material handling measures like inventory levels, handling and transportation lead times and also the information flow in the production process, because without knowing the current states of their processes neither analysis nor improvements can be made.
- Develop a future state with an improved planning and control of the flow by analyzing various aspects like production systems, demand, resource constraints, product variants, information flow.
- To construct an activity cost model in order to calculate the flow cost of each product and also to evaluate the solutions by computing the benefit-cost for the improved flow.
- Implementation and test run of the solution along with the general deployment model, so that the solution could be deployed for other products with same flow.

1.4 Problem analysis and Research questions

As mentioned in the background, one part of the component flow is such that the raw materials (shown in figure 2) are stored in the High bay storage after being received from the supplier. It is then transported the subassembly shop and after the subassembly process it is transported again to the High bay storage, supermarket and kitting area, before being delivered to the different final assembly lines. It is quite unnecessary that the component follows such patterns and since the transport related to the High bay storage are mostly by the overhead conveyors, sometimes there will be more component pallets to be transported, which makes them to wait for longer period, leading to increased overhead-conveyor traffic and inventory at the high bay storage. Also there are few components that serve several final assembly lines, so they follow a different flow pattern altogether. Eventually there are significant unnecessary material handling and transportation in these flows that are non-value adding. Further, these non-value adding activities are unclear as to where it occurs and how. There are no quantitative data regarding the transportation and handling activities from the subassembly shop to high bay storage, its batch sizes, packaging configuration, and lead times, so to capture all the data, the interesting questions would be:

- Which flow mapping methodologies are to be employed and how can they be used in a synergistic way to identify and analyze these losses both quantitatively and qualitatively?

- What are the factors to be considered for measuring the flow performance in this environment?

After collecting the required data it is obvious to analyze and arrive at a better possible future solution, but the analysis is to be done based on several criteria and a suitable production system is to be adopted in the future state, so the question here would be

- What are the criteria that will decide the selection of suitable production system (push/pull) to be employed in the future state, thereby improving the material flow?

Since cost is one of the main performance measures of any organization, it is quite necessary to investigate the flow and compute the cost associated with each activity in the flow of component from sub-assembly shop to final assembly line.

1.5 Scope

The current state map will include components flow from the raw material receipt from supplier to the final assembly lines but the analysis is done only for the flow of components from subassembly shop to the final assembly line because of our project scope. Also only two product families consisting of 60 components are analyzed. The activity cost model that has been done for the flow of components from the subassembly shop to the final assembly lines will not include overhead costs like electricity, information systems running the flow and the capital cost that has been tied up in the inventory. The mapping of product flows focuses only on the basic raw material component of few of the products or product families and its flow from the receiving area to the subassembled products delivered to the final assembly line. All other components in every product and their individual flows are not considered as well as their supportive processes along the products value flow, since they will not have a considerable effect on the flow from subassembly workshop to the final assembly line.

1.6 Thesis Outline

Thesis starts with the introduction chapter, where the case company background and the problem background is explained. Also this chapter contains the Purpose, Problem analysis with research questions and delimitations.

The various theories those are necessary to understand this thesis better like push/pull production systems, mapping tools and costing analysis, are described in the frame of reference chapter along with the view points of various authors.

The next chapter covers the methodology used for this thesis work followed by the current state flow descriptions, where the flows of the product families from subassembly shop to the final assembly lines are explained.

The analysis chapter contains the critical analysis of various processes, its activity measures and potential improvements followed by the future state solutions and evaluation of these future states considering the measures and benefit cost analysis.

Layout planning, other practical considerations during installation are covered in Implementation and monitoring chapter followed by a general future deployment model that could be of use in further streamlining the flow of other product families. Finally the report is completed with the discussions and conclusion in the final chapters.

2. Frame of Reference

This chapter details all the literatures relevant to this project work. The fundamental idea behind the literature review is to develop a theoretical framework based on which the rest of the thesis is built, as well as to provide the reader with necessary background information in order to understand the rest of the project work.

2.1 Value Stream Mapping

A value stream comprises of both value adding and non-value adding activities required to bring a product / service through the main flows essential to every product (Rother & Shook, 1999). A first step to make improvement of a complex system or value chain is to create a macro value stream map of the entire system. A proven method used in lean manufacturing for doing this is 'Value Stream Mapping' (VSM), which was adapted by Rother & Shook (1999) from Toyota's internal 'Material & Information Flow' diagrams. These authors states that

''VSM is a pencil and paper tool that helps you to understand the flow of materials and information as a product makes its way through the value stream.''

This VSM is a qualitative, graphical tool that helps to identify different types of wastes, the sources of its origin and offers a common language about the various manufacturing processes for better understanding and knowledge transfer. This commonality, structured way of analyzing helps to bring shared perception of flaws in the system. It also creates a way of quantifying the processes and encourages and alleviates the subsequent improvement efforts.

The VSM is a communication tool that helps to manage the change process. Apart from mapping the physical flow of materials, the VSM also emphasizes on information flow that are often overlooked by other methods. Rother & Shook (1999) advocates that information flow and material flow are equally important and form the two sides of a coin and both needs to be mapped clearly in order to fully understand and realize the potential improvements in the value stream.

Mapping the value stream is a very simple process. It involves following through a product's production path from customer to supplier back and draw a visual representation of every process capturing both the physical material and information flow information. This tool helps to realize the potential improvements in a system and consequently helps to create a vision of the ideal or improved future state. First step in this technique is to map the current state, which can be done by direct shop floor observation. This mapped current state forms the foundation for analysis, with which future state is developed (second step). The final step is to establish the work plan followed by active implementation. The power of this mapping tool is that mapping and implementation team ends up with only few sheets of paper (future state and implementation plan) that helps to achieve lean value stream.

Thus, a value stream map permits to identify every process in a flow and pull them out from functional departments and build a value stream in compliance with lean principles. In other words, VSM helps to analyze the disconnected material flows and improve them by linking together and thus, creating a continuous flow (Rother & Shook, 1999).

2.2 Material Flow Mapping

VSM is a well known tool across many industrial sectors that facilitate in creating continuous flow. In spite of its wider acceptance, this VSM tool lacks in one particular aspect: it emphasizes more on analysis and improvement of disconnected value adding activities in a material flow and considers material supply activities insignificant (Finnsgård, 2011). Consequently, Finnsgård (2011) adopted this VSM tool effectively to identify and map the material supply activities in the material flow without offsetting any of the merits of VSM tool and turned up to a new technique called Material Flow Mapping (MFM). This tool aims at describing and assessing the performance of material flow in supply chains. This tool measures the material supply activities such as Handling (H), Administration (A), Transportation (T) and Storage (S).

All relevant information for the mapping is gathered through combined direct observation, interviews and video recording of the material supply activities. It is preferable to have uninterrupted video recording of the entire material flow wherever possible and so as to provide timestamp of all the associated activities. These collected data are compiled to create a schematic view of the flow. Then, this video footage is analyzed to describe the processes and derive the material flow map. After having mapped the material flow, analysis of the MFM is performed to denominate the handling, administration, transportation and storage. Summarize the HATS data such as the number of activities, total timing for the categories and averages. With this analysis as a base, a future state is arrived at with material supply activities that better supports value adding activities when compared to using VSM.

2.3 Production Systems

Production system is termed as the management of the flow of materials through the value stream, from the acquisition of raw material to the delivery of finished goods to the customer. Production control systems typically addresses the question of when and how much to produce in order to achieve satisfactory customer service level by having appropriate WIP inventories in various stages of the value stream (Jonsson & Mattsson, 2009). Production control systems in any manufacturing environment can be classified into push-type systems and pull-type systems. The main distinction between push and pull system is based on how the productions orders released to the work station in response to the demand.

2.3.1 Push Production System

Production control strategies that push products through the system based on estimates of forecasted demand are classified as Push-type production system. It is assumed that advanced demand information is available in the form actual customer orders, or forecasts or combination of both. This system is commonly defined as those types of material requirement planning (MRP) systems that utilizes bill of material (BOM) data, inventory data and master production schedule (MPS) data to calculate the net requirements for dependant demand items. The computational and tracking benefits of the computer systems employed by the MRP are used to calculate these demands. In this system, orders are backwards scheduled on the shop floor for completion by specific due dates, based on estimated lead times. MRP assumes infinite capacity as no consideration is given to used and available resources capacity in generating the planed manufacturing orders (Jonsson & Mattsson, 2009).

MRP system that operates with major proportion of forecasted demand tend to maximize the throughput of the system so as to minimize shortage in supply and tend to result in excess work-in-progress (WIP) inventory that masks flaws in the system. This type of push system is best suited for manufacturing environments that produce a number of different products with distinct demands and/or processing requirements, as well as for facilities that makes custom made products in small batches to their customers (Gelders & Van Wassenhove, 1985), (Krishnamurthy, 2004).

2.3.2 Pull Production System

Production control strategies that pull products through the system based on actual customer demands as opposed to forecasted demands are classified as Pull-type production system. In a typical pull system, each station in a product flow acts as a customer to upstream station and acts as a supplier to the downstream station. Pull type systems are based on just-in-time (JIT) philosophy that aims to keep inventory holding costs low by making product in direct response to customer orders only. Typical example of pull system is kanban method, where fixed stock is held for every item and signal for production or material movement is sent to the upstream process for the immediate replacement of any item that are consumed from the stock. Short setup times, small batch production, flow layout, leveled production and stable processes are pre-requisites for a pull system to work effectively (Liker, 2004), (Monden, 1983), (Jonsson & Mattsson, 2009).

This pull system levels the production load by eliminating waste in the production processes by providing right parts at the right place and at the right time. Such systems tend to minimize WIP inventory and expose flaws in the system at the risk of failure to satisfy the demands (Geraghty & Heavey, 2005), for instance, in case of one-piece continuous flow production. This pull system works well in manufacturing environment producing repetitive products with high and stable demands (Krishnamurthy, 2004), (Gelders & Van Wassenhove, 1985).

2.3.3 Hybrid Production System

It is clear from the above literature review that MRP-push system is concerned with planning of production while kanban-pull, on the other hand, is almost exclusively an execution system. Both efficient planning and execution of the manufacturing orders are required to make parts flow through the value stream in such a way that it results in highest quality, lowest cost and shortest delivery lead time.

There have been numerous reported cases of successful implementations of both approaches; however, they still have weaknesses. Pun (1998) states that pull systems lack forward visibility of materials requirements and MRP systems are incapable of solving excess inventory problems in the form of semi-finished and finished goods. In line with this argument, Betz (1996) decribe that push systems are often better at planning than they are at working. At the point of actual production, the execution methodologies such as pull systems are often better utilized. MRP system can also lead to dysfunctional behavior in the presence of inaccurate advanced demand information (Krishnamurthy, 2004).

Pull system has potential drawbacks in case of a value stream consisting of batch processing operations, for example, cleaning, painting etc. and produces multiple product families. Traditional kanban-pull system needs that a minimum inventory of each product be maintained at the outbound buffer of each workstation and replenishment takes place in response to the withdrawal of parts from that buffer. In such scenarios, the replenishment of consumed finished goods takes place well in advance of their needs (Krishnamurthy, 2004). Pull system may not work well in a manufacturing environment with moderate to high demand fluctuation. This may in turn create significant back orders as there will not be enough semi-finished goods inventory. And, also pull system tend to have longer delivery lead time than push system (Ghrayeb, 2009).

Moreover, now-a-days many manufacturing companies are working in a hybrid manufacturing setting (i.e. repetitive with moderate product variety and demand fluctuation production) where the use of a push or a pull system solely is not feasible (Olhager & Östlund, 1990), (Pun, 1998). So, it might be efficient for companies to have both the push (in places where products are diverse and have accurate advanced demand information) and pull (in places where demands is high and stable) systems in their facility.

Many articles also stated that companies already using MRP-based systems, have implemented JIT concepts in their MRP systems to utilize best features of both the systems. So, there is an obvious case for a harmonious integration between push and pull systems that combines elements of the two philosophies in order to minimize inventory and unmask flaws in the system while maintaining the ability of the system to satisfy demand. Such an integration of these two systems helps to address the complex and volatile needs of industry.

Gelders & Van Wassenhove (1985) describes the effect of capacity constraints on the performance of MRP-push and Kanban-pull systems and concludes that hybrid production system can work well if there exists some flexibility in capacity for medium term as both the systems are not capable of tackling tight capacity constraints.

This hybrid production control system can be classified into two categories as follows:

a) Vertically Integrated Hybrid Production Systems (VIHPS) – This production system consist of two levels, usually MRP-push system at planning level (upper level) and Kanban-pull system at execution level (lower level) (Pun, 1998), (Titone, 1994). The problem with this system is that MRP calculations have to be done at each stage in the production system, resulting in relative lack of use in industries (Geraghty & Heavey, 2005).
b) Horizontally Integrated Hybrid Production Systems (HIHPS) – This production system consist of one level, where some production stages are controlled by push system and the others are controlled by pull system. HIHPS concerns with local manufacturing operations rather than on extended supply chain and it is practically feasible and easy to implement this system when compared to the VIHPS (Geraghty & Heavey, 2005).

Olhager & Östlund (1990) describe how push and pull systems can be combined to form an effective hybrid production control system (HIHPS). Three variants of HIHPS are being proposed with respect to i) customer order point, ii) bottleneck resources and iii) the product structure. Case study is conducted in a medium sized company for these three approaches and results indicate significant decrease in cycle time and inventory and considerable increase in sales turnover.

In (Hodgson & Wang, 1991a and 1991b), Markov Decision Process (MDP) model for HIHPS was developed and proposed an optimal strategy for a general multistage serial/parallel production system to use a push strategy in all initial stages of the system and pull strategy for all other downstream stages. The control and information structure of this hybrid system is decentralized control with a centralized coordinator.

Wang & Xu (1997) compared the pure pull and pure push systems against the optimal hybrid strategy proposed in (Hodgson & Wang, 1991b), where the initial stages push and all other stages pull. Their results suggest that the optimal hybrid system out-performs pure push or pure pull strategies. Similar result is found in observed of comparison of HIHPS with pure pull system in (Geraghty & Heavey, 2005).

Cochran & Kim (1998) presents a HIHPS with a movable junction point between a push sub-system and a pull sub-system. The objective function of their model is to minimize the cost of the integrated hybrid manufacturing system and their solutions include three decision variables: (i) the junction point, i.e., the last push stage in the HIHPS; (ii) the safety stock level at the junction point; (iii) the number of kanbans for each stage in the pull sub-system. The trade-off between delivery lead time costs and inventory holding costs are to be resolved using simulated algorithm. This model was applied in a case company and found to save total late cost and inventory cost when compared to pure push approach.

Beamon & Bermudo (2000) suggest a hybrid push/pull algorithm to reduce inventory costs and at the same time, maintain a high customer service level. The algorithm developed is for a multi-line, multi-stage assembly-type production system. The push philosophy is applied for initial stages of material flow and the later stages employ pull system. Based on their study, the results are in favor of the hybrid production system.

Ghrayeb (2009) investigates hybrid push-pull production system of an assemble-to-order environment, where junction point is well defined. In this scenario, push system is employed till the raw material is transformed to common semi-finished products and further downstream operations are dictated by customer orders (pull system). Article concludes that hybrid system often compromises the conflicting performance characteristics of the push and the pull environments. The objective function for the presented hybrid model is to minimize the sum of inventory holding cost and delivery lead time cost. A discrete event simulation model is used to evaluate the objective function.

All the previous research works done shows that hybrid push-pull system performs better in most of the manufacturing environments when compared to the traditional pure push or pull system. Summary of various researchers on hybrid production system (HIHPS) is shown in Table 1. This thesis work also aims to address how this HIHPS can be implemented in an assemble-to-order environment with due consideration of practicalities.

Table 1: Summary of various researches on HIHPS

References	Article Description	Measurements	Article Type	Discussion
Gelders & Van Wassenhove (1985)	Describes the Effect of capacity constraints on system performance		Review	Hybrid push-pull system can work good under no capacity constraints situation
Geraghty & Heavey (2005)	Compares the performance of various	Service level vs. WIP tradeoff	Review	HIHPS performs better than pure pull systems

	combined pull type and hybrid production control strategies			in non-repetitive production environment
Olhager & Östlund (1990)	Illustrates three variants of HIHPS based on i) customer order point, ii) bottleneck resources & iii) product structure	Delivery dependability and production flexibility	Case study	HIHPS results in reduced WIP, increased dependability and flexibility
Hodgson & Wang (1991a & 1991b)	Presents Markov Decision Process (MDP) for parallel multi stage serial/parallel production in HIHPS environment	Total cost including inventory carrying cost and shortage cost	Simulation	Optimization model suggests to use to use a push strategy in all initial stages of the system and pull strategy for all other downstream stages
Wang & Xu (1997)	Presents a simulation software for MDP model proposed by (Dingwei Wang, 1991b) under mass production scenario	Average running cost, total inventory, shortage probability	Simulation & case study	HIHPS performs better than pure pull systems for repetitive environment, where initial stages use push and later stages use pull system
Cochran & Kim (1998)	Proposes optimization model and optimization algorithm for HIHPS with movable junction point between push and pull sub-system	delivery lead time cost and inventory holding cost tradeoff	Simulation & case study	Proposed model determines where to put the junction point, safety stock level and number of kanbans in pull stations
Beamon & Bermudo (2000)	Presents algorithm for HIHPS under multi-line, multi-stage assembly-type production system	Inventory cost and service level	Simulation	Results are in favor of HIHPS, where initial stages use push and later stages use pull system
Ghrayeb (2009)	Investigates HIHPS in an assemble-to-order environment where junction point is well defined	Inventory holding cost and delivery lead time cost	Simulation	Article concludes that hybrid system works better than pure push or pull system

2.4 Performance Measurement

Performance measurement is a process of collecting and reporting the performance of products, services or process. This process helps to understand, manage and improve the performance of a system that is under measurement. Outcome of this measurement process will be quantitative in nature and helps to understand i) how well the system behaves or how efficient the flow is (Finnsgård, 2011), ii) the percentage of value adding and non-value adding activities.

Most of the above stated articles use either a conceptual decision model or simulation model to measure and evaluate the performance of their various production systems and the performance measurements used by them are,

WIP inventory - it is a measure of in-process inventory that exists at various stages in material flow. This WIP inventory can be expressed as number of units or in terms of monetary units.

Service level – it is a percentage of downstream operation(s) that do not experience a stock out.

Delivery lead-time – it is a time that elapses between downstream processes in a material flow places an order for an item and the time that process receives them.

HATS analysis – This is a measure of material supply activities such as Handling, Administration, Transport, and Storage. From the mapping methodologies it will be easy to measure no. of such activities and its lead times in analyzing the complete flow of processes.

2.5 Making Materials Flow

In the recent years, it is witnessed that many companies have started their journey towards creating lean flow in their operations as the companies hear more about value stream mapping and understand the power of creating lean flows. However, it is often seen that the company struggles hard to sustain the steady output in their lean journey. The problem is due to the lack of lean material handling system to support the value adding process. Many firms that have leaned their value adding process are still mass producers from the material supply system perspective (Harris, 2003). This result in

- More search time for operators doing value adding process
- Total inventory in the value stream is more than necessary
- Many forklift movements to transport the pallet load of material downstream the flow, thus leading to safety hazards
- Cost of expediting the missing parts are high

Harris (2003) explains this problem in biological context that `the individual cells were now healthy, but the circulatory system was causing the whole organism to feel sick´. The lean material handling system can be established by following the below described steps in the chronological order. This thesis work considers establishing lean material flow system between subassembly and assembly operation, so the following text is written with respect to this particular environment in order provide better understanding for the readers.

Selection of product families:

Choose product families between value adding processes for which the lean material handling system has to be established. A product family is a group of products that goes through similar processing steps and over common equipment or machine in a value stream. Care is to be taken to choose the manageable number of families for efficient conducting of the lean material handling system implementation.

The Plan for every part:

This step involves collecting all relevant information of the product families in one place (usually in a spreadsheet), thus making the information regarding the whole flow visible. Gather the most common categories of parts information that is in use for daily operation in the company. For example, point(s) of use, rate of usage, container type, standard container quantity, production hours / day, etc. Using this sheet gives the company two advantages: First, it is easy to sort the data based on different categories and second, it is possible to update the sheet with minimal effort. Once all the necessary information in the sheet is filled, it must be maintained or updated regularly to avoid deterioration of data accuracy. Creating this sheet enables the company to increase the percentage of value adding activities (Harris, 2003).

Develop a semi-finished goods supermarket:

Next step is to establish a supermarket in a single location to hold a controlled level of inventory for the product families. As implementation proceeds, company can expand the market for other product families, so location of supermarket has to be chosen by taking this into account. Place the supermarket near the refilling subassembly work station(s) to optimize the material handling and to have better visibility of the available inventory. Clearly demarcate the refilling and withdrawal areas in the market to avoid ambiguity between the material handling operators and place the withdrawal side along the aisle to minimize the handling operation time (Baudin, 2004). Note that each subassembly stations can also have a dedicated rack for itself instead of central supermarket, thereby avoiding the need for extra material handling from subassembly stations to the central supermarket at the expense of little extra distance that is to be covered by the milk run trains.

Planned maximum inventory levels:

Company can calculate the maximum inventory levels for each part in the chosen product families.
If subassembly operation uses pull system to replenish the supermarket, then maximum inventory can be calculated as below:

$$\begin{aligned}\boldsymbol{Planned\ maximum\ inventory\ level} \\ &= \boldsymbol{Minimum\ order\ qty\ (reorder\ point)} \\ &+ \boldsymbol{Replenishment\ qty\ (reorder\ quantity)}\end{aligned}$$

So, reorder point (ROP) and reorder quantity (ROQ) can be computed using the formula below:

$$\boldsymbol{Reorder\ point\ =\ Demand\ during\ replenishment\ lead\ time\ +\ Safety\ stock}$$

$$\boldsymbol{Reorder\ quantity\ =\ Demand\ during\ replenishment\ lead\ time}$$

Else, if subassembly operation uses push system to replenish the supermarket, then maximum inventory shall be calculated as below:

$$\boldsymbol{Planned\ maximum\ inventory\ level\ =\ X\ *\ Daily\ usage + Safety\ stock}$$

Company can go for factor value X depending on the responsiveness of the immediate upstream operation. Choose low factor value if the process is highly responsive and vice versa. For both the above cases, choose a suitable safety stock value to hedge against the demand fluctuation. Now, it is possible to calculate the space required to store these parts in the market based on the size of the emballages corresponding to each part.

Operation of supermarket:

Company can choose to use gravity flow rack to accommodate the semi-finished parts as it offers numerous advantages. The advantages are: flow racks are accessible from either side, i.e., refilling and withdrawal can be done simultaneously, it has good visibility, helps to have controlled inventory of parts, good from ergonomic view point. Parts that are too heavy or too big in size to fit in a flow rack can be sequenced or delivered directly in a pallet to the immediate downstream process. Then, develop a formal address system for storage locations in the market so that it would be easy for storing and retrieving parts from the market. When a part numbers requires several locations in the rack then it is important to maintain FIFO of parts by attaching a small tag or small sign to the location that is currently in use. Put in place procedures for reacting to inventories that go beyond the maximum planned inventory levels (Harris, 2003).

Design of delivery route:

After having established the supermarket, it is now time to design the delivery route to carry the parts from the market to the downstream operation. Delivery route will consist of delivery stops, point of use delivery points for each part and quantities of parts to be delivered. Delivery routes can be designed efficiently by accomplishing the four following steps:

- Identify naturally occurring aisle in the plant and establish two-way or one-way aisle depending on conveyance vehicle dimensions.
- With the aisles in place, the company can then choose to use tugger train to deliver parts to the assembly operations by carrying the mixed load of parts. The advantages of using tugger train are: it can serve multiple locations in a single trip by carrying mixed load, less expensive and more safe when compared to forklift, and minimizes the material handling cost.
- Determine the delivery stops and delivery points. Delivery stops can be chosen such a way that multiple delivery points are served at a stop.
- Establish the point of use racks at delivery points. Size of the rack depends on the number of hour's worth of parts to be stored in that rack. It is actually a trade-off between material handling cost, space constraints at the delivery point and WIP holding cost. Generally, companies use twice or thrice delivery route volume of any given part plus one additional container of that part (Harris, 2003).

Choice of pull signals:

The goal of lean material handling system is to get the production areas exactly the amount of parts needed exactly when needed. Implementing pull system that enables the downstream operations to pull only the material it needs from the immediate upstream operation. There are many variants of pull signals, for example, Andon signals, empty bin containers, physical kanban card, barcode signals etc. to signal the upstream chain for material movement or production. Companies should choose the appropriate pull signal variant based on factors like number of product variants, parts demand, physical configuration of the parts and proximity between preceding and successive operations (Harris, 2003).

After having finalized the pull signal variant, now it becomes necessary to determine how frequent to deliver parts to the downstream operation. The more frequent the deliveries, less inventory there will be in the system and the more responsive the system will be to changes in the demands but results in increased material handling cost. Delivery frequency is a tradeoff between the most efficient use of the material handling resources (the filling degree for both the personnel and the milk run train each trip) and the WIP inventory cost. In a coupled delivery route, the material handling operator will deliver the materials and picks the pull signals and empty containers at the downstream operation and then the same operator will pick the materials corresponding to the pull signals and loads on the cart. The route operator will begin the cycle again and deliver the material.

Then the company can proceed ahead to calculate the number of pull signals for each part. This calculation is rather simple once anyone can able to visualize what is happening. Number of pull signals is calculated based on number of hour’s worth of parts to be stored in the point of use rack at the downstream operation and the delivery frequency.

After having i) finalized the pull signal method, ii) designed the delivery route, iii) determined the delivery frequency and iv) determined the number of pull signals in the loop, it becomes necessary to fill the delivery route. This can be done by establishing the delivery of materials for the chosen product family and then determine the both value adding time of material handling personnel and filling degree of milk run train.

With the aid of filling degree information, the company can expand this lean material handling system to other product families (by using the above described steps) to achieve the good filling degree for both the personnel and the milk run cart.

2.6 Activity-Based Costing

Activity-Based Costing (ABC) helps companies to trace accurately the direct and indirect costs to products according to the activities performed on them. The fundamental idea behind ABC is that cost should be allocated to the activity that consumes a resource, so ABC traces the appropriate resources which it requires for each activity and map out those activities to a particular cost object. Pohlen & La Londe (1994) states that

′′ABC is a methodology that measures the cost and performance of activities, resources and cost objects. Resources are assigned to activities, then activities are assigned to cost objects based on their use. ABC recognizes the casual relationships of cost drivers to activities.′′

This approach of ABC enables to determine the product cost by summing up the costs of activities required to manufacture a product. According to (Popesko, 2010), ABC assumes the following steps:

I. Identify major activities in an organization: The first step is to understand and classify the various organizational processes and then to break down those processes into activities and tasks.

II. Assigning costs to cost pools for each activity: Determine the resources consumed by each activity at the outset. Having identified the appropriate resource consumptions by each activity, now it is possible to assign costs to cost pools for each activity. Generally, resources are grouped to material, labor, facilities, equipment, and capital.

III. Determine cost driver for each activity: In ABC; an activity may have one or more cost drivers, but the most pertinent one have to be used. Cost driver is a factor that influences or causes costs for a particular activity.

IV. Assess total cost: Having determined the cost driver, now it is possible to calculate the total cost by summing up the used amount of the cost driver in accomplishing that activity by unit cost of the driver.

Some of the major advantages of using ABC are: (I) it helps to make better management decisions as it provides more accurate product costs and this in turn enables to achieve desired product profitability levels; (II) it helps to identify and eliminate non-profit products from the company's product ranges; (III) it exposes waste and inefficiencies in the system that contributes to poor production; (IV) it provides quantifiable figures for planning and estimates (Nayab & Scheid, 2012).

Despite the fact that ABC is more accurate than traditional cost accounting techniques in allocating indirect / overhead costs, it does also have few drawbacks: it demands large amount of accurate financial and non-financial in-data; implementing ABC is complex, time consuming and costly; demands significant running and maintenance efforts (Nayab & Scheid, 2012).

2.7 Benefit-Cost Analysis

Benefit-Cost Analysis (BCA) is used to determine whether the favorable results of an alternative are sufficient to justify the cost of taking that alternative (Linn, 2011). This type of financial appraisal of project proposals will consider the potential rewards of carrying out a project against the predicted costs. In these economic times, this BCA can be effectively utilized in appraisal of broad spectrum of projects that demands varying degree of capital expenditures as a penny saved is a penny gained. This tool gives comprehensive set of information in monetary terms that helps in effective decision making. This approach requires following steps (Freivalds, 2009):

- Determine the benefits of implementing a project
- Quantify these benefits into monetary units.
- Determine the cost of implementing these changes
- Divide benefit by the cost to obtain a ratio
- The largest ratio is determines the desired alternative

Especially, the second and third steps seem to be challenging as it depends on the time span over which the costs and benefits are going to be spread.

2.8 Framework Summary

The theoretical framework used in this thesis work is summarized schematically in figure 4. The input to the model is the production system, hybrid mapping tool, recording of processes and requirements.

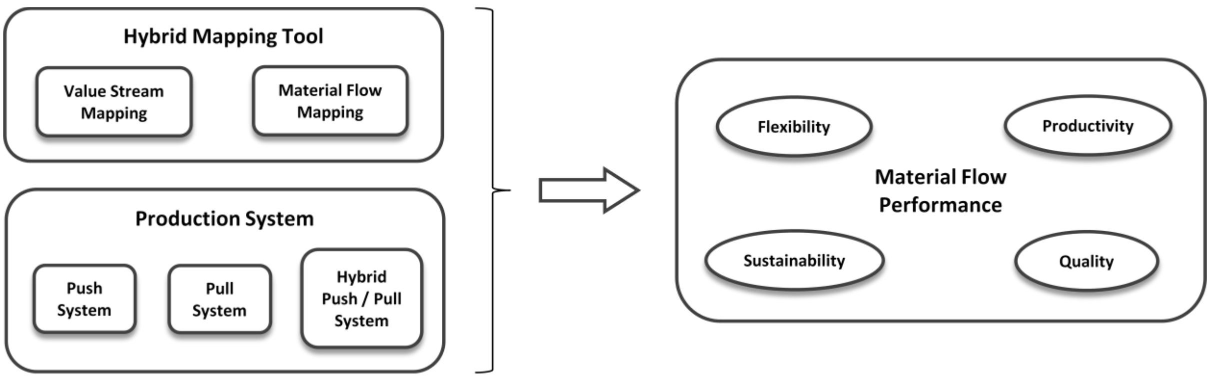


Figure 4: Summary of the theoretical framework

General performance objectives of a system are quality, flexibility, dependability, speed and cost Slack & Lewis, 2008). These objectives are to be adapted to suit the material flows. Dependability and quality is aggregated into quality, as dependability is often a quality dimension (Finnsgård, 2011). Cost and speed are often dependent on each other in the material flows so they are collectively termed as productivity. Sustainability has emerged as an important performance indicator as it emphasizes on environmental dimension (Finnsgård, 2011). So, the output can be aggregated into the resulting variables describing materials flow performance: flexibility, productivity, quality and sustainability.

3. Methodology

This chapter presents the structure of study used in this thesis work. Plan-Do-Check-Act, also known as Deming cycle has two interpretations. First interpretation is that it can be used for all types of processes, where a work is planned first, work is performed, the result is studied and appropriate actions are taken to improve the process. Second interpretation is that it can be applied for a process that is in need of an improvement (Bergman & Klefsjö, 2010). The former interpretation is used as working structure for carrying out this project work. Figure 1 shows the general outline of the methodology used in this thesis work by clearly depicting the various phases of the PDCA cycle. Subsequent sections in this chapter briefly describe these various phases undertaken during this project. And then this chapter is concluded with an overall assessment of the validity and reliability of the chosen methodology.

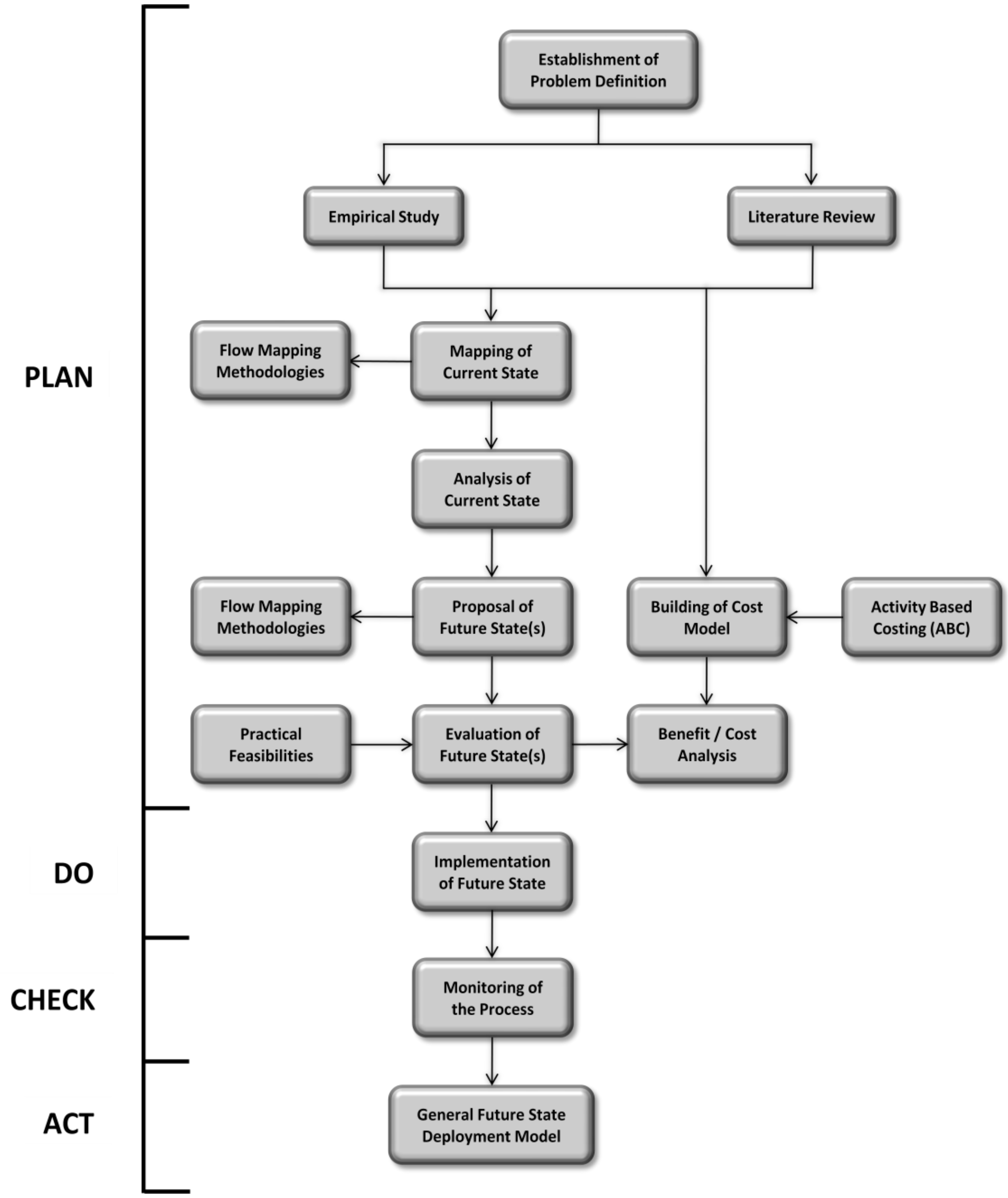


Figure 5: General outline of the methodology used in this thesis work

3.1 Research Approach

There are two types of research approaches that are widely used by researchers for their study work. One is deductive approach and the other is inductive approach. The type of research approach is determined based on purpose and nature of problem under investigation in a research work (Yin, 2003). The inductive approach was used for this project work. This project work started with extensive data collection and then a generic and broader theory or conclusion is arrived at based on the analysis of collected data. In this context, the inductive research approach is found to be more appropriate than deductive approach as suggested by (Saunders, 2009)

3.2 Establishment of Problem Definition & Purpose

In this initial phase, the aim was to clarify the problem's true nature from the outset. To understand the overall work mechanism of various product flows, an onsite observation was carried out from the material receiving area to the final assembly line in the plant. After that, discussion was made with key personnel from various departments to understand their perspective and the problem that exists in the prevailing material flows. Both the onsite observation and inputs from company representatives helped to define the purpose and objective of this project. The purpose and the objective described in the Introduction section facilitated to gain focus on the project and provided a good starting point for the project to progress with.

3.3 Data Collection

There are two ways of collecting data, one is primary and other is secondary. Primary data are collected at first that will be useful for the research work being carried out. The data were usually collected though direct observation, interviews, time studies and experiments. Such collected data are documented for analysis purpose during the later stages of the research work. Secondary data are the one that are available already, for example, journal articles, textbooks, internet, and database. Both primary and secondary data were utilized for fulfilling the objectives of this thesis work effectively. The following sections in this chapter describes the methods employed to gather these primary and secondary data

3.3.1 Literature Review

An exhaustive review of available literature is of great importance to gather the relevant information pertaining to any problem. With a literature review, a broad information search of other researcher's work on the same or closely related problem was performed. This helped to identify the solution that already exists for the problem and to adapt this solution to a particular manufacturing setting or work environment. Thorough literature review was performed with due consideration of both industry and academic perspective in order to fulfill their respective prerequisites.

Search phrase strategy was used in summon at Chalmers Library to gather information relevant to this project. Materials gathered may be of the form electronic journal articles, textbooks etc. At last, Volvo PT has also provided information important for the understanding of the current situation within the company and their way of working.

The study started with searching different theory of referrers in the field of hybrid push/pull production system, lean production, and lean logistics. All information gathered was analyzed carefully by comparing the relevance of the same to the subject of thesis work. After reading through all the relevant literatures, conclusions were drawn from the interpretations of what had been said.

3.3.2 Empirical Study

An empirical study was conducted to accomplish two major goals. First, was to understand the different material flow patterns that exists between subassembly shop and assembly lines and then to identify the inefficiencies present with the current system. Second, was to develop or get ideas to solve the identified problems and how these ideas can be effectively inculcated into the current system. The empirical study was carried out for two product families: Slang product family comprising of 55 parts and Start Element product family comprising of 5 parts. This study was done through different methods: direct observation, Interviews, time study, & data from computer system and each aspect are detailed below.

Direct Observation: This project utilized 'go and see for yourself' approach for collecting data pertaining to different product flow patterns and this was done with the help of company personnel from logistics and manufacturing departments wherever necessary. Data acquired though this method was both qualitative and quantitative in nature. This method of data collection helped to see and understand

- overall working mechanism of different flow patterns
- routines of the company
- physical material flow information of each component, for example, emballage type, number of emballage in a pallet etc.
- standard operating procedures of value adding activities

Interviews: This is a qualitative data collection method where key representatives from various departments were interviewed to get the information that was unable to be captured through direct observation, especially, inputs with regards to the information flow in the various flow patterns. Typically, interviews were conducted with shop floor operators, logistics personnel, planning engineers, production technician, team leaders of subassembly work station etc. The interviews carried out in this project were semi structured as this gives freedom for the interviewee to adjust the interview to the prevailing circumstances as it proceeds without missing any important information. See Appendix 1 for the list of Volvo PT personnel who were interviewed during the project process.

Time Study: Time study is a direct and continuous observation of any activity by using digital stop watch to record the time it takes to accomplish that activity. The main objective of time study is to determine and establish the dependable time standards for efficient operations management. During this project, the activity time for any activity was determined through conducting time studies three to four times at different time intervals and then averaging out these obtained values for that activity.

Data from MRP system: Few quantitative data that were unable to be captured through either of the above mentioned methods were obtained from MRP system at Volvo PT with the help of company personnel. For instance, maximum inventory level at available buffers in the material flow, reorder point, reorder quantity, inventory level at high bay storage etc.

3.4 Current State Mapping

Value stream mapping (VSM) methodology helps to identify various non value added activities that are in the product flow thus serving as an apt tool for this research work. Given the nature of task at hand, the considered product flows between subassembly shop and the assembly line have more of transportation and handling activities. These types of activities are not emphasized in the VSM methodology, as they are considered insignificant. Due to this fact, there is a need for another supplementary tool where these activities are captured. So, a complementary tool, called material flow mapping (MFM) was used along with this VSM in a synergistic manner to meet the requirements of the project. As the fundamental ideas behind these two methodologies are similar, it was quite easy to integrate them and use as a theoretical basis for this project. Integration is done by adding vital MFM elements into VSM concept and simultaneously decreasing the level of detail of the MFM analysis. So, this resulted in a concept called hybrid mapping methodology that captures both the value adding processes and the material supply processes in the flow and helps to achieve better correspondence between the two. Data required for this hybrid mapping are collected using the above stated data collection methods with the aid of standard data collection template (see Appendix 2). See Appendix 3 for various symbols used during the mapping of current state and their descriptions. This structured way of compiling data collected through various means helped to see the whole picture of various product flows between subassembly shop and final assembly lines.

3.5 Analysis

Having acquired the inputs regarding how the information flow and material flow occurs in the current state, it was possible to critically analyze the various processes. As each activity was mapped separately, for instance, handling, administration etc., it was easily possible to identify the inefficiencies inherent in each of those activities. Here each activity was analyzed with respect to their existence and potential improvements that can be achieved, thus reducing the total lead time.

3.6 Future State Proposals

Based on the analysis of current state, future state proposals was arrived at considering the following key aspects

- Placing of flow rack
- Locations in flow rack
- Production quantity
- Production trigger
- Material transport trigger

All the above aspects for each of the proposals was discussed in detail in a common forum where subassembly operators, team leaders, production engineer and logistics personnel were present in order to get consensus across all departments.

3.7 Future State Evaluation

The proposed future states was validated based on the practical feasibilities, for example, layout at the subassembly station, IT considerations, space constraints, material handling route etc. Further, the future states were evaluated based on two of the following parameters.

- **Performance Measurements:** The future states was compared with the corresponding current state and then benefits were evaluated in terms of the performance measures like lead time, handling, transportation etc.
- **Benefit-cost Analysis:** In order to get consent from company's management for implementation of any improvement project, it becomes necessary to translate the benefits incurred into monetary terms. So, the benefit-cost analysis was performed by developing a cost model to get Volvo PT's management support for conducting of this project work.

3.8 Validity & Reliability

Validity and reliability are very essential and basic characteristics for any measurements made in a research work. Validity has no single agreed definition and it generally concerns the accuracy of measurement methods used in a research work. Validity is the degree to which a measurement method what it claims to measure. Often, it is seen that validity is assessed along with reliability. Reliability refers to the degree to which a measurement gives consistent and recurring results (Bell & Bryman, 2011).

Some of the measures presented by Bell & Bryman (2011) were used to assess the validity and reliability of the work presented in this thesis work. To be more precise, four aspects of validity and one of reliability were chosen for use in this work. Four aspects of validity considered are construct validity, internal validity, external validity and ecological validity. Construct validity is concerned with the question of whether a measure used (developed from a theory) actually measures the concept of interest (Bell & Bryman, 2011). Internal validity is concerned with how far the findings of this research work are believable or trustworthy with regards to causality (Bell & Bryman, 2011). External validity is concerned with the extent to which results from a study can be validly generalized beyond its particular context (Bell & Bryman, 2011). Ecological validity is concerned with the extent to which research results can be applied to real life situations outside the research settings (Bell & Bryman, 2011). Reliability is concerned with the extent to which findings from a study are can be replicated using the same method all over again (Bell & Bryman, 2011).

For this research work, construct validity can be considered high as the focus is very clear and various flow performance measurements were used to fulfill the objectives of this study. Moreover, hybrid mapping methodology was used to quantify these performance measurements in both current and future state. Internal validity can be considered high with regards to the primary and secondary data collected because

- Most of the interviews were conducted with the shop floor operators, team leaders, production and industrial engineers who actually experience the shop floor operations firsthand and have much knowledge about the process.
- Onsite observation combined with personal interviews helped the researchers to witness the overall material flow mechanisms between subassembly shop and assembly lines so that misinterpretations are evaded.
- To have high reliable input data, most of the data collected though one mode was confirmed with the same or other mode. For example, personal interviews made with the operators were either confirmed with engineers from respective department or through onsite observation.

- Time studies were carried out three to four times for each activity at different time intervals and the average values were taken. Repacking time calculated / used in the cost model was based on the time study for a particular component and this time may vary slightly for other components, but this will not affect the accuracy of activity cost because of this slightest variation of the activity time.
- It was assumed that all the secondary data gathered through textbooks, journal articles etc. are reliable and truthful.

External validity can be considered to be medium to high. Even though the data collection and methodology used can be said to be biased towards Volvo PT, but the results from the study can be validly generalized beyond the particular scenario where the study was conducted to any manufacturing company where subassembly shop and assembly lines exists, especially the automotive companies. Ecological validity can be considered to be high for this project because this research work concerns about how the theoretical findings can be practically implemented in a particular industrial environment to improve the material flow. Also, other practical considerations such as work organization, ergonomics etc. was taken into account in this research work.

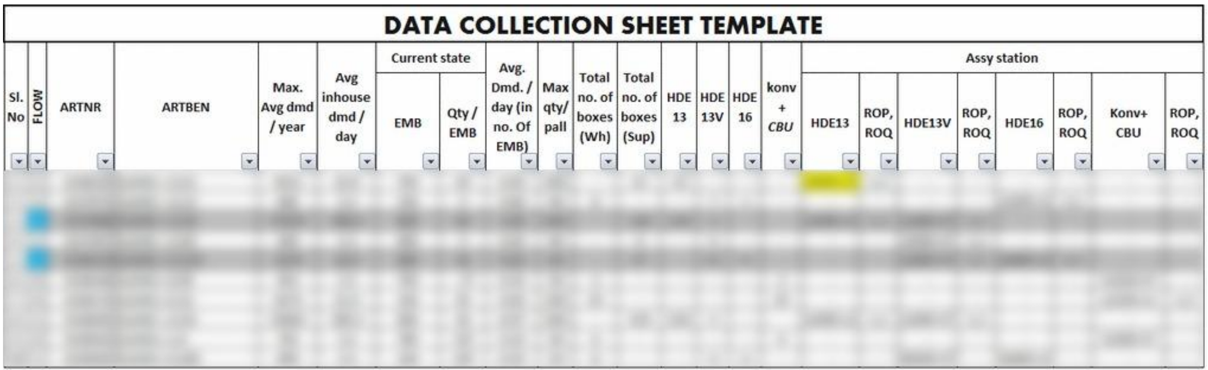
Reliability can be considered to be medium to high as the study was conducted in an environment where changes occur frequently due to highly diversified and competitive market. It is most likely possible to achieve same or similar results if this study is replicated in the same or different company with similar manufacturing setting. At last, the methodology employed in this project in itself uses universally agreed Deming’s PDCA cycle, which enhances the validity and reliability and thus enables to replicate the work at ease.

4. Current state description

As mentioned in the introduction chapter, the thesis will focus more on the flow of components from the subassembly station to the final assembly lines, though the current state map is done for the complete flow from raw material receiving area to final assembly lines. The data collection and physical and information flow of the current state maps will be explained in further in this chapter.

4.1 Data collection

In this project, current state mapping is done for 6 components; see Appendices, representing different flow patterns of two product families (consisting of 60 components). Since this involves 55 component varieties in Slang station and 5 component varieties in startelement, it was not possible to do VSM for all 60 component varieties instead it was grouped according to the flow pattern that the components follow and 6 patterns were arrived at that represents these 60 varieties. Though data was collected using the templates, see Appendix 1, for these 6 representative flows and VSM has been drawn, which is explained in the next chapter, it is also important to collect the data for all other product remaining varieties in the family. To do so it becomes necessary to create a certain spreadsheet template according to the requirement and contains necessary information about the products like demand per day, emballage type, quantity in an emballage, the assembly line(s) the component serves, assembly station number, etc. as shown in figure 6 below. Refer Appendix 4 for the complete template. This makes necessary information for all the component varieties available at one location and also easy to access because of the excel sheet.


DATA COLLECTION SHEET TEMPLATE

Sl. No	FLOW	ARTNR	ARTBEN	Max. Avg dmd / year	Avg inhouse dmd / day	Current state		Avg. Dmd. / day (in no. Of EMB)	Max qty/ pall	Total no. of boxes (Wh)	Total no. of boxes (Sup)	HDE 13	HDE 13V	HDE 16	konv + CBU	Assy station							
						EMB	Qty / EMB									HDE13	ROP, ROQ	HDE13V	ROP, ROQ	HDE16	ROP, ROQ	Konv+ CBU	ROP, ROQ

Figure 6: Data collection template

4.2 Physical and information flow description

Although current state maps of the two product families have been done separately by choosing representative flows, the flow pattern of components is almost the same. It could also be noted that the same component variety from the subassembly shop follows different flow patterns, since the same component variety sometimes is required at different assembly lines, so sometimes the same component variety will branch and flow to different assembly lines as shown in figure 2. The figure 2 below will show the overall view of the flow of components from subassembly shop to different final assembly lines for the two product families. These current state maps along with the performance measurements like handling, transportation, storage, value adding time for these 6 representative flows are calculated as in the Appendices. Both the information and physical flows will be explained in detail under each activity stages further in this chapter.

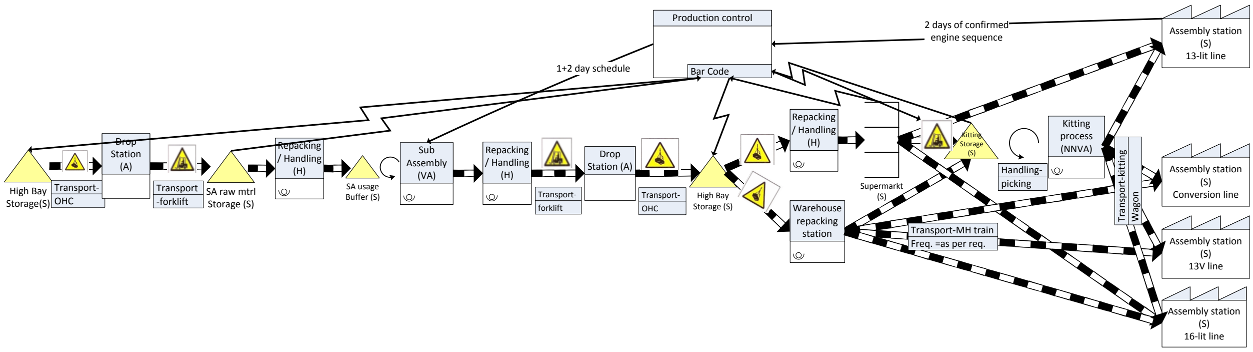


Figure 7: Overall view of components flow from subassembly shop to final assembly lines

4.2.1 Subassembly process

The subassembly shop has many subassembly processes depending upon the products that are being subassembled. In this project we are analyzing only two product families Slang and Startelement. The slang station processes around 55 different slang varieties. All these slang varieties uses different raw material coils that are received from the external suppliers in big pallets. These raw material pallets are not stored in the subassembly shop; instead they are stored in the High bay storage and ordered as per the requirement to the subassembly station through the overhead-conveyor system, which is the integrated with this high bay storage. Here there are two types of buffers storage buffer and usage buffer. Once the material used out in the storage buffer the operator at that particular station scans the barcode and the material is automatically triggered from the High bay storage. Once the material is received at the drop station through the conveyor system, they are then transported to the storage buffer through the forklift. These forklifts receive information regarding which station the material is to be transported, once the raw materials arrive at the drop station. These raw materials are then moved to the usage buffer area as and when required by the subassembly station operator through the stackers. These raw materials are then cut into small slangs as per the product specification. The slangs are cut as per the final assembly line demand (i.e. as per the daily need list received from the planning team, which contains the 3 days demand of the final assembly line). They are then packed into corresponding emballage. Finally these placed in the wooden pallets, so that they could be handled by the forklifts and the overhead-conveyor system. Normally the Slang subassembly station works one shift; they produce the assembly line demand three days ahead and store it in the high bay storage. Figure 3 shows the slang station consisting of an automatic cutting machine and manual cutting, wherein both has the usage buffer and output storage buffer except for the flow that they are in the opposite direction.

Figure 8: Slang station

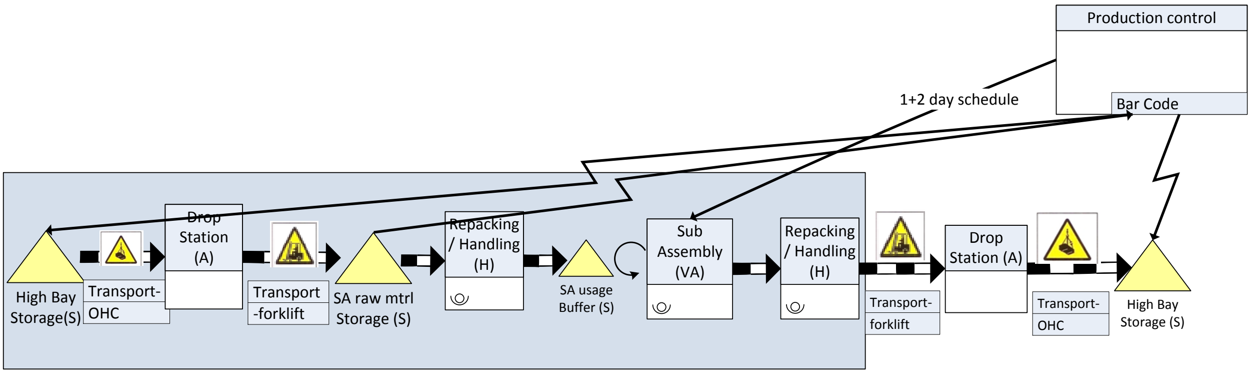


Figure 9: Flow highlighting subassembly process

The startelement family has 5 different component varieties. This product family also has the same flow like the slang family, except for the assembly process and few extra handling before and after the process. The raw materials are received in pallets, which are repacked/downsized into special type of emballages by the assembly personnel, after which they are assembled and tightened using screws unlike the slang family, where they are cut. These special emballages are used for handling of parts within the start element station (internal handling). This station has a testing process for these elements, which is integrated with the assembly process. After assembly they are repacked into corresponding emballages, which are then placed in wooden pallets for the ease of handling by forklift and overhead-conveyor system. The startelement station also subassembles components and sends it to high bay storage but they operate two shifts unlike slang station. Figure 5 shows the startelement station, its internal storage emballages and the output buffer.

Figure 10: Startelement station

4.2.2 Transportation and High bay storage

The transportation activity before the high bay storage can be divided into two parts: one is the transport by forklift and second is by overhead-conveyor system. The subassembled components that are packed in pallets at the subassembly station are transported to the drop station by forklift. Once the components are packed and labeled, the forklift operator gets the information on the system in forklift and the components are then transported to the drop station. There are two forklifts operating in the subassembly workshop and there will be extra one or two forklifts employed according to the requirement, so once the components are packed and scanned whichever forklift operator sees the information first will come and pick the components to the drop station. The next part of the transportation does not include any direct manpower, since the same overhead-conveyor system used to bring raw material pallets to the subassembly shop is used here. From the drop station the subassembled components pallet is transported to the high bay storage.

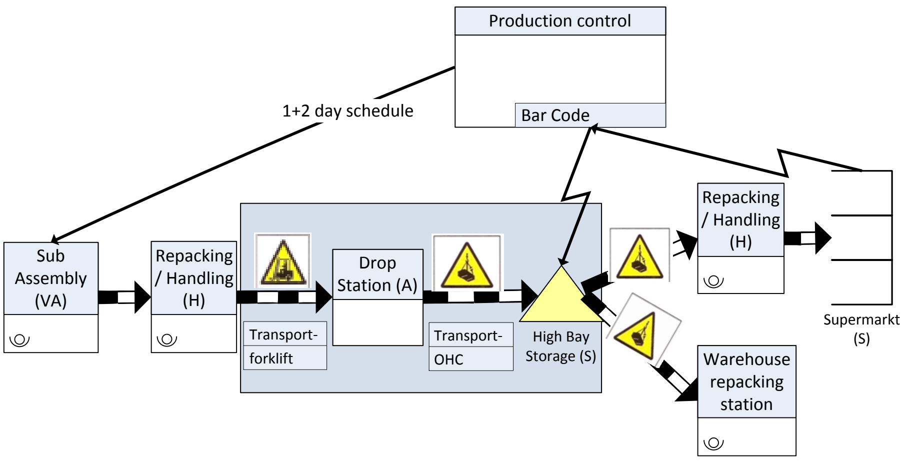


Figure 11: Flow highlighting the transport to high bay storage

The High bay storage is an Automatic Storage and Retrieval system (ASRS), where both the subassembled component pallets and raw material pallets are stored. Also other parts that are received from external suppliers are stored here and supplied to the final assembly line as and when required. There are 48 hooks in this integrated overhead-conveyor and high bay storage system, which serves the purpose of transporting pallets between the high bay storage and 6 drop stations that are available in the factory. There is one manpower in each shift to monitor the efficient working of the high bay storage and conveyor system. It takes almost 15 minutes for a pallet to be transferred from the subassembly station to the drop station and from there to the HBS, but this might vary depending on the conveyor traffic and the availability of the hooks to carry the pallets.

4.2.3 Repacking and Supermarket buffer

From the High bay storage materials are transported down to the supermarket area, where there are two persons working all shift to repack and handle components in supermarket buffer. There are few components that require repacking into different emballages because of the final assembly line requirement, while other components are directly handled from the high bay storage pallets into the supermarket buffer. Once the components in the supermarket buffer reach a certain re-order point, they are ordered to be brought down from the high bay storage. This order triggering from the High bay storage is done automatically, once the forklift operator picks the component (emballage) from the supermarket and to be transported to the assembly lines, the inbuilt system will check for the re-order point and trigger is made automatically. If the ordered pallet from the high bay storage has 8 emballages and the re-order quantity is only 6 emballage, then the remaining emballages with the pallet is sent back to the temporary storage shelves in the high bay storage, which are located near the nearer to the repacking stations so as to reduce the retrieval time of the components.

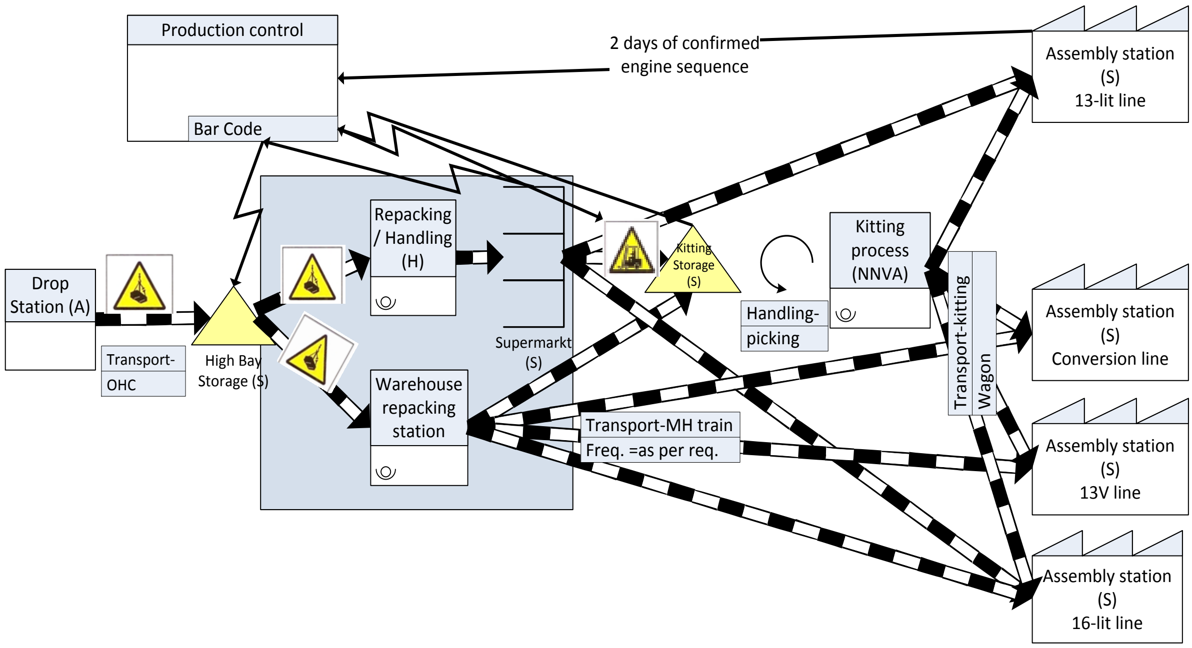


Figure 12: Flow highlighting the Supermarket & Warehouse repacking

4.2.4 Repacking station at Warehouse

The repacking station in the Warehouse does have the same flow (see figure 4) as the supermarket except for the components buffer. Components transported down to these packing stations from the high storage are repacked into respective emballages if needed and sent to the corresponding final assembly lines. If the ordered quantity that is brought down from the high bay storage racks is more than the required quantity, they are sent back to high bay storage racks unlike the supermarket repacking, where they are stored in a temporary storage shelves. There is a time schedule in the warehouse repacking station, when to replenish a particular assembly line. The material handling train operator goes to the corresponding assembly lines as per the schedule and scans the barcode of the empty bins to trigger the material. Thus the material is brought from the high storage down to the repacking station from where the material handling operator picks and delivers to the assembly line.

4.2.5 Transportation and kitting

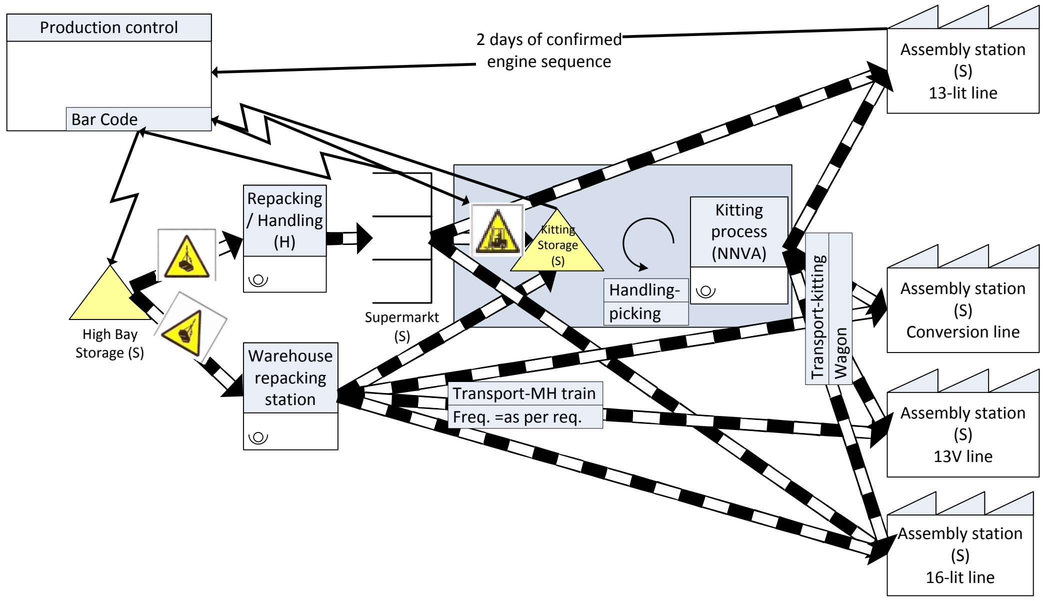


Figure 13: Flow highlighting kitting

Kitting of components is done in all the assembly lines - A few components in 13-lit line, few in 16-lit line, few in conversion line and almost all the components in 13V line. The 13V line has four kitting areas. Kit area 1, 2 & 3 are close to each other and the components are picked manually depending on the picking lists that are printed out by the picking operators themselves. Unlike the kit area 1, 2 & 3, Kit area 4 is separate and operates on 'pick by light' system. There is a separate kit area for 13-lit, 16-lit and conversion lines. These kitting buffers also has re-order point and re-order quantity, once this re-order point is reached the components are triggered and transported from either the supermarket or the warehouse repacking station. The transportation of components to these kitting areas could be divided into two parts: One is the transportation of components from the supermarket buffer, which is done by the milkrun trains. The components are triggered once the empty emballage barcode is scanned by the milkrun train operator; it is then transported to the kitting buffer. The other part is the transportation from the warehouse repacking station, but here the empty emballages are scanned as per the time schedule in the warehouse repacking station. The components are the then transported to the corresponding kitting buffer by milkrun trains or the ergomovers.

4.2.6 Transportation to assembly lines

This transportation of components to the assembly line follows one of these three flow patterns. First is the transportation of components or kits from the kitting areas to the respective final assembly station. Each picking operator prepares 3 kits at a time, serving either 3 assembly stations (1 kit for each station) or 1 assembly station (3 kits for 1 station). Frequency of delivery of kits to the assembly lines varies. For the 13V line it is a fixed interval, the kits are prepared and delivered every 10 minutes. For 13lit and 16-lit line, the kits are prepared and delivered based on the request or material trigger message received by picking operators.

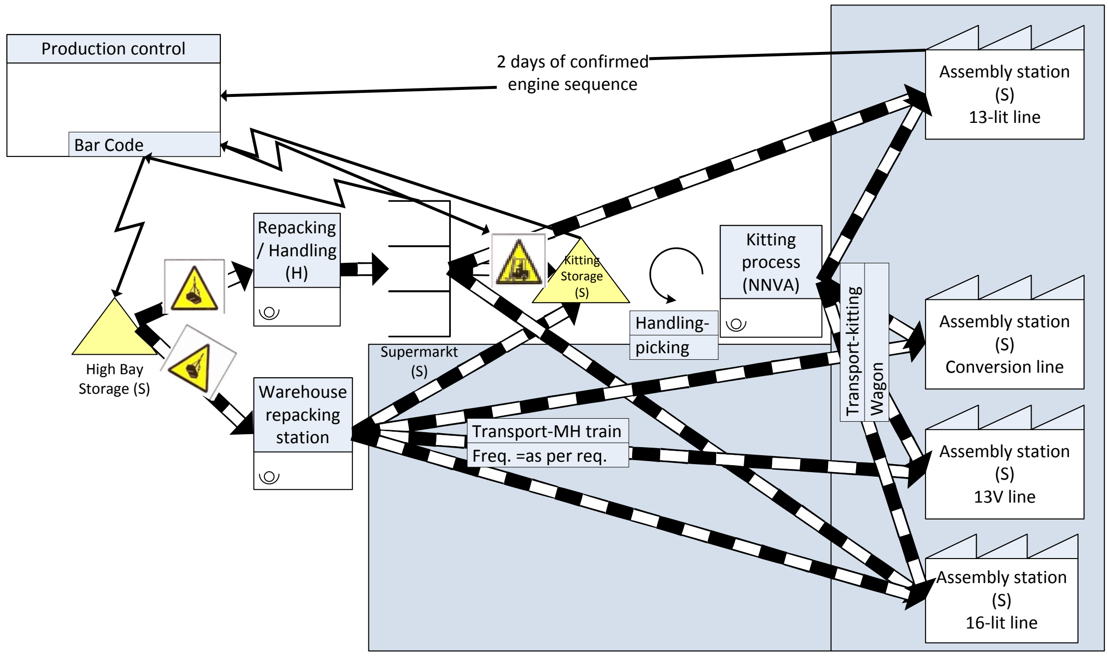


Figure 14: Flow highlighting components transportation to assembly lines

The second pattern is the transportation of components directly from the supermarket to the assembly lines. This is because the components are not kitted instead they are line stocked, but even then these line stocked components have re-order point and re-order quantity. Once this point is reached the milkrun train operator scans the barcode, which triggers the transport of materials from the supermarket.

The third transportation flow is same as that of the second, except the material is moved directly from the warehouse repacking station by ergomovers and milkrun train instead of the supermarket. Also they have some time schedules to check the frequency of transports like it had been explained under the title ‘Repacking station at warehouse’.

5. Analysis

From the empirical findings of the current state flow it is now possible to analyze the process flow from the subassembly shop to the final assembly lines. This analysis section will discuss the performance measurements of each representative flows, that has been specified in the frame of references chapter, since the current state maps that has been done for these six products represents the sixty components of the two product families that this project involves. Further in this analysis chapter, the potential for improvements in these current state flows will be discussed based on few aspects like flow racks, triggers, production quantity, etc., upon which the future state is proposed and implemented.

5.1 Performance measurements

From the different factors explained in the frame of reference for the performance measurement, the one HATS analysis, value added time measurements and total lead time will be used to analyze the six representative flows that have been mapped. The things that are considered as Handling in the flow mostly include material or components movement by the operators manually, packing of components into the emballages and pallets. Labeling of parts, drop stations where the components does not undergo any form changes except for the transits are considered as the Administration activities. Things that are considered as the Transportation are the movement of materials within the station or between different stations, processes that uses forklifts, milkrun trains, conveyors, over head cranes. All the buffers in between the workstation, between the processes, in the kitting area, supermarket where components are just stored are considered as the Storage activities. Things that are done to ease the work load of the operators at the final assembly lines but are not really value adding to the products like repacking to reduce the batch size, kitting, etc., are considered as the Necessary non-value adding activities.

These measurements are calculated from each current state flow maps and are tabulated as shown in table 1. The first flow (see Appendix 5.1) represents all the components in the slang family that follows the flow from slang sub assembly station to final assembly line (13V line) through high bay storage, supermarket and kitting area. Second flow (see Appendix 5.2) represents components in slang family that follows the flow from sub assembly station through high bay storage, supermarket and kitting to both 13V and 16 final assembly lines. The flow of third and fourth flow (see Appendix 5.3 & 5.4) are same from the sub assembly station until the high bay storage and warehouse repacking station after which the third flow follows kitting and to the 13V final assembly line, while the fourth flow follows to the conversion and CBU line. Fifth flow (see Appendix 5.5) represents all the components in startelement family that follows flow from sub assembly station to 13V final assembly line through high bay storage, supermarket and kitting area. The sixth flow (see Appendix 5.6) represent the remaining components in startelement family that follows flow from sub assembly station to 16 final assembly line through high bay storage and warehouse repacking station.

Table 2: Performance measurement analysis of all the representative flows

Performance measurements	Flow-1		Flow-2		Flow-3		Flow-4		Flow-5		Flow-6	
	No. of process	Time	No. of process	Time	No. of process	Time	No. of process	Time	No. of process	Time	No. of process	Time
Handling	2	630 s	2	630 s	2	390 s	2	690 s	2	750 s	2	690 s
Administration	1	-	1	-	1	-	1	-	1	-	2	750 s
Transportation	5	1570 s	5	1570 s	5	1350	5	1250 s	5	1355 s	4	1340 s
Storage	4	~3.1 days	4	~1.4 days	3	~5.5 days	3	~3.3 days	4	~3.5 days	2	~0.95 day
Value adding process	1	51 s	1	51 s	1	51 s	1	45 s	1	174 s	1	312 s
Necessary non value adding process	1	360 s	1	360 s	1	360 s	1	600 s	1	270 s	-	-
Total / Lead time	14	3.15 days	14	1.45 days	13	5.6 days	13	5.6 days	14	3.5 days	11	1 day

From the performance analysis factors for each of these flows, it is obvious that the transportation and storage activities in each of these flows are quite high. Moreover the time the components are being stored is very high considering the value adding time for each flow. The reason for such high transportation could be because of the movement / transport of materials from the sub assembly shop to the high bay storage and then it is again moved back to the final assembly lines. Also because of this more number and long distances of transportation it becomes necessary to produce components in larger batch quantities proving the fact that subassembly workshop operates in a batch production mode where items are produced covering several days of demand and then stored in high bay storage. So this contributes to the large storage times in each of the flows.

Because of such frequent transportations from and to the drop stations at the sub assembly shop and at the high bay storage, it is evident there is more traffic on the overhead conveyor system and more component pallets are waiting to be transported, increasing the waiting time and this contributes to both the overall lead time in these flows and significant amount of capital tied-up as WIP inventory. Lead times calculated in these performance measures will only include the average times of transports and not the waiting times, since it is quite hard to measure such waiting times because of huge uncertainty involved in these waiting and traffics. The future states will be arrived at by analyzing each activities based on whether it is needed in the flow and if not it will be eliminated. Sometimes it is hard to eliminate few activities even though it is non-value adding, so in such situations it will be simplified to a possible extent so as to decrease the total lead time and reduce the number of processes in the flow.

5.2 Aspects considered in the analysis

As mentioned in the methodology, after taking the practical requirements in such subassembly environment and discussion with the concerned department personnel, there are various aspects that are considered for analysis in order to even arrive at the different probable future state solutions. The different aspects considered in this analysis are production quantity, placing of flow racks / location of sub assembled components storage, locations in flow racks, production trigger and material transport trigger. In each of these aspects there are different possibilities and also there are different options when combining all these aspects, which are described in detail further in this chapter along with its advantages and disadvantages in a different environment.

5.2.1 Placing of flow racks / Location of sub assembled components storage

This aspect of the analysis is about the location of subassembled components storage racks or in other terms positioning of the flow racks. Depending on the locations there can be two options- dedicated flow racks and central supermarket.

Dedicated flow racks: This option of the aspect is having a dedicated flow racks to store subassembled components at their corresponding subassembly station itself. Though the option of having flow racks at the subassembly station will increase the transportation of the milkrun operators to each station and there will also be space constraints, there is an advantage of better visibility on available inventory levels for the operators working at the station. This will be better suited for environment where production is triggered by pull signals upon scanning of the empty bins at the final assembly lines.

Central supermarket: This is about having a centralized supermarket for the whole subassembly shop instead of having racks at each station. There will be an optimized transportation in this option, since the milk run trains has to pick components from the central supermarket and needn't have to travel to each station in the subassembly shop. The cons here will be that extra material handling and transportation involved, refilling the supermarket and bringing back the empty emballages to the corresponding subassembly station and also the space requirements for such large supermarket.

5.2.2 Component locations in flow rack

Again there are two possibilities in this aspect depending upon the type/characteristic of the component location- fixed location and flexible location i.e., having a fixed location for the component varieties that have high demand and flexible location for the low demand varieties. When there is a leveled and high demand of a particular component variety there will be frequent order and delivery of that particular component, which requires a fixed location. But in case of low demand varieties, having a fixed location for each component varieties is quite a waste, since they will be lying in the racks most of the time because of low usage frequency & occupying the space. So this kind of having fixed and flexible location will help in the better utilization of space in the flow racks and even reducing the number of flow racks, thereby contributing to the floor space utilization. Fixed and flexible locations are better shown in the figure 15, which is a side view a flow rack with three layers and the different article varieties in bottom two layers depict the low demand flexible locations.

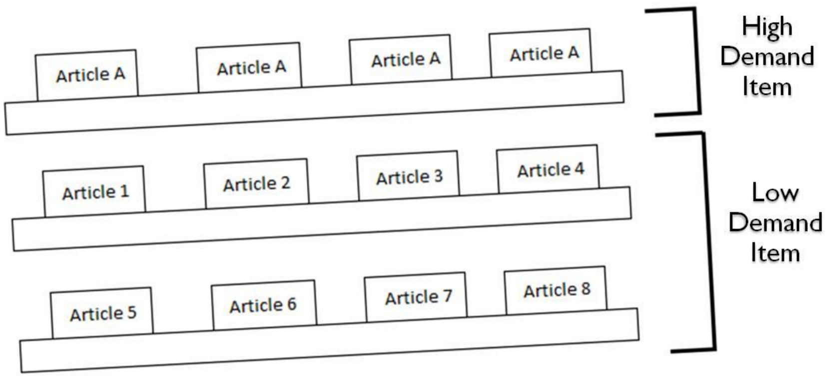


Figure 15: view depicting fixed and flexible locations in a flow rack

5.2.3 Production quantity

This aspect of the analysis is about the quantity of components that is to be stored in each emballage/ box. Based on this quantity there are two options-producing a fixed bin quantity every time and producing as per the final assembly line demand.

Production quantity-fixed bin quantity: This option is about producing to a fixed bin quantity every time i.e., when an order is received the operators at the station subassemble the components and fill the emballage with the fixed maximum quantity even if the requirement at the final assembly line is little lower than that fixed quantity. Even though there will be little higher inventory than necessary it makes the subassembly operators work easy by producing to a fixed quantity irrespective of the actual demand, thereby avoiding chances of manual errors in filling quantity.

Production quantity-as per demand: Unlike the fixed bin quantity, here the emballages/boxes are filled as per the corresponding final assembly line demands. This reduces that little extra inventory to be stored unlike in the fixed quantity option, but the problems in this option surpasses the advantages like it requires exact details regarding the demand at different final assembly lines so that the operator can fill the boxes with exact same quantity and also the transportation needs careful look since, delivery precision of a particular box is to be maintained. All these increase the probability of errors and also requires more IT help in coordinating these activities.

5.2.4 Production trigger

In this flow of components from subassembly shop to the final assembly line, there is an inventory or subassembled components being stored before being delivered to the assembly line, it could be divided into two segments-the first part of sub assembling components and storing in flow racks can be viewed as production trigger part and next part of transporting these stored components to the final assembly lines can be viewed as the material transport trigger. So this aspect of production trigger can happen in two different possibilities-one being push and other being production trigger by pull signal. In push, production is triggered based on the demand/need list received by the subassembly station operators every day. In pull, production will be triggered once the empty bin at final assembly line is scanned by the bar code scanner. The problem or in other words the pre-requisite for this pull option is that it requires the subassembly station to work in the same number of shifts as the final assembly lines, unlike the push option where components are subassembled to stock. But one way of negotiating this problem is to have a sufficient subassembled components inventory at the flow racks to suffice the final assembly line requirement during the non working shift. It requires a little bigger space for the flow racks, since almost all components varieties needs a storage location in the flow racks for a minimum quantity storage. If the particular station has more varieties like the slang family then this adds to the space utilization problems.

5.2.5 Material transport trigger

As explained in the production trigger chapter, the second part of the flow from subassembled components storage in the flow racks to the final assembly lines can be viewed as the material transport trigger. Like the production trigger this aspect also has two different possibilities-transport triggered through pull signal and transport triggered by hybrid signal (combination of push and pull).

Transport trigger-pull: In pull, the material transport is triggered by the scanning of empty bins barcode at the final assembly lines by the material handling operator. Once the signal is received the material handling operator picks the subassembled components from the flow racks and delivers it to the final assembly line. The cons of this option will be less filling degree for the milk run transport, since only few components will be triggered for transport. This degree of filling could be increased if the same is deployed for all stations in the subassembly shop.

Transport trigger-hybrid signal: In this option the material transport is triggered through the scanning of empty bins barcode at the final assembly line for high demand component varieties and push delivery for the low demand component varieties i.e. once the component variety is subassembled and stored in the flow racks as per the demand list, the material handling operator picks and delivers it to the final assembly lines even if there is no empty bins at the assembly line or in other words no demand at that time. In this way filling degree of atleast few trips of milk run transport could be increased but requires little guidance for the IT regarding the labeling of high and low demand varieties and monitoring of the same.

6. Future State

This solution chapter consists of two parts, the first part 'Future state proposals' describes the different proposals that have been made after analyzing the current state and considering the different aspects and combination possibilities explained in the analysis chapter and also describing which flow is adapted for the particular subassembly stations that the project is based on. When combining the different possibilities in each of these aspects, all the four proposals have the few characteristics that are same as explained below:

6.1 Improvement proposals

After considering the potential improvements and different possibilities from all the aspects that have been described and also from combining different possibilities in different aspects, four future state proposals have been made, which will be explained in detail. In all these four proposals there are few characteristics that are kept common.

- Location of subassembled components storage - all the proposals are made considering the subassembled components to be stored in a dedicated flow racks kept at the output area of the corresponding subassembly station. This option was selected over the central supermarket because of the non-availability of floor space to establish a separate supermarket and also because there are already output areas available at most of the subassembly stations.
- Component locations in the flow racks - it is considered that all the high demand component varieties have fixed locations in flow racks and flexible locations for all the low demand component varieties.
- Moreover, when considering the different varieties in each of product families the demand is very low as 2 emballages per week except for few component variants, so after discussion with the concerned department personnel for this demand segregation, component varieties with demand greater than one emballage/box per day are considered to be high demand items and others with less than one box per day to be low demand items.

The characteristics of all the four future state proposals are clearly described in Table 3 showing a little comparison of all the proposals based on the different aspects and also the approximate space requirement along with the specific issues that are to be taken care of.

Table 3: Comparison of different characteristics of proposed future states

Aspects		Future state proposal-1	Future state proposal-2	Future state proposal-3	Future state proposal-4
Production Trigger		Pull	Push (as-is)	Push & Pull	Push & Pull
Material transport trigger		Pull	Pull	Push & Pull	Pull
Flow rack locations		Fixed location-High demand items Flexible location-Low demand items			
Production quantity		Fixed bin quantity	As per demand	Fixed bin quantity	As per demand
Approximate space required (in sq.m)	**Salng family**	4	4.76	4.3	4.6
	Startelement family	1.6	3.2	3	3.1
Proposal specific issues		a) same number of shift as line b) IT Considerations	a) producing to cumulative demand – for articles serving to multiple lines	a) same number of shift as line b) IT Considerations c) Complicates subassembly operator work d) Good filling degree of Milk run Operator	a) same number of shift as line b) IT Considerations c) Complicates subassembly operator work

As shown in table 3, In the future state proposal-1 both the production and material transport are triggered based on the pull signal i.e., once the empty bin is scanned at the final assembly line by the material handler, that serves as a pull signal for the milk run train operator, so that he picks the material from the flow racks in the subassembly station and refills the final assembly buffer and in turn the subassembly station operator produces/subassembles the component and refills the flow rack.

Pull system has potential drawbacks when it comes to multiple product environment. Pull needs that a minimum inventory of each product be maintained at the outbound buffer i.e., flow racks of each subassembly station and replenishment takes place in response to the withdrawal of parts from that buffer. Suppose that work station subassembles/produces a large number of component varieties with possibly distinct demands, this can lead to increase of work in progress (WIP) inventories at each stage of the process. Particularly, certain product environments could lead to situations where the time between demands for some products is greater than their average throughput time. In these situations, the pull strategy could lead to replenishment of inventories well in advance of their needs, resulting in excess WIP inventories and in turn lead to inefficient system performance. In this case, push system might be a viable solution. On the other hand, this push system can also lead to more material storage at the final assembly line leading to handling inefficiencies at the final assembly. So to establish a controlled flow of material to the assembly line and at the same time not increasing the subassembled components inventory (WIP), it is better to combine both these push and pull concepts i.e., hybrid production system like the proposal-3. In case if it is ok to store the subassembled components at the subassembly shop but not at the final assembly lines, where presentation of parts to the operators is important, then it is better to go for push at the first part of the flow and pull at the material trigger like the proposal-2.

So the future state proposals-2, 3 and 4 is based on this hybrid production system, where the production is triggered by push signal in proposal-2 and 4. The subassembly operators produce components as per the daily need list and store it in the flow racks and material transport is triggered by pull signals so as to get a controlled flow. In future state proposal-3, both production and material transports are triggered by the push and pull signals, meaning the high and constant demand component varieties are is triggered by pull signals, whereas push signal triggers the low demand component varieties. The space calculations made are approximations considering the product varieties of the slang and startelement families.

These four future state proposals were discussed in a forum at Volvo PT consisting of personnel subassembly shop and logistics, team leaders, production engineers and material handling operators, where future state proposal-1 was accepted as a suitable solution for the startelement product family mainly because of no resource constraints and less component varieties and proposal-2 as a suitable solution for the slang product family.

6.2 Future state flow description

Though the future state proposals are different for the two product families, the flow of components from the subassembly shop to the final assembly lines for the two proposals remain the same except for the information flow i.e., the production and material triggers. Although the complete future state flow along with the information flow are mapped for slang and startelement families separately (see Appendix 6.1 and 6.2), figure 16 below will depict the overall view of the flow of components in the future states. Moreover, this overall flow can be divided as two segments - subassembly and storage at the flow racks and transportation to the final assembly lines, which will be explained in detail further in this chapter considering the slang and startelement families along with their information flows.

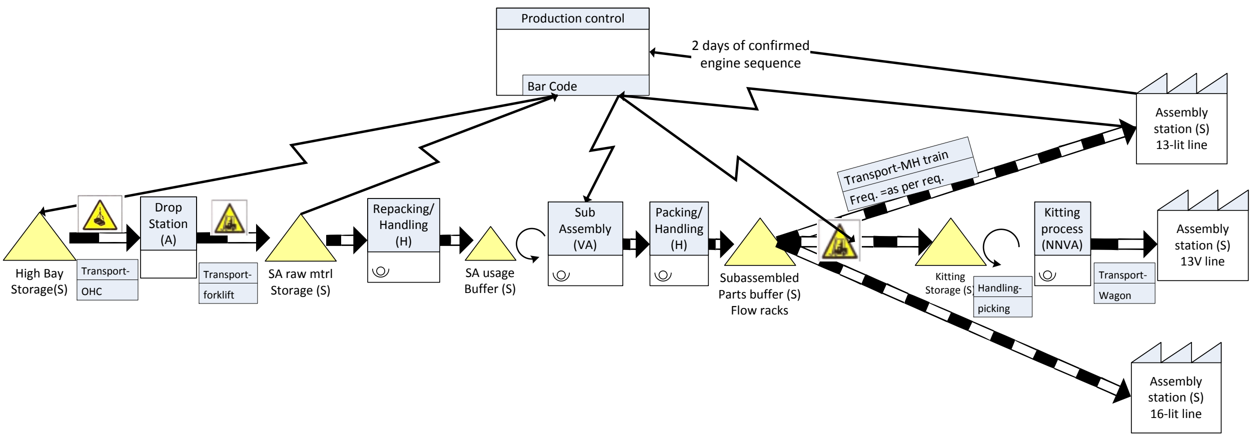


Figure 16: Overall view of component flow in future state

6.2.1 Subassembly and storage at the flow racks

In the first part of the future state flow there are not many changes, which remain moreorless same as that of the current state flow, both for the slang and startelement product families. The main change or improvement will be in controlling the subassembly process and material handling after the subassembly process based on the demand at the final assembly line. In the slang subassembly station, once the slang varieties are cut as per the specification they are packed in their corresponding emballages of fixed bin quantity and are refilled/ stored in the flow racks kept at the output area of the subassembly station (as shown in figure 17), unlike the current state flow that involves transportation of subassembled components in pallets to the high bay storage through the drop station. Also like it was described in the future state proposals chapter, the production is triggered by the push signals i.e. they subassemble components as per the need list received every day and there will be fixed location for high demand slang varieties and flexible locations for low demand slang varieties.

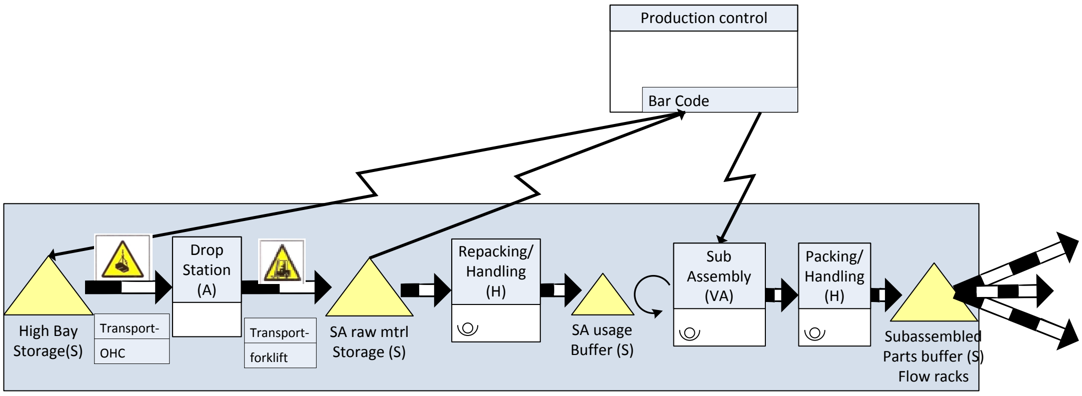


Figure 17: highlighting subassembly and storage @ flow racks

In the startelement subassembly station also the flow does not change much, but after the subassembly process the components are repacked in corresponding emballages and stored in the flow racks. Once the reorder point of that article number is reached, then a production order corresponding to the replenishment quantity is displayed in the computer screen. This acts as a production trigger to the operator at the subassembly station and they start to work on that order to refill the flow rack. Later, when the order is complete, the computer system is updated by the operator and in turn it prints the labels corresponding to the number of emballages produced. The operator then affixes those labels on the emballages and refills the flow rack.

6.2.2 Transportation from flow racks to the assembly lines

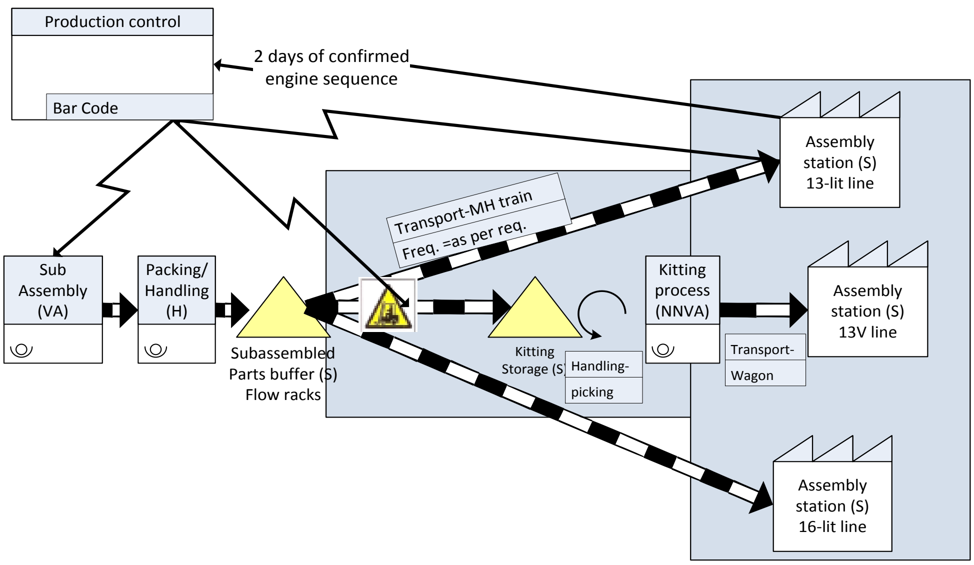


Figure 18: Flow highlighting transportation to kitting and final assembly lines

For both the slang and startelement product families the second part of the flow is same i.e. once the material transport is triggered by the pull signal received through the scanning of the empty bin barcode by the material handling operator.

For the startelement family, the future state information flow is such that once an empty emballage is scanned at the final assembly line, the system allocates one emballage of a fixed bin quantity of that article number to that scanned assembly line from the subassembly station flow racks and at the same time it also checks whether the re-order point has been reached for that corresponding article. So the empty bin scanning at the final assembly line serves as the pull signal for both the production and material transport triggers for the startelement family.

7. Evaluation of the future states

As mentioned in the methodology part of this project, this chapter of the report is divided into three sections, wherein the first section, the performance measures of the future states that have been selected for implementation will be compared with that of the current states measures. The next evaluative parameter considered is the cost. In order to do the Benefit-cost analysis it becomes necessary to calculate the cost of the flow for all the component varieties that are produced in the subassembly shop. So a cost model has been constructed, which is explained in the second section of this chapter, finally ending with the benefit-cost analysis.

7.1 Performance measures comparison

Different performance measures have been described in the frame of reference chapter, but for the comparison and evaluation HATS analysis and lead time are considered since, the flows analyzed in this project involves these handling, transportation, storages and lead times but not the service level and other measures. The comparison of the measures like handling, transport, storage between representative current state flows and the accepted future state proposal for the slang family is in table 4. The Future state flow in the table for the slang family corresponds to the proposal-2 described in the improvement proposal chapter. It could be seen that the number of processes in handling, transport and storage for future state is very less compared to that of the current state flows. The transportation of components from the subassembly shop to the high bay storage through the drop station has been eliminated in the future state and also the subassembled components are stored in the flow racks at corresponding station before being delivered to the assembly lines, these reasons contribute to the fact the total number of processes in the future state flow being half of the current state's.

Table 4: Comparison of current states and future state of slang family

Performance measurements	Current state Flow-1		Current state Flow-2		Current state Flow-3		Current state Flow-4		Future state Flow (proposal-1)	
	No. of process	Time	No. of process	Time	No. of process	Time	No. of process	Time	No. of process	Time
Handling	2	630 s	2	630 s	2	390 s	2	690 s	-	-
Administration	1	-	1	-	1	-	1	-	-	-
Transportation	5	1570 s	5	1570 s	5	1350	5	1250 s	2	490 s
Storage	4	~3.1 days	4	~1.4 days	3	~5.5 days	3	~3.3 days	2	~2.1 days
Value adding process	1	51 s	1	51 s	1	51 s	1	45 s	1	51 s
Necessary non value adding process	1	360 s	1	360 s	1	360 s	1	600 s	1	360 s
Total / Lead time	14	3.15 days	14	1.45 days	13	5.6 days	13	5.6 days	6	2.1 days

Table 5: Comparison of current states and future state of startelement family

Performance measurements	Current state Flow-5		Current state Flow-6		Future state Flow (proposal-2)	
	No. of process	Time	No. of process	Time	No. of process	Time
Handling	2	750 s	2	690 s	2	120 s
Administration	1	-	2	750 s	-	-
Transportation	5	1355 s	4	1340 s	2	410 s
Storage	4	~3.5 days	2	~0.95 day	2	~0.35 days
Value adding process	1	174 s	1	312 s	1	174 s
Necessary non value adding process	1	270 s	-	-	1	270 s
Total / Lead time	14	3.5 days	11	1 day	8	0.35 days

Table 5 shows the comparison of the current and future state measures of the startelement family. The Future state flow in the table for the startelement family corresponds to the proposal-1 described in the improvement proposal chapter. For the startelement family the lead time will be less compared to the future state flow of the slang family i.e. because pull system is used in the startelement's future state flow unlike the slang family, where production triggered is push and the material transport is triggered by pull signals. So a little extra inventory (subassembled components) has to be stored in flow racks than necessary, covering the days demand.

For the two tables above, it is obvious that the value adding process and necessary non-value adding process (i.e. process that adds value to the end user, which in this project are the final assembly lines) cannot be changed much because of the kind of subassembly process these product families have, but the other non-value adding activities like administration, transport and storage have greater impact on these flows and the total lead time. So these future state proposals for the two product families have achieved this objective of reducing/eliminating the non-value adding activities to some extent, yet this can be reduced further which is the case in continuous improvements.

7.2 Construction of the cost model

In order to compute the benefit-cost analysis it is necessary to know the cost of the current flow of components from subassembly shop to different final assembly lines. Therefore an excel sheet cost model is constructed to calculate the cost of all the components that flow from subassembly to final assembly lines. So to construct this cost model various inputs regarding the resources consumed by each activity is considered like labor cost, equipment rental costs, emballage and pallet costs, space cost, maintenance cost of equipments and high bay storage. Assigning a cost to an activity requires another input i.e. the activity time, which is the cost driver (Popesko, 2010). So finally the cost is allocated to each activity in the flow by computing the activity time these resources are used in the components flow from subassembly shop to final assembly lines as described further in this chapter. This cost model includes all the handling, transportation, administration and storage (HATS) in the flow from subassembly to final assembly lines as mentioned in analysis chapter. This is a general cost model, which will be used to calculate cost of the flows for both current and future states. Also it is necessary to map the flows in order to construct a cost model, which is what done in this project with the hybrid mapping method.

The flow is divided into different activities as explained in the current state description and cost is computed. In this model all the cost are computed per minute and for each unit or per piece.

Packing and transport to drop station after subassembly: The resources considered here are labor cost, rental cost of the forklift and maintenance cost of the same and emballage and pallet costs. For this part of the flow the activity cost has to be entered by the user, since not all the components have the same packing time. Regarding the transport time it is constructed in such a way that once the user enters the transport distance the activity time will be calculated based on the input and the speed of the transporting equipment. All these costs are added up and multiplied by their corresponding resource utilization time to give the final activity cost.

Transport to and buffer at high bay storage: In this part labor costs, maintenance cost of high bay storage, emballage and pallet costs and space cost used by the pallets at high bay storage are the resources employed. Here the activity time is fed already in the model based on the standard activity time to transport component pallets from subassembly drop station to the high bay drop station. This standard time is calculated from time studies taken for different components at different time of the day in order to get the average standard time, because of the different traffic conditions at different times.

Transport to supermarket or warehouse repacking station: These two parts of the transportation and handling utilizes the same kind of resources, but the only difference is that the first one is to the supermarket and later is to the warehouse repacking station. Resources used here are labor cost, rental and maintenance costs of the material handling equipments, emballage and pallet costs and space cost for storing these components at the supermarket and also at the warehouse repacking station output area.

Transport to kitting area and kitting process: Labor cost, material handling equipment rental and maintenance costs, space cost of storing the components at the kitting area are the resources used here. The extra costs involved here is for the kits and the little extra labor hours compared to other activities. The activity time for transport is calculated based on the user input of the distance and for the kitting process; the activity time is calculated based on the time study taken for kitting process. In order to arrive at an average standard time for kitting different trials were conducted with different kitting personnel at different time period and finally averaged out.

Transport to assembly lines: Again this activity has more or less same resources like labor cost, material handling equipment rental and maintenance costs and emballage cost. The time is calculated based on the input distance by the user.

7.2.1 Computing the flow cost using the model

This cost model is constructed using excel so that it will be easy to use. To compute the flow cost for a particular component, the user has to enter few input data. User has to enter the article number, annual demand and available production time at the final assembly lines to start with. Then comes the different activity sections as explained previously. Time for packing must be typed in manually, emballage size and number of emballages can be selected from the drop down list as shown in figure

19. Once these data are fed the cost of that particular activity in the flow will be seen on the right (i.e. cost SEK) that cost is for one piece. In the similar way all the data input box (indicated in green color) should be entered for all the activities to get the cost of that particular activity. If a particular component being computed does not have that activity, then the data input box can be left blank. Finally when all the data are entered, the individual activity costs will be displayed in the corresponding activities right most cell. Moreover the final cost of the flow of that particular component will be displayed at the bottom cost summary box.

Figure 19: Cost model

7.3 Benefit-cost analysis

Benefit-cost is actually a ratio to realize the financial benefits for the company through implementation of the project. So to calculate this benefit-cost ratio the cost savings through the implementation of the project must be calculated. Production cost for the flow of components from subassembly shop to the final assembly lines in the current state and in the future state must be calculated for all the 60 component varieties (55 slang variants and 5 startelement variants). From the constructed cost model it is now possible to compute this cost benefit that will be realized. By using the cost model the production cost per piece for all the 6 representative flows is calculated and the values are as in figure 20. Both the current state and future state flow cost per piece are calculated from the model. Each flow's cost is multiplied by their corresponding number of component variants it represents, both in the current and future state. From these total current and future state costs the cost savings that will be realized is calculated. Now in order to implement the project there are few implementation costs involved, from which the benefit-cost ratio is finally computed to be around 4.55, which is a quite good cost realization according to the project team at Volvo PT.

Flow type	cost ref. article no.	Flow includes	Flow cost per unit (SEK)		No. of articles following this flow	Total demand of all articles/year following the flow type	Total cost (SEK)/year	
			Current state	Future state			Current state	Future state
1	3137088	supermrkt,kitting-13V line	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	3138119	supermrkt,kitting-13V & 16 line	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	3138510	Wh-repacking station, kitting-13V line	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	3137988	Wh-repacking station, Konv+CBU line	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	20940342	supermrkt,kitting-13V line	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	21068425	Wh-repacking station, 16 line	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
							[illegible]	[illegible]
							[illegible]	
	Implementation costs involved:							
	Manhour		[illegible]					
	Others (Maintanance, Label printing machine)		[illegible]					
			[illegible]					
	Benefit cost ratio		4.55					

Figure 20: Benefit-cost analysis sheet

8. Implementation and Monitoring of Future State

This chapter describes the various steps that are undertaken for efficient implementation of the future state proposed in the previous chapter and further how to monitor the implemented future state.

First, the implementation steps for the startelement product family are detailed. Volvo PT has unused flow racks in the other parts of their facility so the same rack was retrofitted to suit the startelement product family. The size of the flow rack chosen was 1 m wide * 1.5 m deep.

The proposed future state for the startelement family employ pull production system, so the reorder point and replenishment quantity for all the product varieties was calculated. With this, it was possible to calculate the number of emballages that needs to be stored in a new flow rack and the number of levels required in the flow rack to store these emballages. Calculation of the reorder point, replenishment quantity and number of levels in a flow rack etc. are described in detail in the 'General Future State Deployment Model' chapter. See Appendix 7 for the flow rack arrangements of the startelement product family.

Necessary changes were made in the IT system with the aid of Volvo IT personnel to facilitate information flow in the future state. Then, these changes made were simulated in software to foresee any problems in the information flow.

Figure 21: Startelement station after implementation

Startelement subassembly cell was reorganized to accommodate the flow rack, a computer system and a printer. This flow rack was placed in the outbound buffer of the cell to store the sub assembled startelement and also located besides the aisles to facilitate for easy picking of emballages by the milk run trains. The computer system and printer were placed besides the working table in order to have a better visibility to the personnel working in the cell. This visibility enables them to act on the production orders displayed in the computer screen within nominal time.

The proposed future state for the startelement family was implemented only between the subassembly cell and final assembly lines but the extra material handling as described in the current state remains unchanged. But, Volvo PT can realize the benefits of this proposed future state well once the future state is also implemented within the subassembly cell, that is, the removal of extra material handling. Figure 21 shows the startelement station after the implementation of the changes discussed so far. The material handling route was established by the Volvo PT personnel through the naturally occurring aisle routes between the subassembly shop and final assembly lines.

A Checklist was developed for the post-monitoring of the implemented future state for the startelement family and refers to Appendix 8 for the same. This checklist captures the salient aspects of the future state like material flow, information flow, stock outs, and overflow of materials etc. for keeping the process in control. After implementation, monitoring of the process was done both by the Volvo PT personnel and the researcher of this thesis to capture all the aspects described in the checklist.

The future state implementation steps for the slang product family were worked out in a similar fashion and were proposed for the Volvo PT.

9. General future state deployment model

Like the cost model this general deployment model is also constructed using Microsoft excel to make it user friendly and easily understandable. Actually the deployment model is built to easily use the strategy for other product families in the flow from subassembly to final assembly lines. In order to achieve this, the deployment model (see Appendix 9) is constructed to calculate the number of emballages to be stored in the flow racks and number of emballages to be replenished with, when it reaches the minimum quantity. From these quantities the number of locations required in a flow rack is calculated and thereby the number of levels or number of racks required.

The deployment strategy is clearly depicted using a flowchart (figure 22), which starts first with checking whether the product family being analyzed has the resource constraints like subassembly shop and final assembly lines does not have same number of shifts and no leveled production, if yes then hybrid system will work good and if not user can go for pull system throughout. Next will be checking the number of variants in the product family if it is low, it is good to go with fixed location for all variants and if it is high then all the high demand items can have a fixed location and low demand items can have a flexible location. So the model is constructed based around this strategy to calculate the minimum and replenishment quantity in the flow racks and the number of racks required.

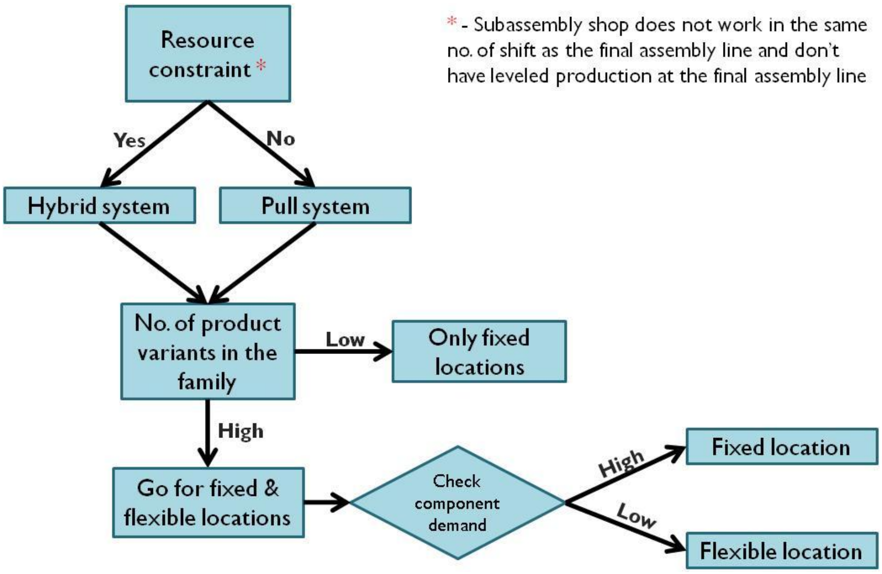


Figure 22: Flowchart showing general future state deployment strategy

The overall strategy mentioned above is used in the construction of the model which will be explained in detail. The average demand per day is calculated from the demand per year of the product variant and considering the average working days per year as 200. As said in the strategy if the product variants are less than 10, then fixed locations will be made, if not then it will check the demand per day (emballages/day) if it is greater than 1, it will take a fixed location else a flexible location. In case of pull system, the minimum quantity is taken as 0 (if flexible location) and same as replenishment quantity (if fixed location). The replenishment quantity is calculated using the average demand, lead time for sub assembling the product and also the number of final assembly lines the product variant is delivered to. In case of hybrid system, only total number of emballages to be stored is calculated, since it doesn't have the minimum and replenishment quantities, considering 1.5 days demand in order to include the safety space required in the flow racks. Finally, when the length and breadth of the flow rack is fed in the corresponding input field, the total number of levels required in a flow rack is generated from the locations calculated.

The model is constructed in such a way that user has to feed in the data for the fields under the title marked in green color, the blue and grey colored columns will automatically calculate the values based on values fed in the input fields. Based on the flowchart shown in the deployment model (see Appendix 9), select the type of production system from the dropdown list as either hybrid or pull. Next fill in the details like article number, demand per year, emballage type and quantity in each and also the number of final assembly lines it is being delivered to for all the product variants in the family. The model will calculate the minimum quantity, replenishment quantity and location details for the articles. Finally, enter the length and breadth of the flow rack in the corresponding input field (at table at the top right of the model) to get the total number of levels required in the flow racks from the fixed locations and flexible locations can be calculated manually from which user can get the number of flow racks required.

10. Discussion

This chapter describes the theoretical, practical and managerial implications of the methodology used and the results achieved in this thesis work.

10.1 Theoretical Implications

Though the internal logistics has always been important part of company's production operations, its relevance and importance to value adding processes has gained significant attention during the recent years. This perspective demands for a tool that helps to map and quantify the efficiency of both the material supply activities and value adding activities in a material flow and hence paving way for better coherence between the two. So, this thesis work has developed and used the hybrid mapping tool that meets the above stated needs. This hybrid mapping tool is useful due to its holistic approach to analyze the product flows at system level. Such a hybrid tool helps to design material supply processes that better supports value adding processes and also helps the material supply system in itself has to maintain and, in fact, improve its efficiency. Further, this hybrid tool helps to identify the planning and control issues. The use of such a hybrid tool helps to further streamline the shop floor operations efficiently.

This thesis work shows that it is possible to effectively combine both the push and pull production philosophies in a synergistic way as evidenced by previous researchers in this field. But, most of the previous researchers proved it through a conceptual decision model or simulation model to measure and evaluate the performance of their proposed hybrid production systems and on the other hand, this thesis work demonstrated it by practically means. Moreover, the same performance measures used by the previous researchers are utilized in this thesis work to evaluate the proposed system and the improvements observed in the form of WIP inventory reduction, lead time reduction etc. are in line with the previous researches.

10.2 Practical Implications

Now-a-days companies operate in a hybrid manufacturing setting as stated earlier in the theory chapter. So, the future success of manufacturing cannot depend on only one of these push or pull concepts; a company must draw from the entire spectrum to extract what makes sense for that particular firm.

It is also clear from this thesis that certain portion of a manufacturing setting can operate in a particular production mode (push / pull / hybrid) while the other may operate in another production mode. So, the choice of production system is solely dependent on the particular product family environment and the same system may not be applicable for the entire workshop or the entire firm. Institutionalizing appropriate production system helps companies to customize the material and information flow that better suits the particular product family environment. This in turn contributes to a good service level by making any workstation in a value stream to produce right product at the right time with the right quantity. This perspective enables to improve the company's overall operational efficiency in a better way and thus helps to achieve sustainable competitive advantage.

This thesis work identified three important variables that determine the choice of production system for a particular product environment. Those variables are degree of leveled production, product variety and resource constraints (in this case, it is available / required production time at workstations in a material flow). Moreover, these variables are identified based on the detailed analysis of practical aspects such as placing of flow racks, component location in flow rack, production quantity, production trigger, material transport trigger. So, this finding may be applicable to any similar manufacturing environment with minor adaptations.

The cost model developed is based on ABC system, so it gives a clear and accurate overview of the various processes involved between subassembly and assembly process and hence facilitates to calculate the overall flow cost. This model can be utilized as a decision support tool for logistics and production engineers for choosing appropriate material supply system. Further, they can calculate the predicted cost before the launch of a new item and evaluate different steps and principles. This tool can also be used to balance the cost effect with the complexity of the chosen solution.

It is quite difficult to say that the cost computed using this model is absolutely precise as it does not take into account of the capital cost of equipments, capital cost tied-up in inventory and overhead costs. In ABC system, it is also complex to inter relate the cost of all resources into specific activities. Maintenance and service costs considered are based on the values from the year 2010 and this value may vary from year to year due to variations in the production rate and depreciation of the capital equipments.

Both the cost model and general deployment models are constructed in Microsoft Excel so they are easy to comprehend. Any user can easily get acquainted with these developed models and further the users can also easily update or edit these models. Also, both the models are developed such a way to facilitate easy computation, wherein appropriate in-data are fed in manually and in turn it automatically calculates the required output. For instance, it automatically calculates cost of an activity (in case of activity cost model) and it automatically calculates the reorder point, replenishment quantity and number of levels in flow rack required etc (in case of general deployment model).

10.3 Managerial Implications

This section addresses researcher's beliefs of how the effectiveness of this project and other aspects connected to this project could be improved at the studied company Volvo PT.

The study focuses on improving the material and information flow between the subassembly workshop and multiple final assembly lines. Even though the company is very much interested in pursuing this project; they lacked some of the key points in carrying out a production improvement project. Some of the recommendations that could benefit Volvo PT are presented below.

It is worthwhile to say that Logistics Department is a supportive function to Operations Department. Even though this thesis work concentrates to a great deal on internal logistics, the outcome of this project still affects the work methods devised by the production department. For instance, it involves layout reorganization, establishing reorder point, replenishment quantity etc. in this thesis work. So, mutual involvement of the personnel from all involved or affected department are very vital for any improvement project. Harris (2003) also states that involvement from the three departments, as shown in the figure 23, helps to complete a shop floor improvement project effectively and further to sustain the improvements made.

All these departments need to tightly coordinate their efforts in the project right from the initial stage (scope definition) till the project closure. Such an association helps one to get buy-in from the other easily and also helps to realize high level benefits at ease. For instance, different future states were proposed for both the product families but, the implementation was carried out only for the startelement family and not for slang family. The reason behind this is that implementation of the future state for the slang product family involves higher degree of changes in the subassembly process and layout reorganization when compared to the startelement family. This further demanded for higher degree of coordination between various departments and this missing facet caused delay in the future state implementation for the slang product family. An effective coordination and involvement from all the affected departments would have helped Volvo PT to realize the fullest benefits of the proposed future state.

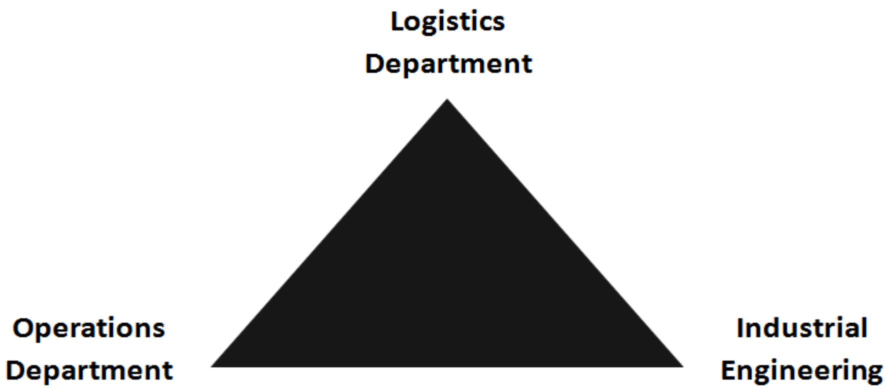


Figure 23: Door-to-door materials triangle (Harris, 2003)

A traditional kanban-pull system is one where any two processes in a material flow are tied together by having predetermined inventory between them. This fixed inventory is calculated based on the demand at the immediate downstream process at a given point in time. In reality, this demand tends to vary with time and thus causes unnecessary problems like stock outs (if the demand is increased) and excess inventory (if the demand is reduced). Therefore, this stresses for updating of this predetermined inventory at regular intervals, say, for every six months. This work has be made as a routine within the company and once again demands for coordinated efforts from all the involved departments.

11. Conclusion

Volvo PT is interested in ascertaining the efficiency of product flows that exists between the subassembly workshop and multiple final engine assembly lines. This finding enables them lean their production operations. So, the main purpose of this thesis work as stated in the Introduction chapter is:

> *'Streamline the material and information flow between subassembly shop and multiple final assembly lines '*

Further this higher level purpose is broken down into manageable and achievable multiple low level objectives in the introduction chapter. The intention is to highlight how these objectives are achieved either during the project progress or as the project outcome.

First objective: Investigate and map the current state map

Two mapping tools called Value Stream Mapping (VSM) and Material Flow Mapping (MFM) were combined in a synergistic manner and arrived at a hybrid mapping tool to meet the project needs. This hybrid mapping tool helps to capture both the material supply activities and the value adding activities in a value stream. Various performance measures were used to investigate the performance of the current state flows and those include: handling activities, administration activities, transportation activities, storage (WIP inventory in terms of number of days demand) in the material flow, value adding activities, necessary non-value adding activities and lead time. Various activities in a value stream are categorized into these measures and consequently facilitating for further systematic assessment.

Second objective: Develop the future state map

With the analysis of current state flows as the basis, several future state proposals with improved manufacturing planning and control were arrived at considering the following key aspects: placing of flow racks, locations in flow rack, production quantity, production trigger and material transport trigger. These future states were validated with due consideration of practical implementation feasibilities and particular family context in consultation with Volvo PT employees across all involved departments.

Consequently, different future states were chosen for the two product family under study. Horizontally integrated hybrid push/pull production system (HIHPS) was proposed for slang product family and on the other hand pure pull system for startelement family. These two different future states were suggested based on three important variables: available / required production time at subassembly workshop and final assembly lines, the degree of leveled production and product variety.

Third objective: Construct a activity cost model

Before developing the model, the various activities involved in the current states and future states were indentified along with the resources which it consumes and time it takes to complete the entire process. Then, a cost model which is based on activity-based costing (ABC) system was developed to identify the cost of flowing an item from subassembly to the final assembly lines for both the current states and evaluated future states. With this as the basis, the benefit-cost analysis was carried out for the evaluated future state solutions. This financial appraisal helped to obtain buy-in from the Volvo PT managers in proceeding ahead with the implementation of these future states.

Fourth objective: Test run of evaluated future state solution and to develop general deployment model

A test run of the accepted future state was carried out for the startelement product family. Later, the implemented future state is monitored to ensure that the perceived results will be realized. In a similar fashion, the same has been worked out for the slang product family and the company has accepted this proposal and it will be implemented in the facility in the near future. Finally, a general deployment model was developed for cascading the same to the other product families in the subassembly workshop. This model will help Volvo PT for easy deployment of this streamlined material and information flow between subassembly workshop and final assembly lines to the other product families.

12. Recommendations and Scope for Future Research

This chapter details some of the recommendations that Volvo PT can consider for the future and also the scope for future research in the academia. Recommendations that are pertinent to the Volvo PT are,

- This project work scope is to streamline the segmented material flow only, that is, the flow that occurs between the subassembly workshop and final assembly lines. So, the company can still work further to subordinate / improve the material flow that exists upstream the value chain, that is, from the supplier to the subassembly shop.
- The cost model developed represents the segmented material flow only and further it can be developed to encompass the value stream that exists from the supplier end to the subassembly shop. This will help Volvo PT to compute the flow cost of an item from the supplier till it is delivered to the assembly lines.
- The pilot run of the proposed future state is carried out for the startelement product family and on the other hand another future state proposal is being accepted by Volvo PT for the slang product family and it is going to be implemented in the near future. Also, a future state deployment model and a cost model are developed to facilitate deployment of these proposals for other product families in the subassembly shop. With this as an aid, the company can proceed ahead with further cascading of these proposals to other product families at ease in the future.

Upon implementation of the above three recommendations, will help Volvo PT to realize the benefits of lean value flow to a greater extent.

Next, the scopes of future research in the academia are,

- This thesis work has utilized the hybrid mapping tool by conjoining the two different mapping tools that is Value Stream Mapping and Material Flow Mapping in order to address the project needs. As this type of hybrid mapping is not established so far in the scholastic world, the further research in this field helps to effectively integrate these two tools and in turn can pave way for new directions in the production improvement projects.
- This thesis work has found three important variables that decide the choice of production system (push / pull / hybrid). Those variables include the degree of leveled production, product variety and resource constraints. Further research would be highly appreciated in the same and other manufacturing environments like job shop, a value stream that possess batch processing operations (painting, cutting, stamping, cleaning) etc to identify those variables that determines the appropriate production system selection.

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Appendix:

Appendix 1: List of Interviewed Personnel at Volvo PT

Anna-Karin Wiik, Production Engineering Department

Stig Dahlberg, Materials Department

Maria Broman, Production Engineering Department

Erika Hernefur-Persson, Material Handling Department

Anna Olsson, Production Engineering Department

Christer Nordqvist, Material Handling Department

Johan Karlsson, Material Handling Department

Rolf Krantz, Information Technology Department

Jan Gustavsson, Material Handling Department

Kenneth Andersson, Production Department

Jan Gren, Logistics Department

Jonas Håkansson, Logistics Department

And other shop floor personnel.

Appendix 2: Data collection template

Process:

Handling
Administration
Transport
Storage/Buffer

Previous Process:

Operators	qty.		Space	m2
Cycle time	sec.		Distance	m
Value Creating time / Process time **	sec.		Quantity	*
Change over time / Set up time	sec.			
Uptime	%			
Scrap	%			
Frequency of process				
Batch size / Delivery volume	qty.			

Control (Information flow)	
From, How	
Frequency (how often)	

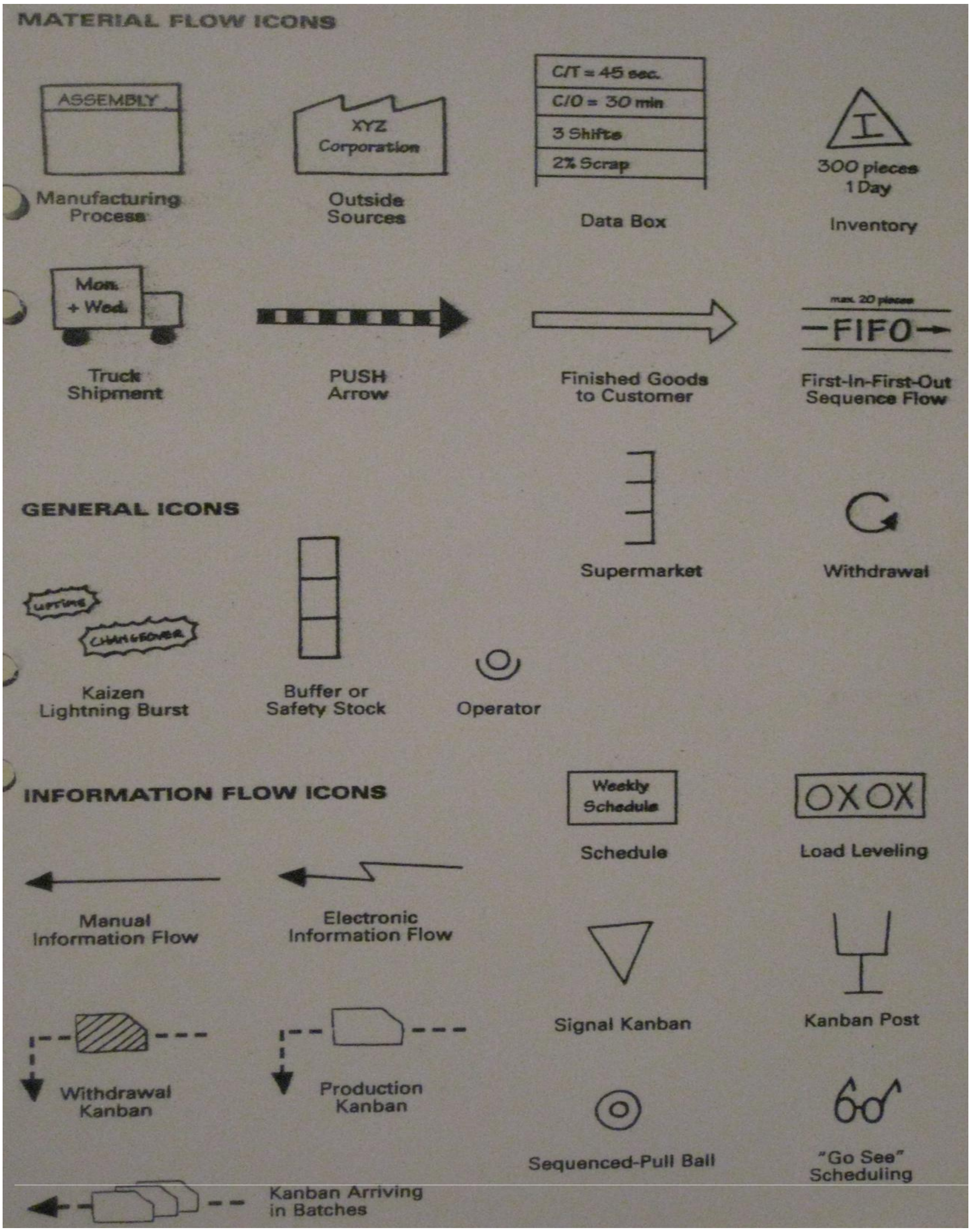
Component/item characteristics	
Quantity and volume per package	
Equipment	

Next Process:

Comments:

*Do not forget to note type of unit (e.g. component or package type) ** Man & machine time per product

Appendix 3: Symbol library for mapping



Appendix 4: Data collection spreadsheet template

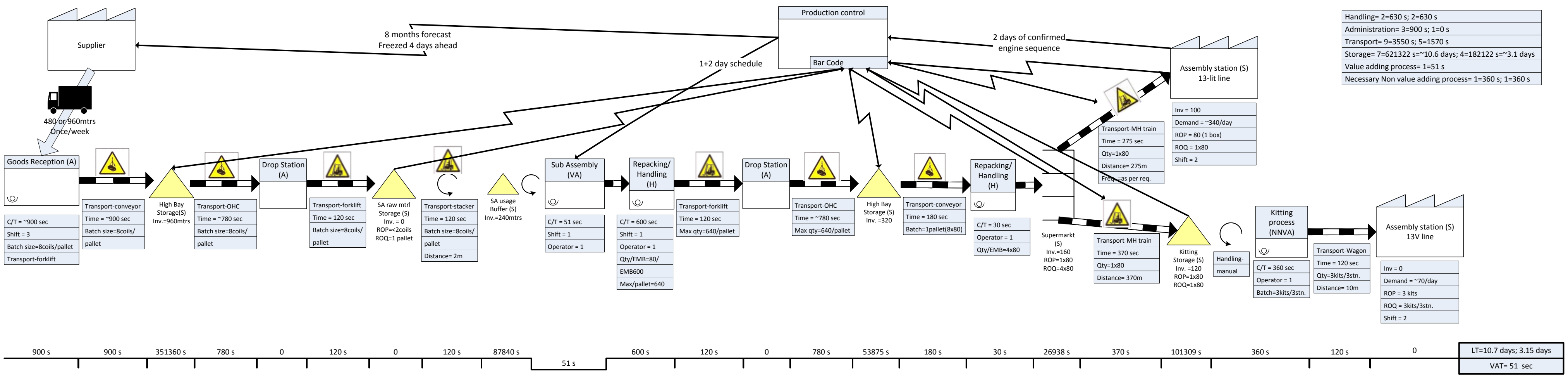
Sl. No	FLOW	ARTNR	ARTBEN	Max. Avg dmd / year	Avg inhouse dmd / day	Current state		Future state		Avg. Dmd. / day (in no. Of EMB)	Roundoff avg dmd / day (in EMB)	Spce Req.d	Fixed (1) / Flexible (0)	Max qty/ pall	Total no. of boxes (Wh)	Total no. of boxes (Sup)	HDE 13	HDE 13V	HDE 16	konv + *CBU*	Assy station							
						EMB	Qty / EMB	EMB	Qty / EMB												HDE13	ROP, ROQ	HDE13V	ROP, ROQ	HDE16	ROP, ROQ	Konv+ CBU	ROP, ROQ
1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix 5: Current state maps

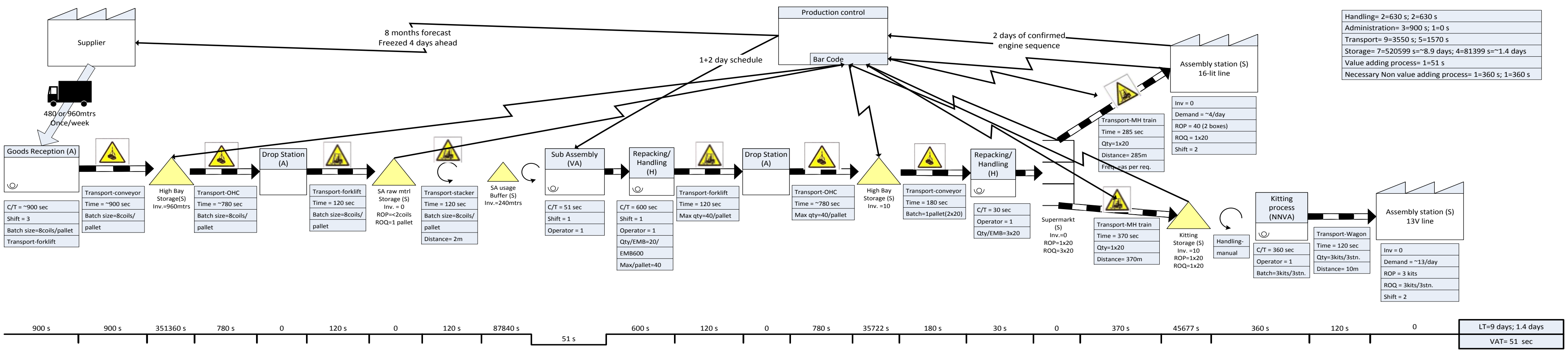
These are the current state map of the 6 articles representing different flow patterns of 2 product families (consisting of 53 articles in total)

[Note: In the time line box and data box for HATS (at the top right corner of each map), the time will mentioned as-for example,630s;630s. The time before colon(;) mark is total time for the entire flow and time after ";" mark is for the total time from Sub assembly to the final assembly station. This is just for our understanding, since our scope is more focused on improving the flow from sub assembly shop to the final assembly line.]

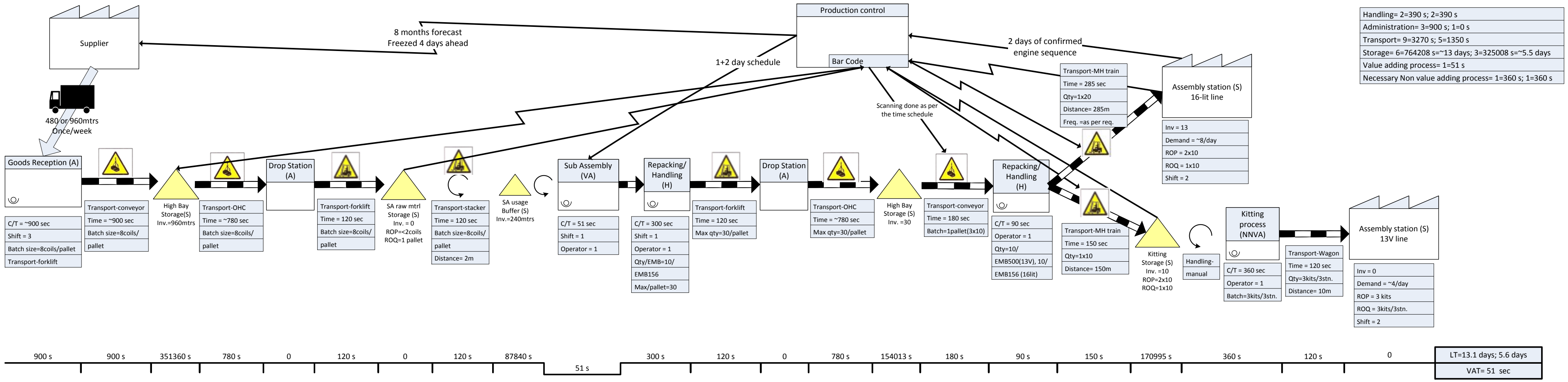
Appendix 5.1: Current state map-1



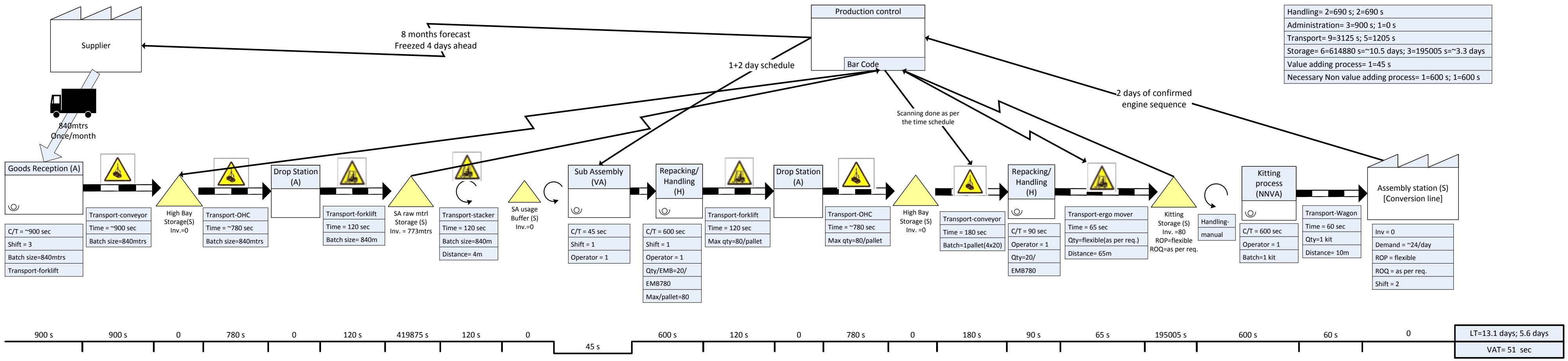
Appendix 5.2: Current state map-2



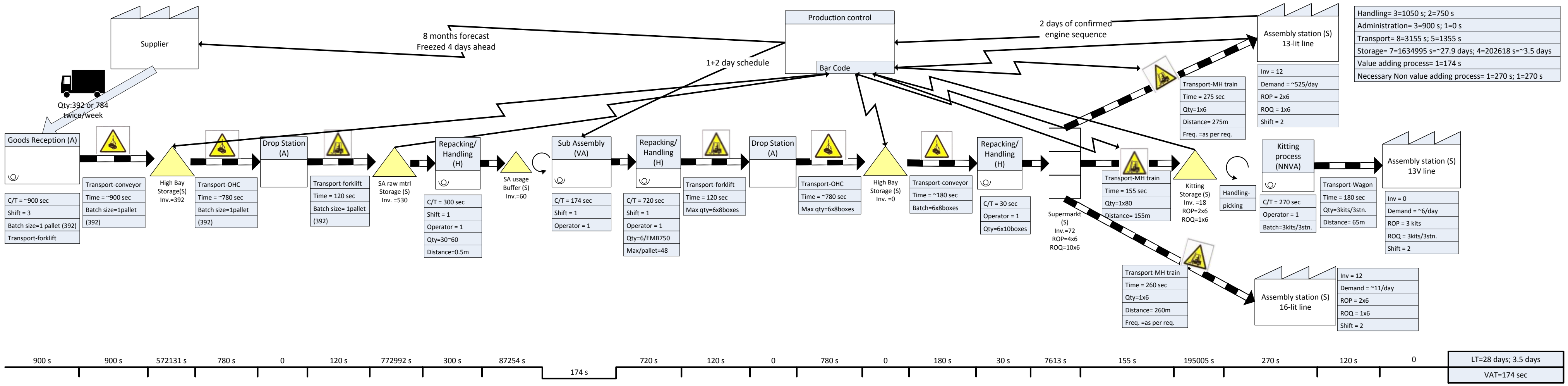
Appendix 5.3: Current state map-3



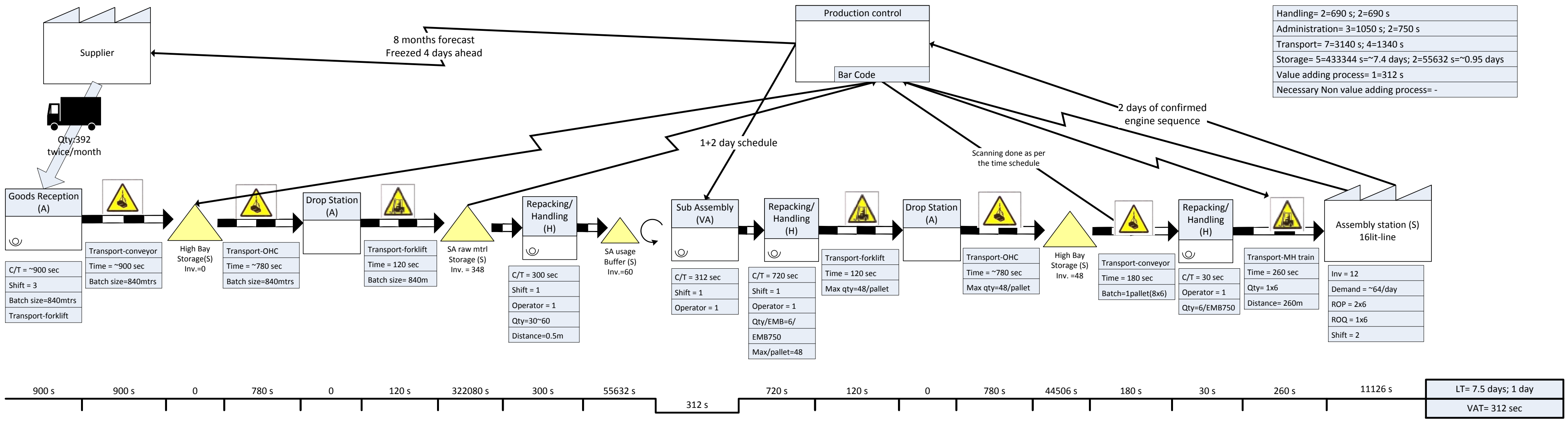
Appendix 5.4: Current state map-4



Appendix 5.5: Current state map-5

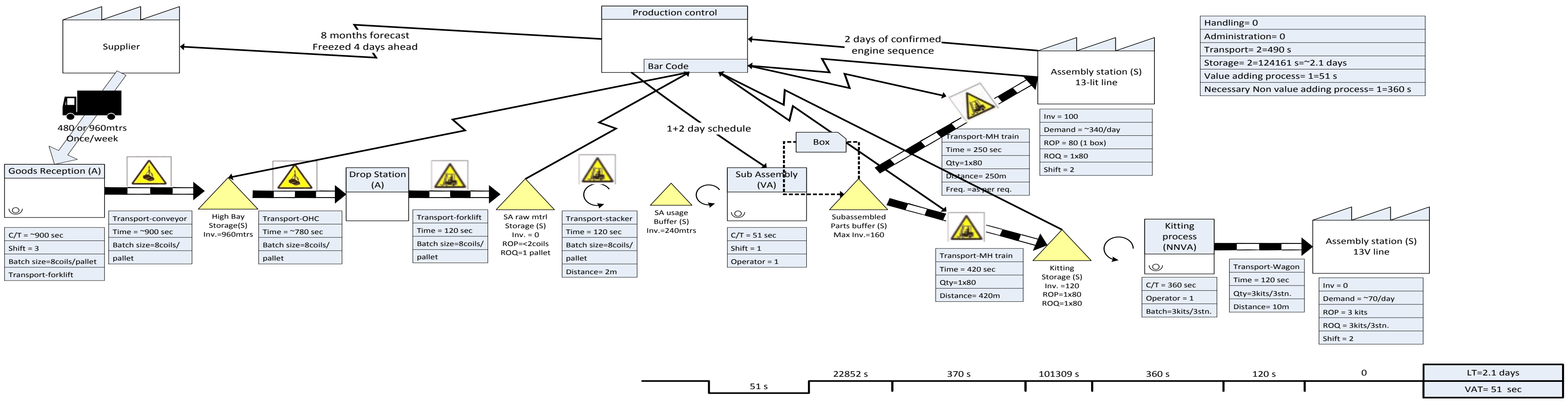


Appendix 5.6: Current state map-6

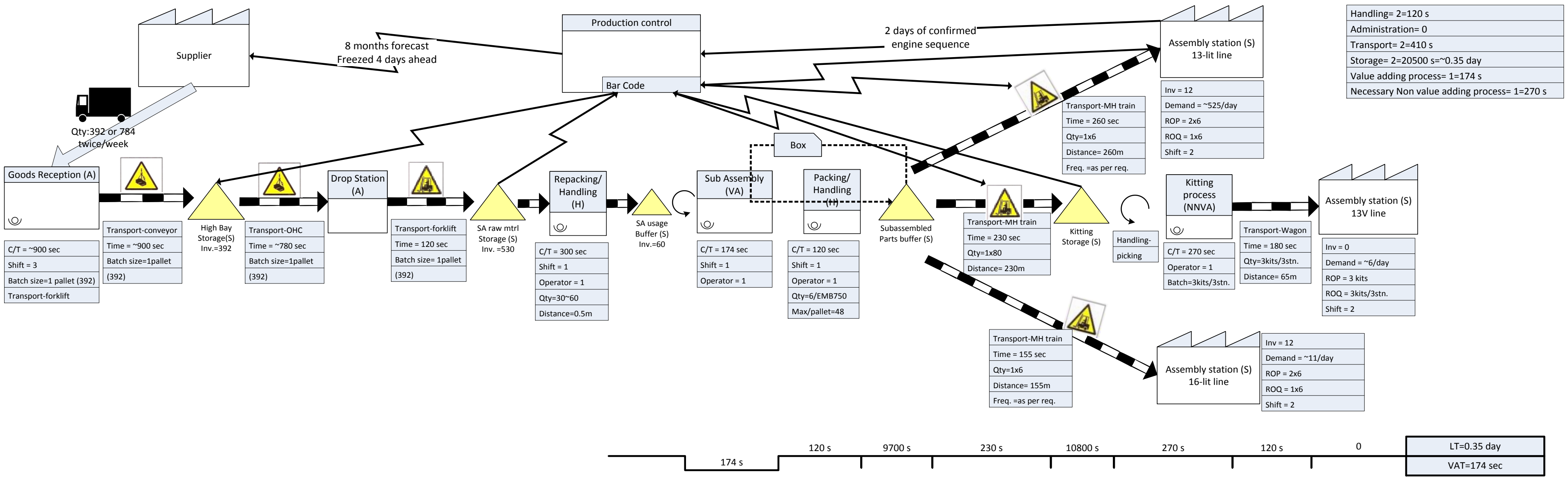


Appendix 6: Future state maps

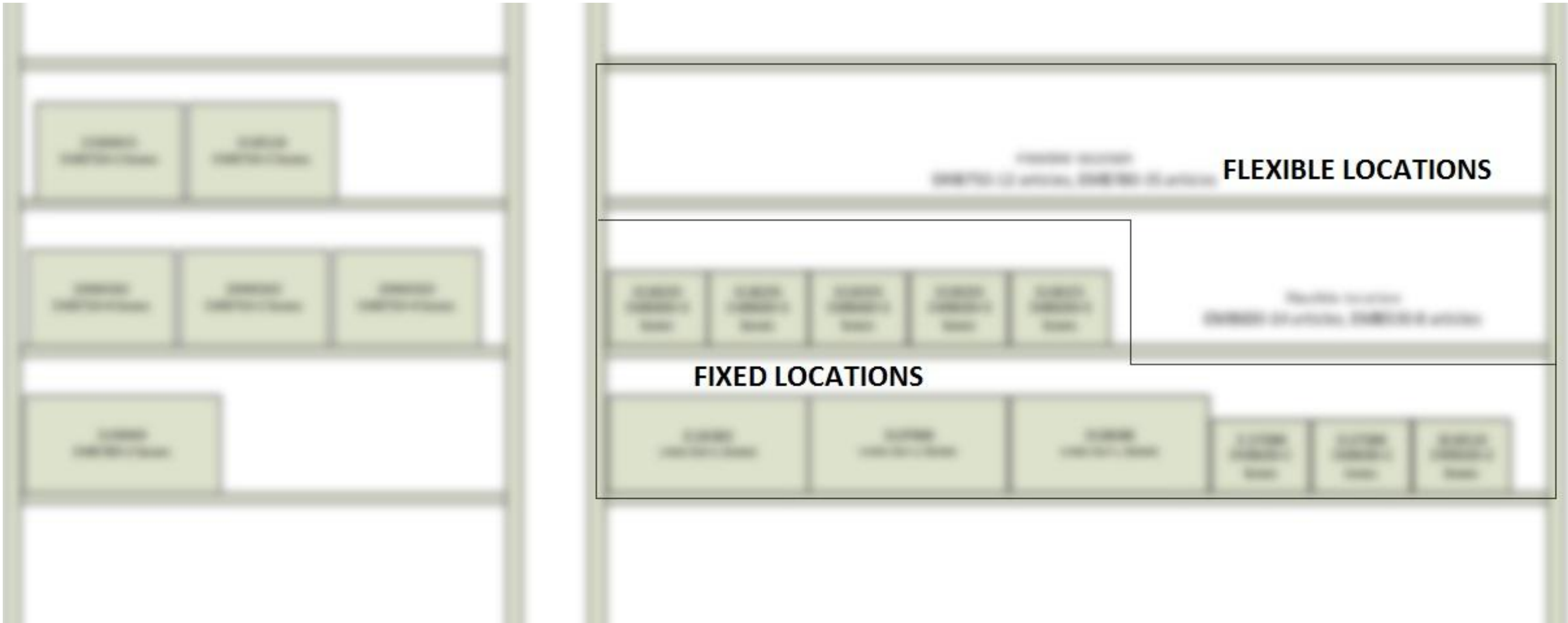
Appendix 6.1: Future state map-slang family



Appendix 6.2: Future state map-startelement family



Appendix 7: Flow Rack Arrangements – *Startelement (left) and Slang (right) family*



Appendix 8: Check list for monitoring the implementation

Checklist for Monitoring the Implementation

S. No.	Description	Yes	No	Corrective Action
1	Subassembly station receives the pull signal via computer system? (for start element family)			
2	Work Instructions updated in accordance with the future state?			
3	Labeling machine gives out labels once the work order is completed and updated in the system?			
4	Overflow of materials in the flow rack? (for slang family)			
5	Flow rack works well from ergonomic view point?			
6	FIFO is maintained for the parts that have more than one location?			
7	Materials handlers face any stock outs in subassembly flow racks?			
8	All materials in its designated location?			
9	All locations in racks are clearly labeled?			
10	Material handling routes are followed properly?			

What is the utilization rate of the route operator? ………………………………………………………….

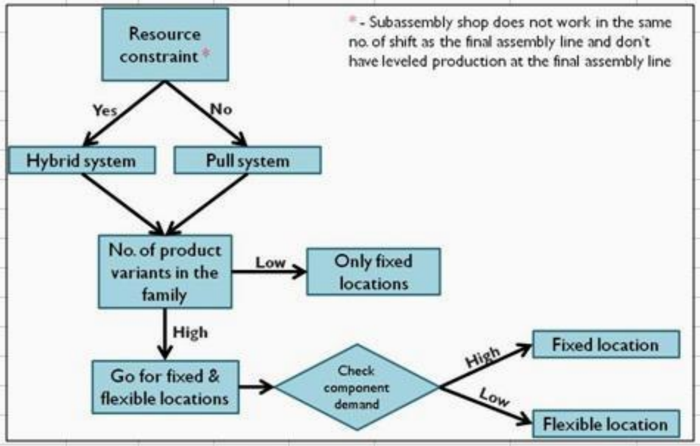
Please describe below for any other problems if exists.

S. No.	Description	Corrective Action

Appendix 9: General deployment model

Based on the flow model(shown in fig) select the type of production system. Next, if the product variety is high for the family being analyzed, fill the details in the below data sheet to get the minimum quantity, replenishment quantity and location details for the articles. Finally enter the no. of articles that can placed in each flexible location for different EMB types and also the length of the rack. (table at the top right).

[Note: All input fields are marked in green color & output are in grey & blue]



Production system	Hybrid
Available assembly line production time (in min)	[illegible]
Lead time for subassembly and packing of 1 EMB (in min)	[illegible]
Number of articles (variants)	5

	Fixed locations		Flexible locations
EMB type	No. of articles	No. of locations	No. of articles
780	[illegible]	[illegible]	[illegible]
750	[illegible]	[illegible]	[illegible]
600	[illegible]	[illegible]	[illegible]
500	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]

Length of the rack	1000
Depth of the rack	1700
Total no. of levels required in a rack (for fixed locations)	[illegible]

No	Art. no.	Art. Name	Demand year	EMB type	Qty EMB	No. of lines, the article is delivered to?	Assy station				Avg. demand/day (in no. of EMB)	Roundoff avg dmd/day (in EMB)	Location in racks	If it is Pull system			If it is Hybrid system	No. of fixed locations needed
							HDE13	HDE13V	HDE16	Konv+ CBU				Minimum qty (in no. of EMB)	Replenishment qty (in no. of EMB)	Inventory (Total EMBs to be stored)	Inventory (Total EMBs to be stored)	
1	20940342	STARTELEMENT KOMPL.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	20940350	STARTELEMENT KOMPL.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	21068425	STARTELEMENT KOMPL.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	3138404	STARTELEMENT F\RMONT.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	3138134	STARTELEMENT,F\RMONT.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6											---	#VALUE!	---	---	---	---	---	---