CHALMERS

PRINCIPLES OF MATERIAL SUPPLY AND ASSEMBLY SYSTEMS IN AN AUTOMOTIVE PRODUCTION SYSTEM

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

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Preface

This report is the result of Master Thesis in Production Engineering supervised by the Department of Product and Production Development at Chalmers University of Technology and performed at Volvo Car Corporation (VCC) Trim and Final Unit, Torslanda, Sweden.

We would like to thank VCC for supplying us with all necessary substances to perform the thesis work, such as information, support, data, working time, equipment and the opportunity to get an insight about the car assembly unit – which is valuable for our future careers. At the same time we would like to thank people who provide us right information at right time for leading this project to a success. We specially thank Dr. Anna Davidson and Mr. Mattias Eliasson for guiding us throughout this project. We also hope that VCC would find use of some of the results and recommendations that we discovered, or at least get some stimulation for their future work.

We are also thankful towards our academic supervisor at Chalmers, Tommy Fässberg, for help and guidance during the thesis work.

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2011-09-05

Abstract

The main objective of this project is to construct and develop a cost model that Volvo Car Corporation can use to determine the costs of the different material flows and assembly systems available in an automotive production system. To achieve the above result, the task requires identification of different steps and principles obtainable in each stage of the material flow and assembly process.

To fulfill the purpose of this study, case study was carried out on few targeted components in downsizing, internal and external sequencing flows. In the above three category, the first task requires identifying different steps and principles within the flow for the targeted components and it is mapped using flowchart.

The next main task was to develop a cost model using ABC costing system. Before developing the model the activities are identified for the targeted components with the resources which it consumes and time it takes to complete the entire process. Time studies were conducted in places where Volvo lacked sufficient data regarding activity time details and other data's were collected according to what is required for the ABC costing system. Finally a cost model is developed using Microsoft Excel mentioning different motives and principles for all the stages.

Contents

1. Introduction

This chapter illustrates the background to the master thesis project and to the Volvo Car Corporation (VCC) followed by problem definition, purpose, objectives and delimitations.

1.1 Background

In today's automotive industry competition is becoming highly challenging. Products are becoming increasingly customized in order to attract customers. At the same time, reduced lead-time, lower cost and improved quality are required. Increase in the customers need on product variety is greatly affecting the material supply system and assembly systems due to increase in the number of components. Due to many product variants, the complexity of material flow is increased which in turn requires more work space at the stations and increases in need of different assembly tools. (E Johansson 2006, Fasth 2009)

The above problem is handled by implementing mixed model assembly system to an automotive production system. Mixed model assembly intends to commonly exploit equipments. Due to this mixed model assembly system many components have to be stocked beside the work station, which leads to difficulty in the material flow. Material flow complexity is handled by following several flow patterns called sequencing, kitting and batching.

To remain competitive in an automotive production, VCC needs to investigate the different principles used in each steps of the material supply and assembly systems and the costs associated with each principles. This is to ensure that the most cost effective solution is being used and proper cost calculation method can be made in an early stage in the planning process.

1.2 Problem definition

In today's automotive industry, increasing customers need on product variety is greatly affecting the material supply in assembly systems which are due to increase in the number of components. Due to increasing variants, Volvo cars find it difficult to deploy proper methods at each step of the material handling and assembly process. Beside there is no appropriate cost tool for calculating the cost incurred per single component in the entire flow of the production system.

Volvo cars needs a reliable tool that could aid in identifying the best principle at each process in the material handling and assembly systems and calculating the cost of the existing and the new components that will be introduced in the assembly plant.

1.3 Purpose

The purpose of the thesis study is to develop a decision support tool that could help VCC for identifying the appropriate principles and calculating the costs of material supply processes and assembly systems in each stage of the flow.

1.4 Objectives

The objectives of the thesis are:

- To identify different steps and principles available in material handling activity and assembly process and to create a flowchart that comprises of all the activities used in each stages of the production system.

- To develop a cost model that aid to estimate the cost of different material flows and assembly systems.

1.5 Delimitation

The delimitations of the project are listed below:

- The study includes only internal material supply and assembly processes.

- Only a few targeted components will be studied to represent the different material feeding systems and parts of the assembly line.

- The cost model will not include overhead costs like electricity, space, information systems running the flow and the capital cost that has been tied up in the inventory.

- Only a final assembly environment has been studied (TC).

2. Frame of reference

This chapter summarizes the most relevant theory that is considered for the study.

2.1 Materials feeding

The process of feeding materials to the assembly line is termed as *"materials supply process"* and the system of supplying materials to the assembly process is termed as "*materials supply system*". Johansson (2006) defines a materials supply system as follows

> "The materials supply system is the system that supplies materials from suppliers through the focal company's production system to industrial buyers. The materials supply system thus comprises materials flow between plants which includes both physical flows and planning and control".

The materials feeding system generally concerns the principle selection in supplying the materials to the assembly line. Johansson (1991) illustrates three different principles of material supply to the assembly line and they are continuous supply, batch supply and kitting, as shown in figure.2.1.

	Selection of part numbers	All part numbers
	BATCH	CONTINUOUS
Sorted by assembly order	KITTING	

Figure.2.1 Categories of materials feeding principles (Johansson, 1991)

In the research paper from Johansson and Johansson (2006), a fourth principle is identified in the material supply which is sequential supply and it is illustrated below in 2.1.4.

2.1.1 Continuous supply

Johansson (1991) illustrates that materials in continuous supply are delivered to the assembly station in units, which are best suitable for handling, and the units are replaced immediately when they are empty in the line. All part numbers required for producing a product will be available all the time in the assembly station. Refilling of parts in the line is usually done by the store men, either in fixed bins or in some sort of two-bin system.

According to Bozer and McGinnis (1992), the most beneficial effect in continuous supply is that preprocessing of the parts is not necessary and more often there will be continuous availability of stock at the assembly line. A good example for this is if any one of the part in the bin is missing or defected, assembly operator can pick another one in the bin. On the other hand there are some disadvantages too, if there are excess numbers of parts to be assembled in the line, a huge capital is to be invested for maintaining the stock and at the same time the shop floor will be overcrowded by the parts. It burdens the operator to move lot many parts here and there and time is lost looking for the right part numbers.

2.1.2 Batch supply

Johansson (1991) illustrates that materials are delivered in a specific number of assembly objects. Batch supply will usually be a batch of necessary part numbers or a batch of specific part numbers in required quantity. The first case differs from continuous supply in the sense that small quantities have to be stored at the assembly line and that different part numbers are filled at different points in time. The left over material is returned back to the warehouse after completion of the batch of assemblies, unless it is to be used in the next batch. This job is eradicated in the latter case, but instead there is a need for counting the parts, which involves technical and administrative systems.

2.1.3 Kitting

According to Johansson (1991), kitting means that the assembly is carried out with kits of components. A set of components for one assembly object is supplied in one kit. This differs from batch supply where components are arranged by part numbers. Kitting supply process is best suitable for assembly systems with parallelized flows, product structures with many part numbers, when there is a requirement of high quality assurance and for high price or value of components.

Some of the benefits of kitting are described below according to various authors:

1. It saves assembly space in the shop floor. (Bozer & McGinnis, 1992; Medbo, 2003)
2. It reduces operators walking and searching time in the assembly. (Johansson, 1991; Schwind, 1992)
3. It has better shop control by just feeding the kit containers rather than supplying every component container in the assembly system. (Bozer & McGinnis, 1992; Ding & Balakrishnan, 1990; Ding, 1992; Medbo, 2003)
4. It reduces the frequency of assembling the wrong component in the end product and missing parts in the end product. (Bozer & McGinnis, 1992; Schwind, 1992; Sellers & Nof, 1989)
5. It reduces material delivery to assembly stations by removing the need to supply individual component containers. (Bozer & McGinnis, 1992; Ding & Balakrishnan, 1990; Medbo, 2003)

2.1.4 Sequential supply

Johansson and Johansson (2006) exemplify that the rapid increase in the product variants during the last decade has made continuous supply impracticable due to high capital investment and lack of space at the assembly stations. Further if the component is assembled on a serial line, kitting is less advantageous as because only few components are assembled at each station. Best way to resolve this issue is to use sequential supply.

Sequential supply means that the part numbers required for a precise quantity of assembly point are displayed at the assembly stations, i.e. the part numbers are sequenced as per the car model that stream in the assembly line. The sequencing operation can be carried out within or outside the assembly plant and it is shown in figure.2.2

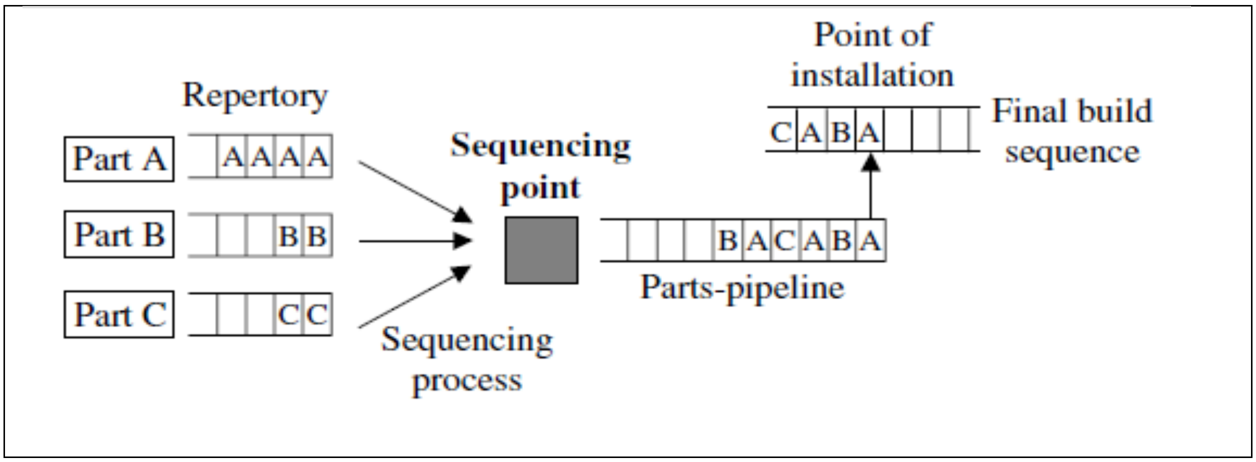


Fig.2.2 Sequencing Operation (Swaminathan & Nitsch, 2007)

2.2 Assembly systems and assembly processes

According to Cochran, et al., (2000) the assembly system consist of various methods of manufacturing and assembling the products to be produced by the production system, together with all actions and supporting functions to make the assembly processes operational.

According to Blackstone & Cox (2008) an assembly line is defined as

> *"An assembly process in which equipment and work centers are laid out to follow the sequence in which raw materials and parts are assembled"*

The different types of assembly processes on an assembly line can be classified according to single models, mixed models (several variants assembled on the identical line, for example with or without sequence control) and multi-models with variants produced in batches (e.g. sequence control).

From the definition of assembly line as mentioned above, the action that take place on the assembly line constitute the assembly process, i.e. the operations required to assemble the raw materials and parts into finished goods or into a component of a higher level.

2.2.1 Assembly workstation

The assembly line is basically a series of workstations (Wild, 1995). A workstation/workspace is a place where designated assembly operations are carried out, by covering a precise area and known work task. Components that are assembled to an end product require series of assembly operations at workstations (Bozer & McGinnis 1992; Bozer & McGinnis 1984).

Assembly workstations are designed according to the layout of the shop, i.e. sequential organization of workers, tools or machines and parts. The motion of workers is reduced to the extent possible. All parts and sub-assemblies are handled either by conveyors or motorized vehicles such as forklifts or order pickers. Heavy lifting in the plant is done by equipments such as overhead cranes and forklifts. Each operator in the shop has to perform designated operations. In closeness to the workplace, the material supply system delivers the material or subassembly parts to the point-of-use. Therefore, the point-of-delivery often decided from the geographical location of the materials coverage, i.e. the transitions between the materials supply system and the assembly process. Further, the term point-of-assembly is the location where the component or subassembly part is assembled to the end product easily. (Finnsgård, 2009)

2.2.2 Assembly workstation activities

Jonsson *et al*. (2004) have divided the different activities of manual assembly into value-adding activities also called direct work and non-value adding activities also called indirect work. Pure assembly work is classified as value adding activity. The left over operations for example materials and tools fetching, walking time, handling time, inspection, adjustments, reporting, consulting, waiting are considered as losses and therefore counted in the category non-value adding.

The transition between materials supply system and assembly process is of much interest and this kind of transition is called picking. Picking is where a component or sub-assembly is ready to pick or retrieve from its uncovered position in assembly station. The picking time is, when an assembly operator picks a component at the workstation, i.e. defined as the time it takes after the finish of the previous activity to the start of the new operation at the workstation. This type of picking is represented by Baudin (2002) as line-side picking.

2.2.3 Assembly workstation ergonomics

According to Baudin (2002), ergonomics is an area closely linked to assembly workstation performance and materials exposure. Baudin states that the working environment for the operator requires sufficient place to work from an ergonomic perspective, ensuring both productivity and safety of the operator. Well-designed workstations are required in avoiding unnecessary strain or injuries to operators and to increase productivity (Falck, 2009). Poorly designed workstations will lead to many types of injuries and other problems like musculoskeletal disorders (Falck, 2009). Back injury is one of the most common categories in occupational injury in the EU, with more than 25% of operators complaining of back pain. This kind of disorders will lead to high indirect costs to reduced overall firm performance. (EASHW, 2009)

2.3 The total cost concept

The main purpose of the total cost concept is to estimate the total cost which is required to produce a component. Total cost analysis is the way to manage the cost of production systems.

The projected cost concept of an assembly system follows the theory developed by Boothroyd (1982) and originates by defining the seven major categories of assembly cost: equipment investment cost, material handling cost, energy cost and consumables cost, maintenance cost, labor cost, space utility and layout reorganization costs.

In Boothroyd (1982), investment cost is defined as the cost of equipment/machinery purchased, tools and other aids used to sustain the assembly activities. It corresponds to the time value of money and payback period. Materials handling costs correspond to the investment on material handling equipment and running cost of moving parts from stores to assembly workstations and warehouses. The replenishment cost is represented by considering the activity time of material handling, which is calculated using Methods-Time Measurement (MTM) standards. The other assembly processes that consume resources like power, maintenance, labor and common utilities supporting assembly are represented as costs.

2.4 Activity based costing

Activity based costing is a system required to determine all the direct and indirect costs that are relevant to value adding activities performed. The idea with ABC is that costs should be allocated to the activity that consumes a resource, therefore activity-based costing traces the suitable resources which it requires for each activity and map out those activities to a particular cost objects. This means cost units are assigned to individual activities, e.g. Picking assembly and quality control using a resource cost driver or activity cost driver (Popesko, 2009).

2.4.1 Implementation of ABC system

Based on Popesko (2009) application of ABC system follows the following steps:

I. Identifying the major activities taking place in an organization: Here the first step is to understand and classify the organization process and then to break down the process to activities and tasks. An activity is defined as,

> "*An activity is a process, function, task, or step that occurs over time and generates results that the company uses to produce and sell its products and services". (SiliconFarEast, 2005)*

A process flowchart should be created for presenting well and understanding activity chain in material flow and assembly systems.

II. Assigning costs to cost pools/cost centers for each activity: To do this, firstly the resources consumed by each activity have to be identified. The resources are usually grouped to labor, equipment, material, facilities and capital. Once the resources used are determined then it is possible to assign costs to cost pools of an activity.

III. Determining the cost driver for each activity: In ABC system for each activity, there has to be at least one activity cost driver. Some activities may have several cost drivers, but only the most relevant have to be used. For a specific activity the cost driver is just a factor that causes or influences costs. The activity cost driver must be directly related to the intensity or effort needed to accomplish the task. A cost driver is usually expressed on a cost per unit basis (Popesko 2009, F. Bartolacci 2004).

IV. Assessing total cost: Once the cost drivers are determined the total cost of an activity is computed as the sum of the used amount of a cost driver in performing that activity by the unit cost of the driver.

2.4.2 Drawbacks with ABC

Despite the fact that the ABC system is more accurate than traditional costing technique in allocating overhead costs, there are shortcomings associated with it. ABC usually processes large quantities of financial and non-financial data, and implementation of the method is complex, time consuming, and costly. The process of data collection and data entry requires considerable resources, and remains costly to maintain (N. Nayab, Jean Scheid, 2011). Beside that, lack of accurate cost data and the difficulty of allocating every resource cost to every activity cause problems (F. Bartolacci 2004).

3. Methodology

This chapter summarizes the working structure of the different processes followed by research methods that are chosen for the study in order to make sure high quality and reliable results.

3.1 Working structure and methods used

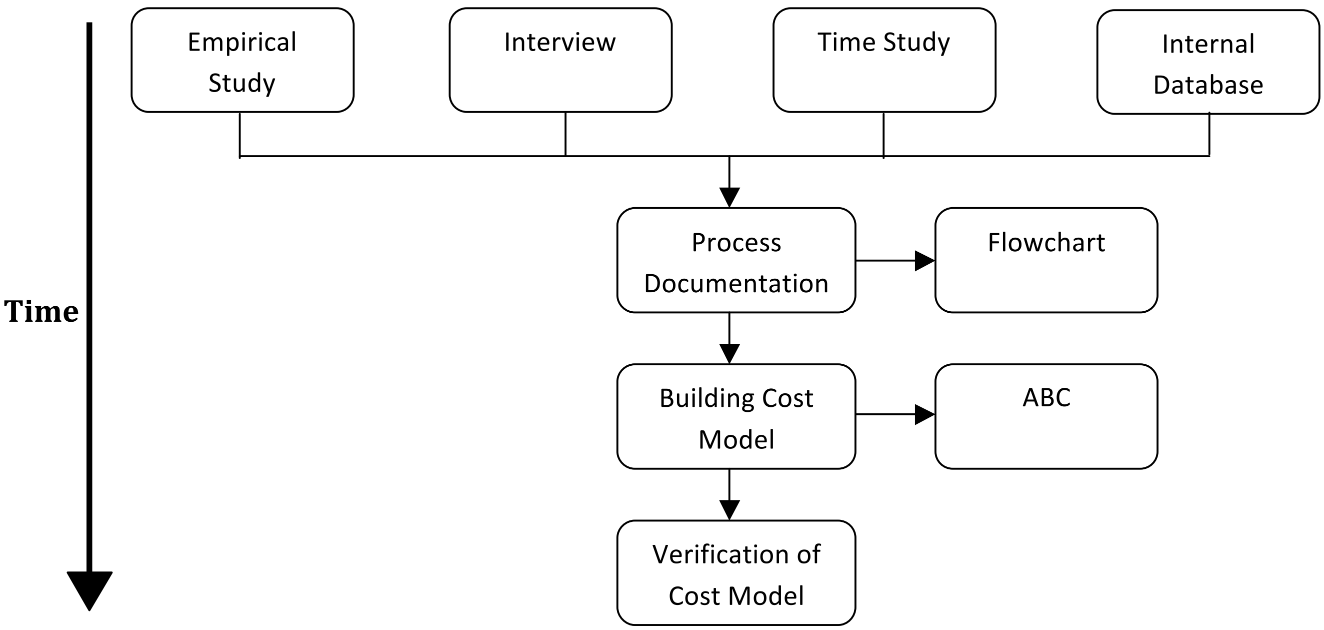


Figure.3.1 The working structure during the project

The study started with searching different theory of referrers in the areas of material supply and assembly system. To know the different process of material supply and assembly systems in the assembly shop, a detailed observation was carried out from the material receiving area till final assembly in the plant. The observation carried out with the assist from concerned personnel's in logistics and local manufacturing engineering and also discussion was carried out about the overall working mechanisms of the different processes.

With the consultation of manufacturing and logistics personnel's, an empirical study was carried out by selecting fifteen target components. The selected components include all category of material supply so that it is able to represent the whole picture of the factory. After that flow charts were used to map the different production flow with the selected components. Process documentation using flow chart or other chart type helps for best understanding of the production flow. The flow charts (see in appendix A) are constructed based on direct observations and interviews made from the plant.

In this project, data collection was carried out through different methods. The majority of the data are collected through Volvo internal data base search and existing documents. Different formal and informal interviews with concerned personnel were carried out in order to verify the accuracy of the collected data. Time study (see section 3.8) was conducted for the data that are not available. Most of the logistic activities time was collected by conducting time studies.

A cost model was then built using an activity based costing system method (see section 2.4). Each process was break down to an activity or task and then documented using flow chart. Then the cost model was developed based on the created flowcharts. The cost model structure was constructed in Microsoft Excel. Finally the model was verified to assess its level of accuracy.

3.2 Research approach

There are many ways to do research and each one has several advantages and disadvantages. The research approach must be determined with regard to the idea and the different type of problem in the research methods. (Yin, 2003)

In research, there are two different types of method used namely inductive and deductive approach. The main idea of inductive research is all about the researcher collects data and develops theory or methodology as a result of the data analysis. A disadvantage with this research method is less possibility that it uses all observations. In deductive research, the researcher develops theory and hypothesis for designing the research strategy and also to test the hypothesis. A disadvantage with this research method is that, it does not describe or develop knowledge but rather set up a rule (Saunders et al. 2003, Fasth 2009). In this study deductive research approach was mainly followed.

3.3 Research strategy

According to Saunders et al. (2003) the research strategy sets a different plan on how to answer the research questions and it includes clear purposes, resulted from the research questions. According to Yin (2003) there are four significant strategies to do research and they are:

1. Experiment
2. Surveys
3. Case study
4. Action research

A case study methodology is one of the most suitable research strategies for 'who or why' research questions, and contemporary event when there is no control on the events by the researcher (Yin, 2003). The case study method contains direct observation of the activities being studied and interviews of the employees involved in the activities. Also, it has the ability to deal with a full variety of data – documents, interviews and direct observations. This study is mainly based on the empirical investigation accomplished by interviews, documentary analysis and direct observations.

3.4 Qualitative and quantitative method

Data can be of qualitative or quantitative in nature depending on how data is collected. Qualitative data is one, which people say about their meanings and interpretations. Qualitative research in general involves qualitative data, i.e., data acquired by means of interviews, on-site observations and analyzes data that is in narrative rather than arithmetical form. Quantitative methods can be illustrated in terms of numbers and figures that are examined with numerical and statistical methods. However most of case studies are related to qualitative in nature. (Bockmon and Rieman, 1987)

To accomplish the objective of this study, a mixed approach has been applied. The end result of plan has a quantitative nature and is represented in figures while qualitative studies were required to analyze the costs in the cost model.

3.5 Data collection

There are two ways of collecting data, one is secondary and other is primary. Secondary data is one which is collected already, i.e. it can be found in journals, books, databases or in the internet. Primary data is collected for the first time for the purpose of the research at hand. The data is usually collected based upon observations, interviews and experiments and it will be documented for analysis purpose. (Yin, 2003)

For better achievement of the objective of this thesis, both primary and secondary data were utilized. Primary data was mainly gathered through interviews with employees and through direct observations at the shop floor. The secondary data was gathered using internal database from the VCC internal web page.

3.6 Validity and reliability

Reliability and validity are very essential and basic characteristics of any research measurement procedures. Reliability refers to the consistency and repeatability of measurement results. Validity indicates the accuracy of method of measurements and if they are truthfully measuring what they are intended to measure. (Golafshani, 2003)

In order to ensure high validity concerning the primary data, interviews were conducted with the employees. These interviews have mainly been conducted with the operators as because they know much about the process knowledge. Personal interviews and observations were made to map out the current material flows so that confusion could be evaded and to assure high validity. To increase the reliability about the primary data, the results from the interviews with the operators were confirmed by interviewing the production engineers. The respondents have strong knowledge about the various activities and they are well suited in answering all queries and verifying the results.

It is assumed that all the secondary data gathered through books and articles are reliable and truthful. Data which are gathered from the company (VCC) internal database and from necessary documents are also assumed to be updated regularly.

To enhance the dependability and the level of accurateness regarding time studies, the time required to finish each activity has been measured three times to get the mean value. It is necessary to note that the times studied might not be the exact time.

3.6.1 Literature study and interviews

Literature study was carried out first within the subject and then followed by a brief empirical research. As one part of the project was to map out the internal material handling activities, process documentation was formed based on the empirical research.

3.7 Process documentation

According to Harrington (1991), a process is any kind of activities that takes an input, adds value to it and provides output to an internal or external consumer. According to Ungan (2006), a process is essential for all kind of organizations before it challenges to process related initiative.

Organizations generally document and map their processes in the purpose of illustrate, analyze and develop their processes. It is classified in to two categories: process flowchart and process map. Both represent the same function. Before developing the process documentation certain steps to be followed for the success of documentation and the effective use of resources.

According to Ungan (2006), the important thing for process documentation is to select the process first in a constructive way. The objectives should be clearly defined why this process needs to be mapped, i.e. is it just for briefing the process or is it for improving the process. Many authors indicate that the process map should be short, precise and understandable. On the other hand the process must be documented in a detailed manner in order to make further improvements, i.e. brief mapping or description of the entire process is needed.

Different methods can be used when collecting necessary information for process documentation. There are two common ways of documenting; one is by interviewing and second by team methods, where both the interviewer and the team members should have a great expertise and knowledge about the processes. Interviewing is appropriate for complicated processes with few members and limited scope. Other way of documenting is gathering information based on observations and translating old written documents. Once all information has been collected and prior to start any improvements, a clear definition of the process must be made. The current process performance is also important to identify the process measure, which differs based on application area.

According to Ungan (2006), the information should be collected from the one who has more knowledge and experience about the processes. When adequate information has been collected, the interviewer needs to step in to the process with a "process master" to see if the information is correctly understood. The concepts are written down once when the interviewer and the team members agree with the process master.

The different steps to be followed during the process documentation can be seen in figure.2.2

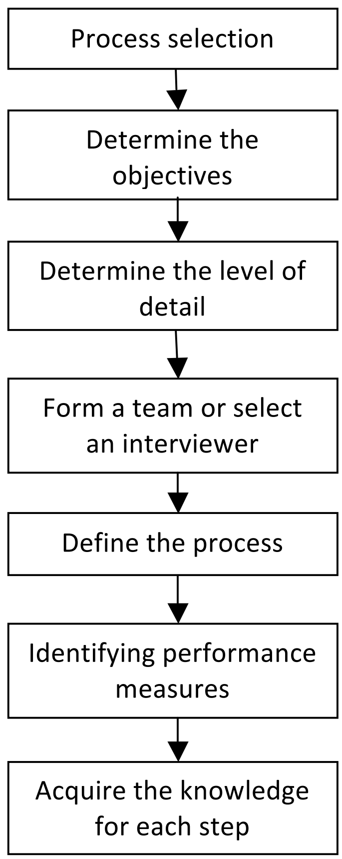


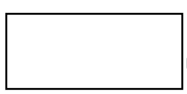
Figure.3.2 A step-by-step procedure for process documentation (Ungan, 2006)

Process documentation was very much important for better understanding about the plant and different processes and also helps to create a better cost model at the end. The first step in the documentation is to gather all sorts of information about the different processes. To get the right information, it is necessary to speak to the right person with the right knowledge. Information was also collected through previous printed documents and also it is necessary to collect from the employees at the department of Logistics and Local Manufacturing Engineering.

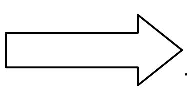
To understand the various processes of material supply and assembly systems, a thorough observation was carried out by going through the different flows with the concerned personnel's from logistics and local manufacturing engineering and also discussion was carried out about the working structure of the different processes. After collecting all the information's, first version of the flowchart was created. The information gathered was verified with the employees in order to confirm the flowchart created was correct or not. The flowchart was created as a basis for developing the cost model. After the final flowchart was created, it was verified with the concerned personnel, i.e. engineers at both the department and the employees working with the different processes have the chance to check the flowchart.

3.7.1 Flowchart

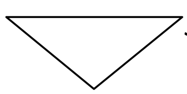
According to Harrington (1991), one way to document or map the process is by creating a flowchart. A flowchart is a step-by-step process that illustrates existing or new process by using plain symbols, lines and words to pictorially exhibit the activities and sequences in a process. Flowcharts graphically symbolize the activities that build up a process. An advantage of using flowchart is different elements can fit together. Standard symbols are mainly used for constructing a flowchart, the most used and common ones are:



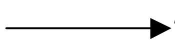
Operation: A rectangle represents if there are changes in every activity. It is used to denote the different activity/process with a short description in the rectangle.



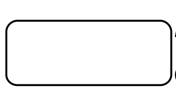
Transportation: A block arrow is used if there are any transport activities, for example transporting parts from warehouse to assembly.



Storage: A triangle is used if there is any storage between each activity.



Flow direction: A line arrow is used to represent the direction of the work flow and also to represent the connection between two activities.



Boundaries: An elongated circle is used to represent both the start and end of a process.

3.8 Time study

Time study is a direct and continuous observation of any activity by using digital stopwatch device to record the time it takes to fulfill that activity. It is often used where there are repetitive tasks of short to long duration and extensive variety of dissimilar work. The main purpose of a time study is to determine the dependable time standards for the efficient and effective management of operations (Wikipedia, 2011). In this project, when determining the activity time of each activity, time study was conducted three times at different intervals and average values were taken. This will help to reduce possible variations and errors. The values obtained from each time study carried out at different intervals of a specific activity are more or less similar and it is found that clocking three times for each activity is adequate.

3.9 Cost model

Before determining the cost, a process flowchart was created for the material flow and assembly process. Each process has been broken down to activities and in each process all possible principles that could be used was also identified. Once detailed flowcharts that show all the relevant activities have been prepared it was time to determine the activity cost. To assess the activity cost, the resources utilized by each activity was identified.

A cost model was developed once the different costs were identified. The model is fully constructed in Microsoft Excel to make it easy for understanding and to use it. Microsoft Excel is selected as it is widely used at VCC and therefore everybody can make use of it easily. Then finally validation of the cost model was done.

4. Current state analysis

This chapter summarizes the material supply, assembly and control processes. The explanation is based on personal interviews conducted with the employees and direct observations at the shop floor.

The different steps available in the production system are *internal transport, repacking, replenishment, securing right article mounted, lifting, assembly and control station process*. In each of these processes, several principles were indentified and are discussed one by one as follows.

To create a better cost model, a thorough understanding about the material flows and assembly systems in the plant is necessary. To get this understanding of both the systems, fifteen components were selected. To study the flow thoroughly for the fifteen components, flowcharts were created. Each flowchart denotes different flows in material handling and assembly systems. The flowcharts are based on the interviews and observations made from the plant.

4.1 Internal transport process

The internal transport process major task is to unload the material from the truck and transport it to different warehouse and temporary storage area in the plant. It also includes the transportation or returning back of the empty packaging to the truck again.

Once the material is received from the supplier in to the different receiving gates like TB1, TV1, etc., the different emballages that are available inside the truck will be unloaded by the forklift operator. After unloading from the truck the forklift operator has allocated space to keep it temporarily in the ground. Once all the goods are unloaded it is verified for the right type of component is received with right quantity at right time using scanning machine in the forklift.

Transportation of materials from receiving area to main warehouse is shown in figure.4.1.

Figure.4.1 A forklift picking the pallets from material receiving area

From the unloading place, the goods will be transported to warehouse by forklifts, train wagons or conveyors, i.e. if the components are needed to be sequenced internally or downsized to specific unit loads as per the different car models and production order, it will be transported to warehouse else it will be transported to a temporary storage area near the assembly line. The components are stored in the storage racks after it is transported to the warehouse.

Different emballages consists of various components are transported from receiving area to main storage in train wagons, is shown in figure.4.2.

Figure.4.2 A train wagon loaded with blue boxes and pallets

The material arrives in different emballage types. The most common is pallet type but other packaging's are also used, i.e. bigger part size with no variants are received it by combitainers, bigger part size with different variants are received it by external sequencing racks and smaller parts are received it by small blue boxes. All empty emballages are returned back to the truck if all the components inside the container are emptied.

The different emballage types (principles) used in internal transport are *pallet, box, combitainer and external sequencing rack*. All four types of emballages are explained below.

The ***pallet*** type emballage is used for material handling in the warehouse, i.e. to transport material from receiving gate to warehouse, from warehouse to shop floor and empty packaging inside the plant.

All pallet goods received from the supplier will be unloaded from the truck in the receiving dock at TB1 and TV1. Each pallet will have specific ID with unique part number, quantity available and car model. All pallet ID's are verified for right amount of quantity at right time using the scanning machine. Most of the pallet materials are transported using train wagons and some of them are placed on conveyers to transport it to main storage racks.

The ***combitainer*** type emballage is mainly used for material handling of large items/goods in warehouses. The combitainer materials have allocated space to store it in warehouse or it can be stored temporarily in assembly line side. After production order is received, the materials are repacked to other specific container as it required by the assembly line. The advantages of using combitainers are fast shipment to warehouse and for bigger part size. The empty combitainers are transported back to the concerned warehouses.

The ***box*** type emballage is used for material handling of small items/goods that enter the plant. Blue box materials are stored in specific racks as it is allocated. Some components in the blue box are delivered directly to the line due to high frequency and some of them are repacked to small blue box as it required in the assembly line. Repacking to blue box is mainly based upon production order/requirement and space availability in the assembly line.

The ***external sequencing rack*** type emballage is used for material handling of large items with many variants. The components are sequenced externally by the supplier in the sequencing racks due to large variants, space constraint in plant and assembly line and product specification.

4.2 Repacking process

Repacking process major task is to repack/downsize components of specific quantity in to smaller blue boxes. When repacking is necessary the components in bigger emballages are unloaded from the storage racks in the warehouse, transported to the repacking/downsizing place by forklift, downsized to defined unit loads as per the component usage in the line, transport it again to main racks and stored for a temporary period.

As soon as the production order is received, components are delivered to the assembly line. The repacking principle *blue box* is described below.

The downsizing/repacking activity is carried out by manually in the downsizing station (TV) which is called “Market Place”. The components are repacked to smaller blue boxes in downsizing station and it is specified with the new ID sticker mentioning the new unit load, part number and component name. After placing the new ID sticker in the boxes, the label is scanned for the database purpose.

The re-packing activity carried out by an operator in the downsizing place is shown in figure.4.3.

Figure.4.3 Re-packing activity

The components that are used frequently in line are not repacked; rather it goes to assembly line in same packaging as it received from the supplier. The components that are received in pallets are stored in the warehouse and feeded to the assembly line in the same unit load. Similarly the components that are received in combitainers are stored in an allocated place inside the shop floor and feeded to the assembly line in the same unit load as it received from the supplier. The components are delivered to the line based upon the production order.

4.3 Replenishment process

Replenishment process major task is to refill the components in the assembly line, i.e. before the component gets emptied in the line it is to be refilled with the new ones. The replenishments are based upon the production order from the assembly.

Once the materials are prepared in different emballages as it required, it is delivered to the assembly line using various transport modes like forklift, train wagons and order pickers. The empty emballages are transport back to the material preparation area. The replenishment of material is carried out based upon six different principles.

Replenishment of materials from storage to assembly line is shown in figure.4.4.

Figure.4.4 Replenishment of goods in train wagon

The different types of principle used in replenishment are *pallet, box, batch, internal sequencing rack, kitting and external sequencing rack*. All principles are explained below.

In ***pallet*** type principle; material will be ordered by pre assembly and assembly team as a full pallet or in a certain quantity. Some of the low frequency materials are repacked in fewer quanitites and delivered to assembly line.

The components that are not repacked and stored in the warehouse (TV) are transported to assembly line using forklift. The advantages of using pallets are fast shipment to line, easy way of handling, part geometry and also when there is high frequency of usage in line. The empty pallets are transported back to the particular warehouses (TV/TB).

In ***box*** type principle; the downsized materials are transported using order pickers from market place to the assembly line (TC). Blue box is mainly used for small sized components like fasteners, bolts, etc. The advantage of using blue box is that it can accommodate several boxes with different part numbers in the same order picker, which is a time saving process. Similarly it requires less space in the line as it is possible to stack several boxes in a single rack.

On the other hand if the assembly workers have emptied the box in the rack, they remove it and the next one slides forward automatically. The emptied one is kept down in the rack for the order picker to replace it from the line. The order pickers pick the empty boxes and transport it again to the warehouse (TV). At the same time the empty boxes can fit inside the other without the lid while transporting.

The ***batching*** principle is similar to pallet process, i.e. the material will be delivered to line in pallets without any repacking activity. Due to few variants available in the product, the forklift operator takes few batches in each pallet and feed it to the line. Batch supply will be usually a batch of specific part numbers in required quantity to line. After all batch items are emptied, the pallets are returned back to the concerned warehouses.

In ***sequencing*** principle the components with many variants are sequenced in the sequencing racks. The sequencing operation will be carried out in allocated place by using voice picking operation (see figure.4.5), i.e. the operator receives information from the system about the component picking in the repertory through headphone device. The system tells which component to pick at what sequence in order to put in sequencing racks.

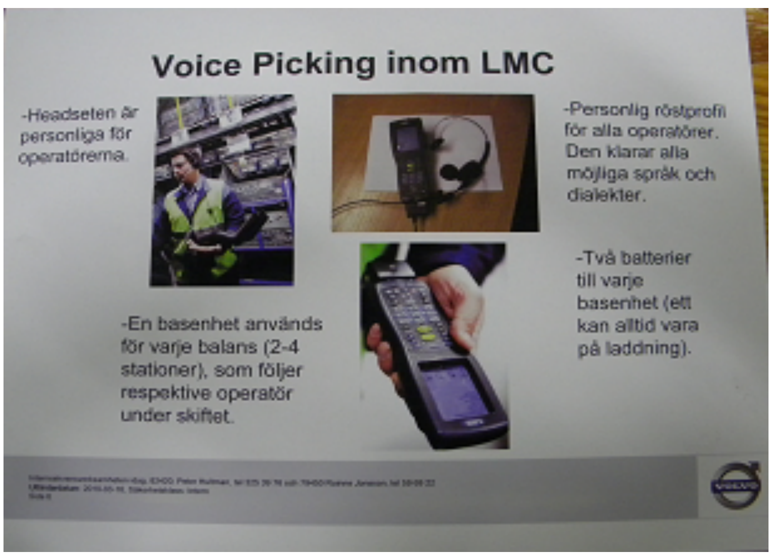


Figure.4.5 Voice picking operation instruction sheet

Some of the sequencing operations are usually carried out in warehouse (TB1) and some of them in the assembly line. The advantages of using sequencing are to reduce space in the assembly line when there are many variants and different product specification for the same component. After the sequencing process, the sequencing rack (see figure.4.6) is transported to the assembly line using forklift and the same forklift comes back with the empty rack.

Figure.4.6 Sequencing rack loaded with materials

In ***kitting*** principle, the variety of parts with many variants that are to be assembled in the same station are kitted in the sequencing racks. The kitting operation will be carried out in allocated place by using voice picking operation. The difference between sequencing and kitting are, in sequencing only one component with many variants are sequenced in the sequencing racks whereas in kitting if there are assortment of parts with many variants that are to be assembled by the same team in the same station are kitted in the sequencing racks.

Some of the kitting operations are usually carried out in the warehouse (TB1) and some of them in the assembly line. The advantages of using kitting are to reduce space in line, reduce transportation and minimizing the risk of assembling the wrong component due to large variants. After the kitting process, the kitted component in the sequencing rack is transported to the assembly line using forklift and the same forklift comes back with the empty rack to the warehouse.

In ***external sequencing rack*** principle; the supplier will be responsible in delivering the sequenced materials to assembly line. After it is received from the supplier it is stored temporarily in the allocated space near the assembly line. From temporary storage it is transported to assembly line using forklift. The same forklift replaces the empty one with the new one to the line. The empty racks are delivered to the truck immediately.

4.4 Securing right component process

The major task in this process is to secure the right article from the assembly line storage i.e., before it is lifted to the car, an operator has to know which component should be assembled to a specific car.

The different types of principle available in securing right article mounted are *specification sheet, pick-to-light and scanning*. The components that are secured based on the above principles are explained below,

The first principle in securing right component process is ***specification sheet***. The specification sheet (see figure.4.7) has different part numbers that are to be assembled in the specific station. At the start of every station in the line, specification sheet will be stick to the car by an operator. Also at each station, there is an instruction or work element sheet that shows detailed operating instructions of the assembly process. It is mainly for new employee who works in the line.

Whenever a new car arrives to the station, an operator reads the part number in the specification sheet and he has to look for the exact part number in the line storage to eliminate uncertainty in picking the component.

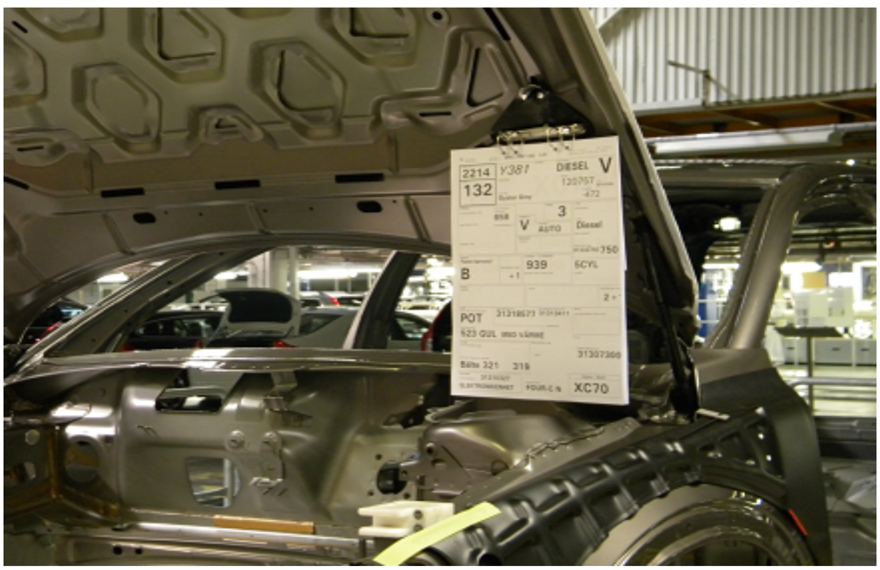


Figure.4.7 A specification sheet with many part numbers hanging in the car

The second principle is ***picking to light*** method (see figure.4.8); where it indicates the operator to pick the right component in the line storage, i.e. the equipment is an effective error proofing device by directing the operators to pick the right parts and quantity of each required. The advantage of using pick to light is if there are many variants in the identical component, the device will point out the right one to pick it from the box that are shelved at the racks.

The device has both green and red lamp at the top of the specific station. If the operator picks the right component it glows with green lamp else it glows with red. The below figure shows pick to light device with different boxes shelved at the racks.

Figure.4.8 Pick to light system for components with many variants

The last principle is ***scanning*** system; where it is mainly used to scan the sequenced and kitted components in the assembly line. Once the components are replenished, the operator in the assembly line scans the document which is available in each tray inside the sequenced rack.

The sequenced and kitted components are individually numbered and assigned with corresponding bar code from the information system. The operator scans the bar code to identify that the right component has been picked from the tray. Once immediately after scanning, the specific number assigned to each component are stored automatically in the database and it is used for follow up in the future.

4.5 Lifting process

Once the right part number is identified by the operator, it is lifted to the car either based upon the following three principles namely *manual, semi-automatic and robot*. The different lifting principles are explained below,

The first principle is ***manual lifting*** process; where lifting/picking is carried out only by the operator. If the components are in small size and with less weight (less than 5 kg), components are lifted manually. Lifting by manually is based upon certain ergonomic criteria such as weight of the part to be lifted, the part distance from the body, the part travel distance, the employee work posture, the velocity and acceleration of the lift, the lifting frequency and the physical capabilities of the employee.

The second principle is semi-automatic lifting (see figure.4.9); where an operator uses the lifting equipment to fetch the part. It is mainly used for parts - weighing more than 5 kg, difficult in handling and to be lifted frequently in the line. If the part has to travel certain distance from line storage to assembly spot, the part is lifted with the help of specially designed lifting equipment. These kinds of lifting equipments are available in many stations in the plant. The main advantage of semi-automatic lifting in the assembly is to pick the heavy component, reduce lifting time and to reduce operator fatigue and injury.

Figure.4.9 Semi-automatic lifting process

The third principle is robot lifting; where lifting is carried out only by robot. It is mainly used to lift parts - weighing more than 5 kg, to move in difficult positions inside the car, to lift in high positions and also if there is high frequency in line. Robot lifting is very limited in the assembly plant when compared with other two categories. The main advantage of robot lifting is to save a large amount of time in the lifting process and it does not require any manpower.

4.6 Assembly process

After picking the right component, it is assembled to the car based upon following four principles namely manual, hand-tool, machine and robot. The four principles are explained below.

The first principle is manual assembly process; where components are assembled to the car physically as per the work element sheet. Some component may require more than one more principle to assemble in the car, i.e. it requires manual first and then necessary assembly equipments based upon the assembly process. For example: shark fin antenna is a component where it requires both manual and robot assembly in the car, i.e. it is first assembled manually by an operator and then sticking operation is done by a robot. Similarly there are lots of operations of this kind available in several stations.

The second principle is hand-tool assembly process; where fastening operations in the assembly are carried out by an operator with the help of a pneumatic or electrical nut runner. Some fastening operation requires certain torque requirements, where it will be connected to the

CC1 (Consequence Class1, which measures tightening of screw joints automatically) measurement program to meet the exact torque specifications. The main advantage of using hand tool is to eliminate non-value adding time in the assembly process.

The third principle is machine assembly process; where specially designed instruments are used to assemble the components. It does not require any manpower to do the operation. The main advantage of using machine is to reduce operation time and improve quality in the assembly.

The last principle is robot assembly (see figure.4.10) process; where assembling the component to the car is accomplished by robot. The robot will do the assembly process automatically as per the pre-defined program. The main advantage of using robot is to reduce non-value adding time in the assembly process, cost efficiency over labor cost and improve quality in the assembly.

Figure.4.10 Robot assembly process

4.7 Control station process

The main objective of control station is to ensure that a component is secured properly during assembly operation. Depending on the component type and criticality, several types of checks like point of assembly, torque specifications, functionality of component or system etc are carried out. In the control station process five types of controlling methods or principles are identified as follows, which are self control, manual control, standardized inspection point (SIP) control, CC1 measurement program and vision camera. All the five principles are explained below,

Self control/no control is the standard method, where the assembly operator who accomplishes the assembly operation is also responsible for controlling. For the majority of the components there is no separate controlling system performed. In this method there is no dedicated resource assigned for control process.

Second principle of controlling process is manual checking, where an independent operator checks whether assembly operations are done as per the requirements. The operator assigned for controlling process checks like presence of component, alignments, and marks on preformed activities etc.

The third method used is SIP-control which is also a manual control done as quality check. This quality check is made for some components by separate operator, just manually aiming to eliminate major fault in further assembly.

Fourth principle of controlling process is CC1 measurement, which is computerized way of controlling. Some fastening operation requires certain torque requirements, where it will be connected to the CC1 measurement program to meet the exact torque specifications. The main advantage of using this measurement program is, when the tightening of screw joint fails to meet the exact torque specifications, the system will alarm and so the operator can tighten it properly. Here, for the purpose of controlling process, equipment like display hardware, processor and software are only used.

The last principle is vision camera (see figure.4.11) which is mainly used for process control, complex assembled parts and if many parts/check points are to be checked in fraction of time.

Figure.4.11 A process control vision camera

5. Development of the cost model

A cost model that used to calculate the cost incurred in the entire flow of material and assembly of a single article to final product has been developed to be used at VCC Torslanda assembly plant. Accurate and up to date input data is necessary in developing useful cost model. Great effort is taken in collecting and using the right input data. Both historical and time study data was used to assign the cost to each activity in the material flow and assembly operations.

For data that are not available and difficult to obtain, time studies were conducted. The time studies conducted in the plant are carried out for three intervals and average value was taken in order to reduce the influence of possible variations and errors. The resulted cost is more or less based on effective time of the activities.

5.1 Identifying the resources

Activity based costing system is mainly based upon activities, where it may or may not require resources to perform any task. To determine the activity cost, the resources consumed by the activities needs to be identified. In this study, the resources considered are grouped to the following categories:

Labor- considered whenever manpower is involved in performing any task or activity.

Equipment- while performing each activity, different equipment may be required. Those equipments include:

- Transporting/material handling equipments like forklift, train trolleys emballages, racks, order pickers etc
- Assembly/lifting equipments like hand tool, machine and robot
- Other equipments like Poka-yoke, scanner, vision camera etc

Maintenance and ***service-*** equipments are repaired when it gets breakdown and they need planned preventive maintenance and services to function properly.

5.2 Stating the cost driver

Cost driver enables to assign costs to an activity (Popesko 2010). The cost driver indicates how much effort is required to perform a task. In this study, an activity time is the cost driver. In order to assign cost to an activity, activity time to each activity has been collected through time study and from existing database.

5.3 Assigning costs to activities

The costs incurred by each activity are stipulated by activity time which is the cost driver. The different resource costs are labor cost, equipment cost, maintenance cost and service cost. Allocation of costs to a specific activity in each process is shown below.

5.3.1 Receiving and warehousing process

The receiving and warehousing process activities needs labor resource to drive forklift/truck and perform receiving activities. The equipment resources included in the above process are forklift truck, emballage and sequencing rack.

To calculate the labor cost, average hourly wage of employees working in all area both at day and evening shift was collected from responsible personnel of plant man hour control. Since the activity time is stated in minute, any cost related to an activity has to be also stated per minute. Therefore, the average hourly wage of an employee is also converted to wages per minute (man-hour cost per minute).

Equipment cost is contributed by forklift rent, emballage rent and rack. Rental cost of the forklift differs from model to model. To get the equipment cost of forklift, the monthly rent is divided by the total available minutes per month in both working shifts. To calculate the emballage cost per activity, yearly rental cost is divided by total number of round usage per year.

Maintenance and service cost of the forklift is calculated based on the previous year data. Total yearly maintenance and service cost incurred by the forklift is divided by total available minutes per year to get the cost in minute. All costs are expressed in Swedish Crowns.

5.3.2 Re-packing process

Re-packing process needs labor resource, forklift, repacking station equipments and maintenance and service resource of the equipments. When calculating labor cost, forklift rent cost and maintenance and service cost of forklift, the same procedure is used as mentioned in the previous section 5.3.1. The re-packing station equipments (which includes camera, computer, working table, etc) costs are calculated based on the initial installation total cost. The total installation cost is then distributed to service time and finally stipulated to rate per minute.

5.3.3 Replenishment process

Replenishment using sequencing and kitting rack uses labor resource, forklift, sequencing rack and maintenance and service resources. When calculating labor cost, forklift rent cost and maintenance and service cost of forklift, the same procedure is used as mentioned in the previous section 5.3.1. Equipment cost of sequencing racks and kits are calculated based on initial buying cost and rebuild cost and the same cost is distributed to the expected working life of the equipment. Finally the cost for one round or batch is determined by assigning cost to activity level.

Replenishment using other methods utilizes labor resource, forklift and maintenance and service resources. The cost is calculated and determined with same approach as discussed in the previous chapter.

5.3.4 Securing right article mounted process

Securing right component is mounted by specification utilizes labor resource which contribute labor cost. Securing using pick to light needs labor and Poka-yoke equipment, which results into labor cost, equipment cost and maintenance and service cost. Securing by scanning needs labor and scanner system, which results into labor cost, equipment cost and maintenance cost. When calculating the equipment (Poka-yoke, scanner system) cost, the depreciation cost per year is determined and divided by the total available working minute per year to state the cost in minute. Maintenance and service cost for these equipments is based on data obtained for the year 2010 and to put this cost in minute the yearly maintenance and service cost is divided by the total available working minutes per year.

5.3.5 Lifting component process

Lifting process manually needs labor resource as a result labor cost is only considered. Semi-automatic lifting utilizes labor and lifting tool/machine, which results into labor cost, equipment cost and maintenance and service cost. Lifting by robot needs equipment resource and therefore it results into equipment cost and maintenance and service cost.

In calculating cost, the equipment cost for lifting tool and robot is determined based on depreciation in each year. The depreciation cost per year is divided by total available working minute per year in order to state the cost in minute. Similarly, maintenance and service cost is calculated based on data obtained in the year 2010 and to put the cost incurred in minute, the total annual maintenance and service cost is divided by total available working minute per year.

5.3.6 Assembly Process

Manual assembly needs only labor resource and generates labor cost. Assembly using hand tool require labor and equipment resources, which generate labor cost, equipment cost and maintenance and service cost. Assembly by machine or robot utilizes equipment resource, which generate equipment cost and maintenance and service cost.

Equipment cost of machines, hand tools and robots was stipulated based on depreciation cost per year. In order to put the cost in minute the depreciation cost per year is divided by total available working time in minute per year. Maintenance and service cost of these equipments is also determined based on data obtained in the year 2010 and to mention the cost incurred in minute, the total annual maintenance and service cost is divided by total available working minute per year.

5.3.7 Controlling process

Self control does not require any resource and therefore results no cost. It is part of assembly process which is performed by the assembly operator. Manual and SIP control uses labor resource and generate labor cost only. CC1 and vision camera control uses equipment and consequently generate equipment cost and maintenance cost. Depreciation cost per year was considered when determining equipment cost of CC1 and vision camera. Annual depreciation is divided by total available working time in minutes per year to put cost in minute. Similarly for the other equipments, the maintenance cost is calculated based on the year 2010 cost data and to mention the cost incurred in minute, the total annual maintenance cost is divided by total available working minute per year.

5.4 Computing activity total cost

Once the activity time and resource cost is determined, total cost of each activity is computed. Activity time is multiplied by each resource cost and then summed all these to give the total cost of each activity. Total cost of the material flow and assembly system is computed based on those activities cost. The activities total cost is shown in appendix B.

5.5 Cost model structure

The cost model was fully constructed in Excel to make it easy for users. The model helps to guide the user in selecting proper principles (see chapter.4 in each process) and compare the cost produced by each principle at each level of the production system.

Each process is represented in its own sheet to make simple for the user when using and make improvements (see appendix B). All activities included in the process are listed in the sheet. An activity is represented by a row in the Excel and on the columns; activity time and all the different costs of the activity are represented. The last sheet represents the model which the users will work when determining the methods to be used and the resulted cost at each step of the production system.

5.5.1 How to calculate the cost of production flow using cost model

When calculating the cost, the user only needs to work on the cost model sheet. In each process the principle is selected and then the cost is generated automatically for a single component. In choosing a principle/method the comments/reasons in the model (see figure.5.1) can guide which principle is used when and even more than one principle can be used to compare the costs for the same component.

Calculating the cost begins from receiving process. The cost calculation for receiving process is based on the separate receiving process sheet. To get the cost, a principle is selected in the principle drop down menu and then in the unit load row, the unit load for the selected principle (whether box, pallet or other) is to be entered by the user as because the unit load differs from component to component. Then the cost incurred per single component will be automatically generated in the next cell.

In similar way for repacking and replenishment, cost calculation is also based up on its corresponding separate sheet. To determine the cost per single component, just select the principle and enter the unit load on the corresponding column. For securing right article mounted process, the user only need to make selection of a principle and a resulted cost will be displayed. A part of the cost model is shown below in figure.5.1

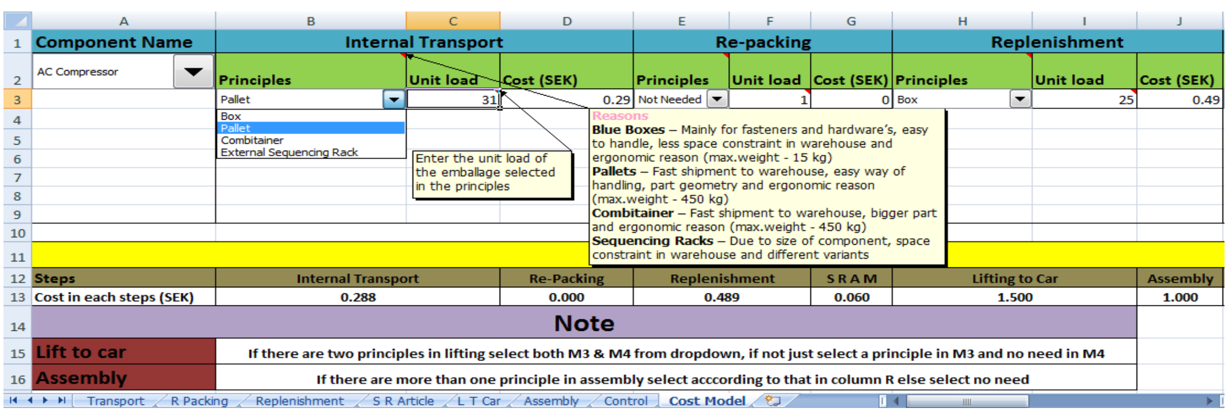


Figure.5.1 Part of the cost model

For lifting to car and assembly process input data for the model like lifting and assembly time in second, initial investment on lifting/assembly equipment and its depreciation period are to be feed by the user in its consequent position. This is due to values of the input data varies highly from component to component. In some cases lifting or assembly process requires more than one principle to accomplish the task and for such cases one more additional row is provided below to the previous row. Then the costs on the individual rows are summed to obtain the total cost of process .

For the control station process just the principle selection is required and the corresponding cost will be generated automatically in the next cell. When all the process is filled with the required information, the total cost of the material flow and assembly process flow is displayed on the last column. This cost value is the total cost resulted per single component.

5.6 Verification of the cost model

To verify the cost model a few components were selected in each flow, i.e. two in internal sequencing, one in external sequencing and two in downsizing flow. For the selected components, time study conducted for the material receiving process, repacking (downsizing) process, replenishment process and some part of control station activities. It was able to obtain historical time data in the above three different flows from VCC. The time data for assembly, lifting and securing right article process could be obtained from Volvo internal database. This time data are used for both verification model and as well for the ordinary cost model while calculating the costs.

For the selected components, firstly the cost was calculated based on the model. This cost is obtained based on average activity time of entire components used in the model. To validate this cost is relevant; the selected components were followed in the shop floor and time study was carried out to the activities associated to those components and finally a cost based on the time study conducted for each component was calculated. The cost calculation was made by modifying the average activity time available in the model for each flow to the direct activity time of each component. The above two costs were finally compared. The table below provides the results obtained from the selected components.

Component name	Using average activity time of all components (SEK) (using model)	Using direct activity time of specific component (SEK)	Difference in percent
Rear carpet	6.22	6.78	9 (↑)
Fuel pump	6.13	5.86	4.4 (↓)
Charge air pipe	6.95	6.49	6.6 (↓)
Jack	5.77	7.23	25.3 (↑)
Energy absorbent	5.09	5.81	14.1 (↑)

Table.5.1 Cost comparison using average time from model and direct activity time

The cost figure shown in the table is incurred per component from the material receiving process till final assembling it to the car. The cost results above in the table are using the model and direct activity time of selected component for the validation. The results show that there is no much variation while comparing these two costs. Also it is observed that for some components, the cost obtained using direct time is slightly larger than using the model and for others it is slightly lower.

6. Discussion and Conclusion

The purpose of the study was to identify different principles in each step of the material flow and assembly process and to develop a cost model for calculating the cost of different material handling activities and assembly systems in trim and final unit at Volvo cars, Torslanda. Volvo cars wanted to have a better costing system for estimating the overall cost of the production process. The model can be used as a decision support tool for logistics and production engineers. They can calculate the predicted cost before the launch of a new component and evaluate different steps and principles. With this tool they can balance the cost effect with the complexity of the chosen solution.

The cost model was built entirely in Microsoft Excel. The model was constructed based on activity time and cost of each resource used. The cost model is able to calculate the overall cost of each available component in the assembly shop, i.e. to calculate the cost of any component from material receiving process till assembly. Each step in the cost model has proper guidelines in selecting the appropriate principle for any component.

It is difficult to say that the model developed is absolutely precise in calculating the costs due to the following mentioned reasons. In ABC costing system, it is complex to inter relate the cost of all resources in to specific activities. Activity time for each activity is only based on the effective working time, so the costs do not include waiting time and other unavoidable ineffective time taken by working employees in reality practice. Considering only effective working time has the advantages of avoiding more costs allocating to activity than it is actually consumed. Maintenance and service costs are based on the values from year 2010 and this value may not be remaining same from year to year due to variations in production rate and life of equipment.

The outcome from the validation shows that the cost model is accurate to large extent. The calculated cost using the model and direct time from the components verified are found to be more or less the same. However validation was carried out for five components, i.e. two components in each category of flow and perhaps the validation results may vary if more number of components would have been selected.

The model is able to guide both the logistics and the local manufacturing engineering department to select the most suitable principle for any new components, that will arrive in the near future and it enables comparisons of the cost of different principles available in each step and also helps to identify the cost efficient one. The cost model is easy for to comprehend, to use and to edit by any user. When there is a deviation in the activity time and resource costs in the near future, the appropriate user can edit it easily but if any new principle or technology needs to be introduced, a significant effort is required to update the model.

7. Recommendations

Some recommendations that VCC could consider in the future are,

- If the model is developed further, it is possible to get a better estimate of the cost for the material handling activity and assembly systems. For calculating the accurate cost, the model is required with exact activity time details and the cost of all resources used.

- This cost model can serve as a basic tool and it can be adapted to other assembly plants of Volvo cars. It needs certain changes as per the process and requirements from the specific plant, where it is to be implemented.

- The cost model can be used by several potential users and the recommended users are the logistics department, local manufacturing engineering department, core manufacturing engineering department, strategic management department, finance department, which is allocating budget for the resources and finally the cost reduction team.

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9. Respondents from Volvo Car Corporation, Torslanda

Plant Man Hour Control, Man hour cost and time, VCC

Logistics Manager, Internal material handling, VCC

Logistics Engineers, Internal material handling, VCC

Unit Production Manager, Assembly process, VCC

Production Engineer, Assembly process, VCC

Packaging Engineers, MP&L department, VCC

Manager, Tools & Equipment department, VCC

Engineers, Tools & Equipment department, VCC

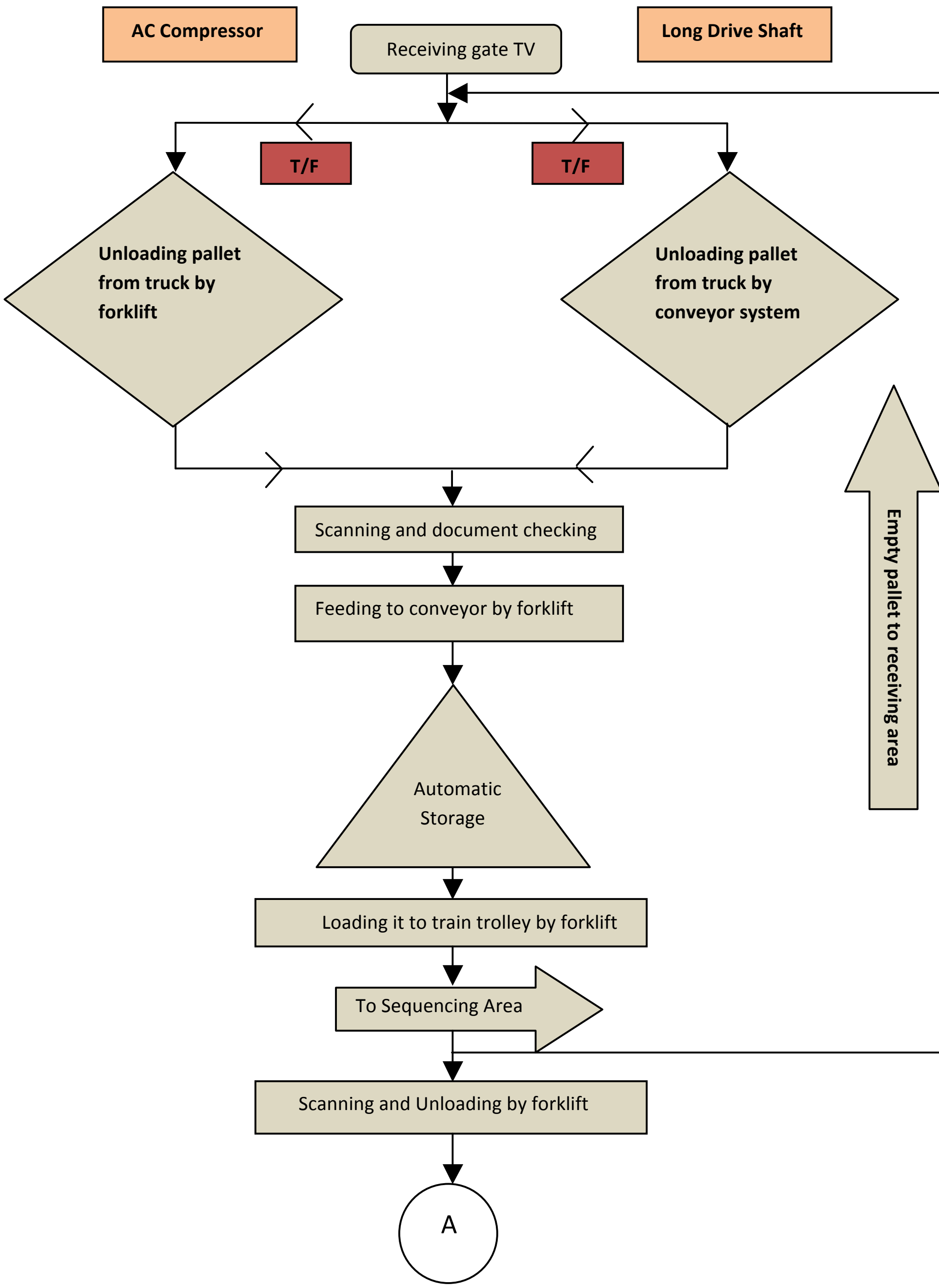
Engineer, Maintenance department, VCC

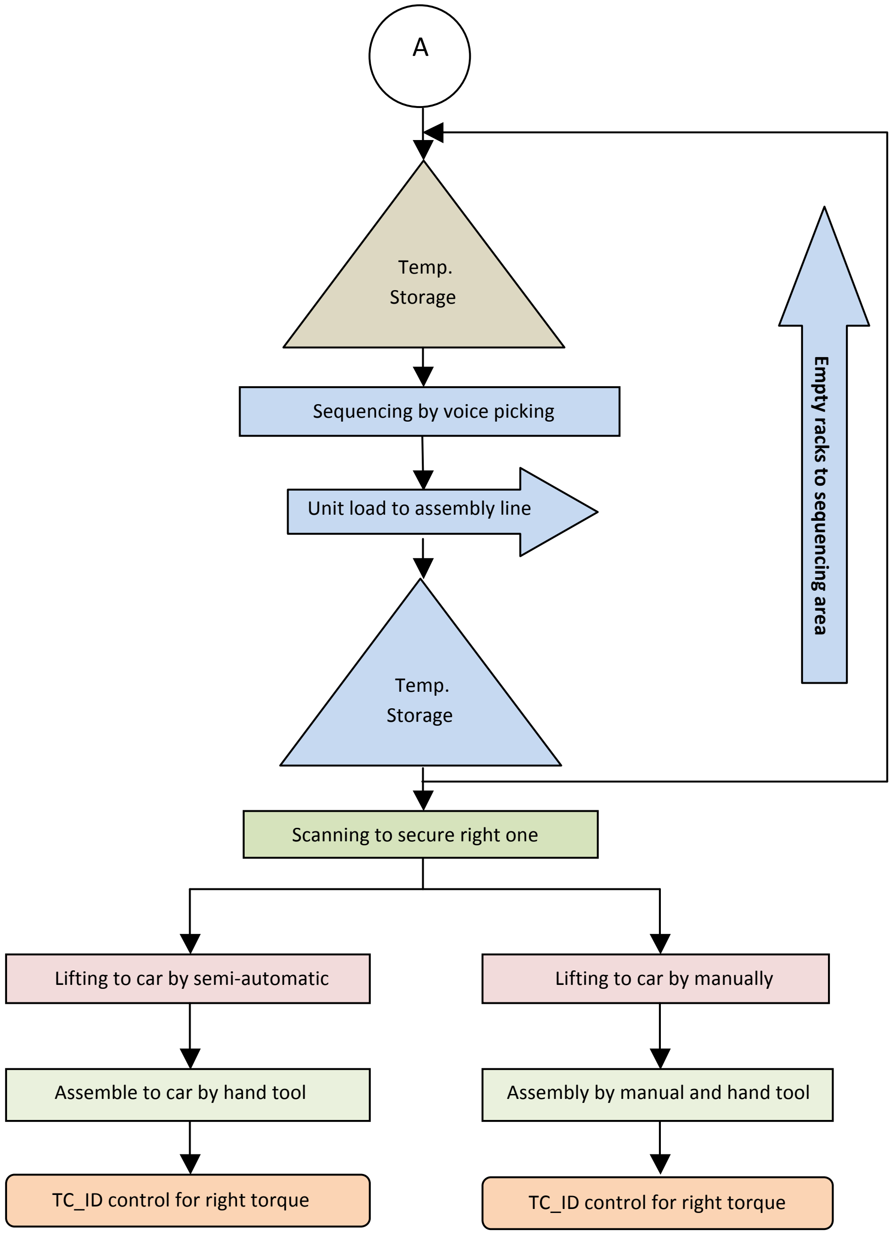
Control Station department, VCC

Appendix A

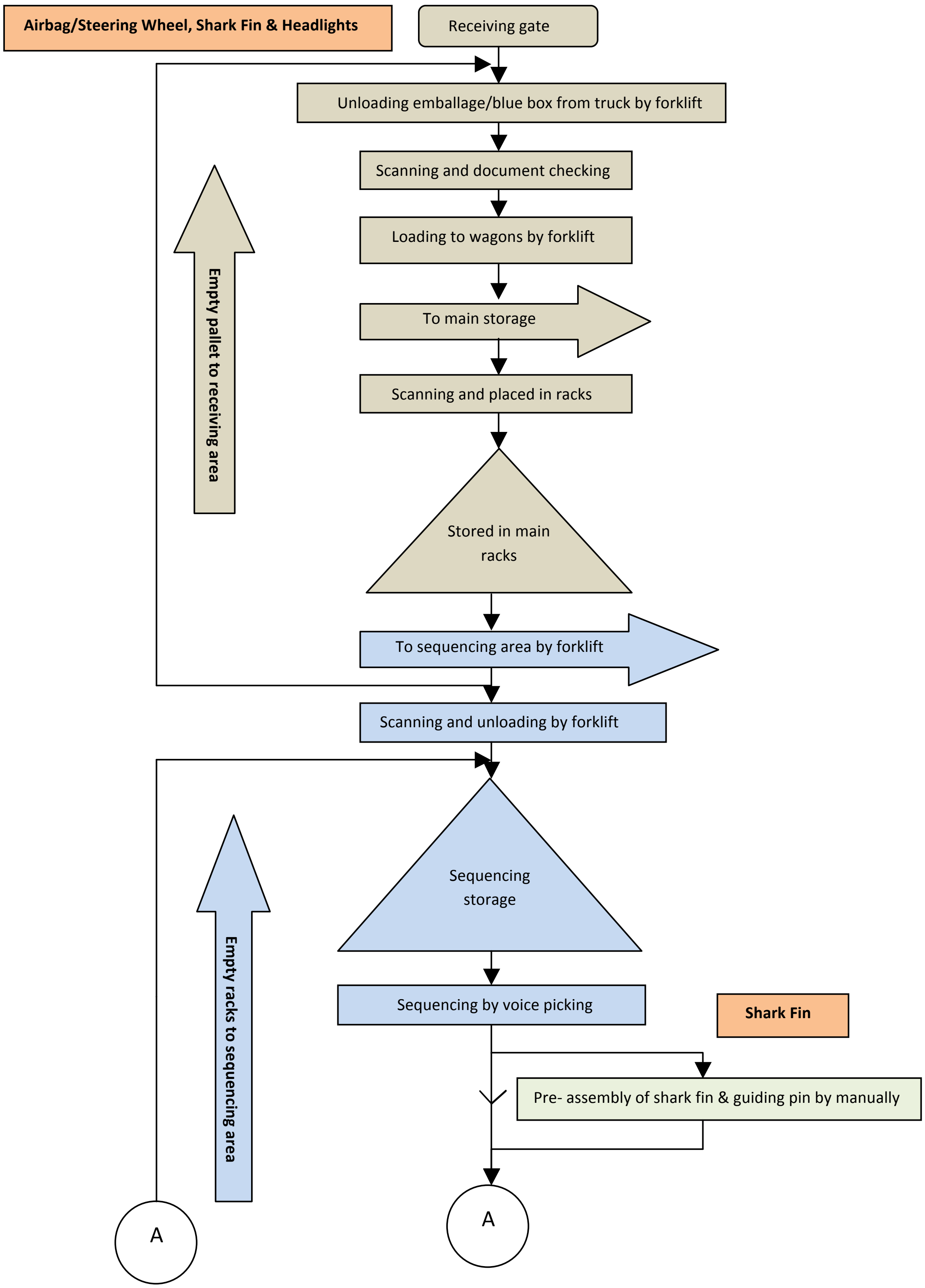
1. Generalize flowchart of internal sequencing flow

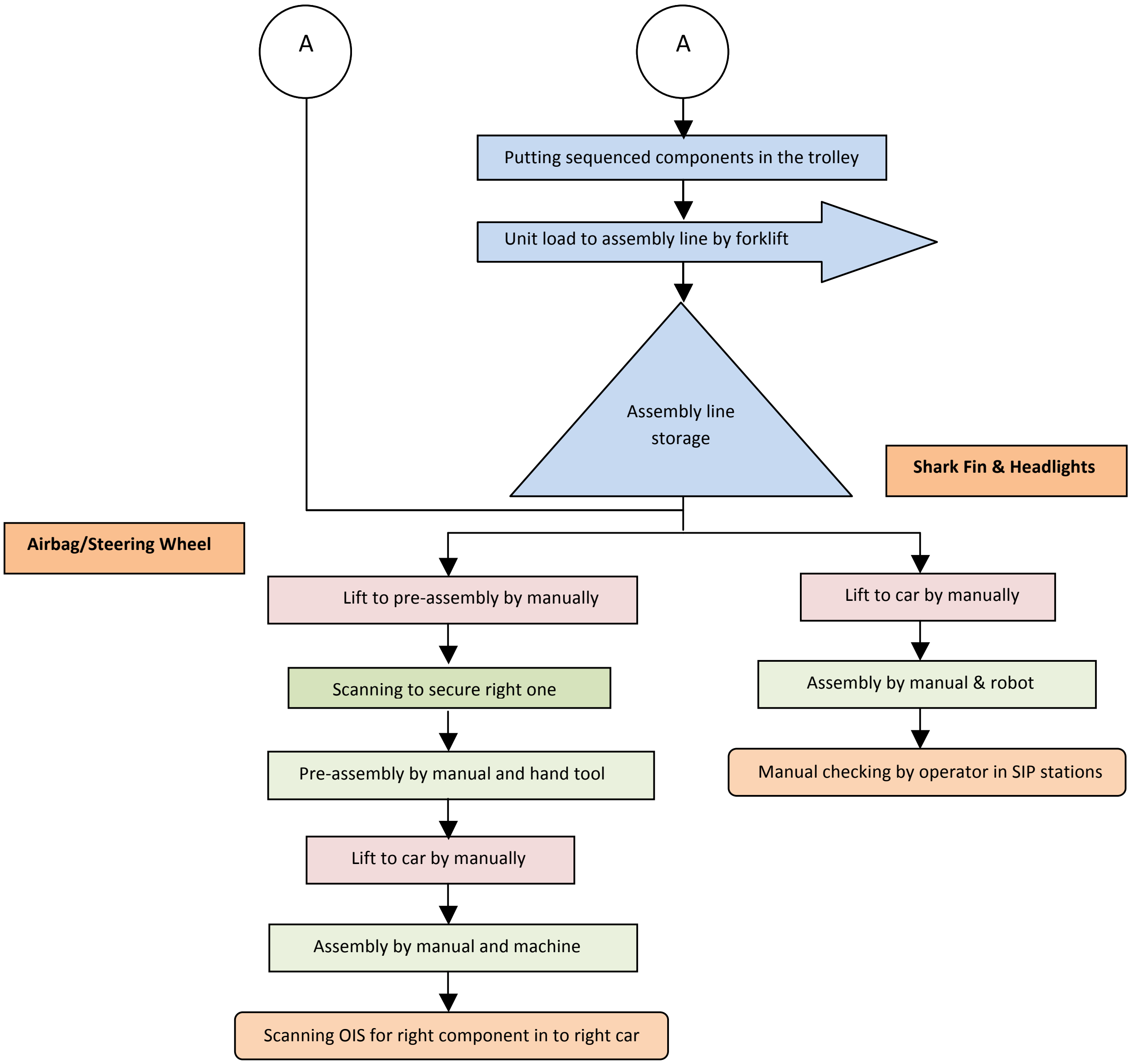
Internal sequencing components: AC Compressor and Long Drive Shaft




A
Temp.
Storage
Sequencing by voice picking
Unit load to assembly line
Temp.
Storage
Empty racks to sequencing area
Scanning to secure right one
Lifting to car by semi-automatic
Lifting to car by manually
Assemble to car by hand tool
Assembly by manual and hand tool
TC_ID control for right torque
TC_ID control for right torque

Internal sequencing components: Airbag/Steering Wheel, Shark Fin and Headlights

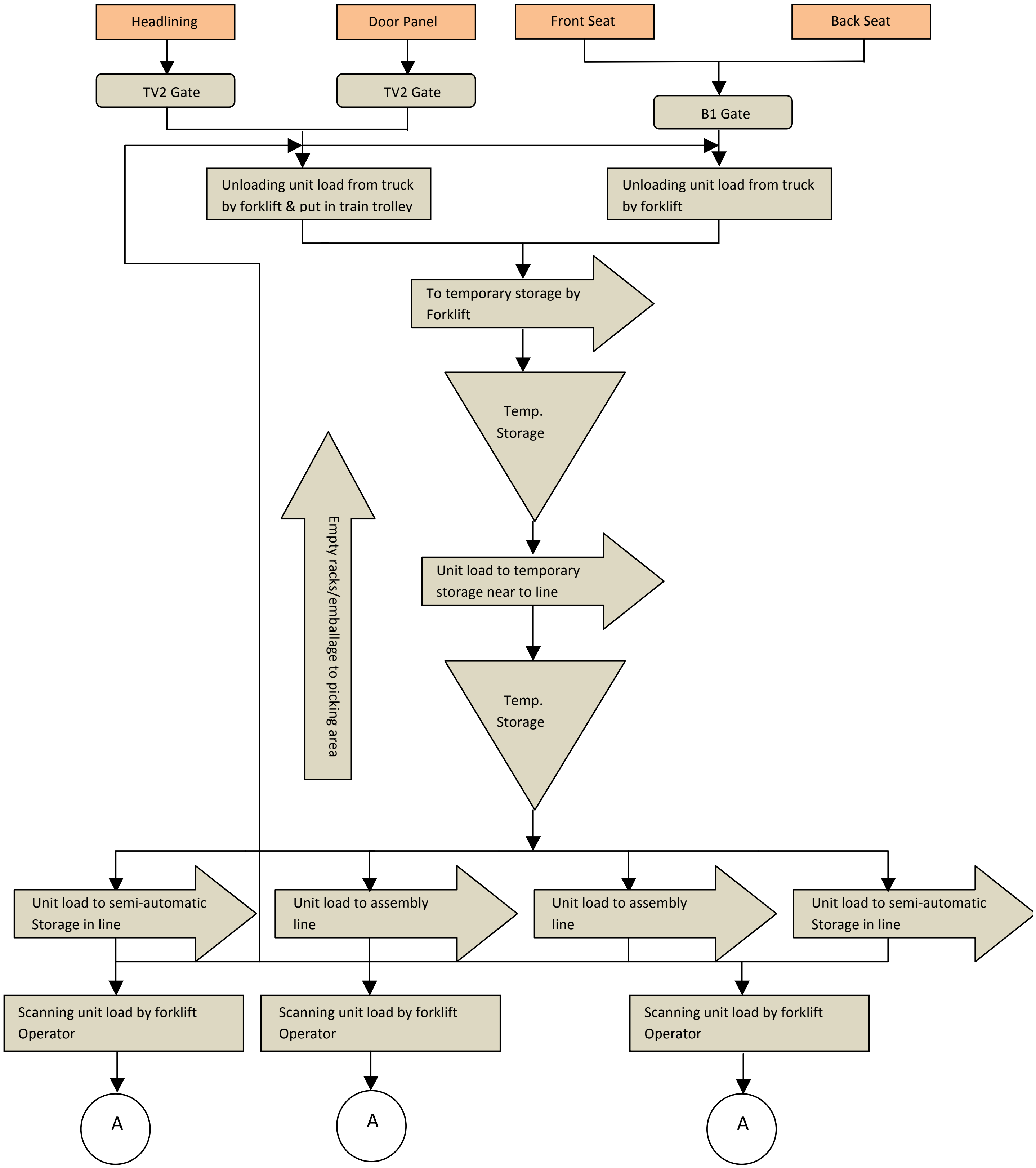


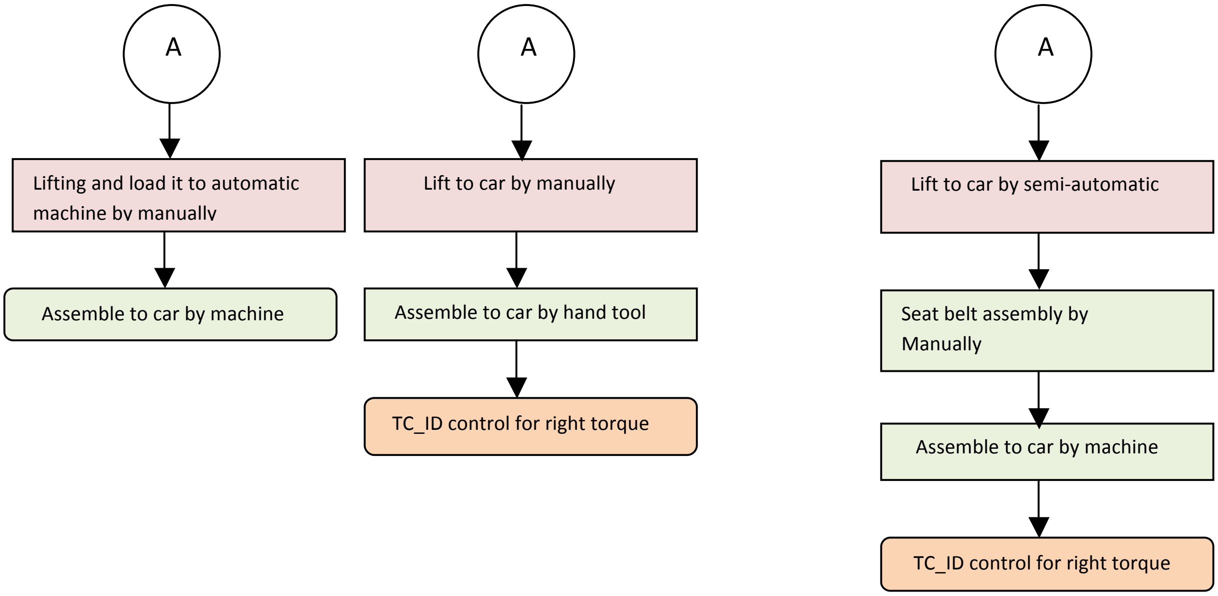

A
A
Putting sequenced components in the trolley
Unit load to assembly line by forklift
Assembly line storage
Shark Fin & Headlights
Airbag/Steering Wheel
Lift to pre-assembly by manually
Scanning to secure right one
Pre-assembly by manual and hand tool
Lift to car by manually
Assembly by manual and machine
Scanning OIS for right component in to right car
Lift to car by manually
Assembly by manual & robot
Manual checking by operator in SIP stations

- **True or False**
- **Component name**
- **Transport**
- **Replenishment**
- **Securing right article mounted**
- **Lift to car**
- **Assembly**
- **Control station**

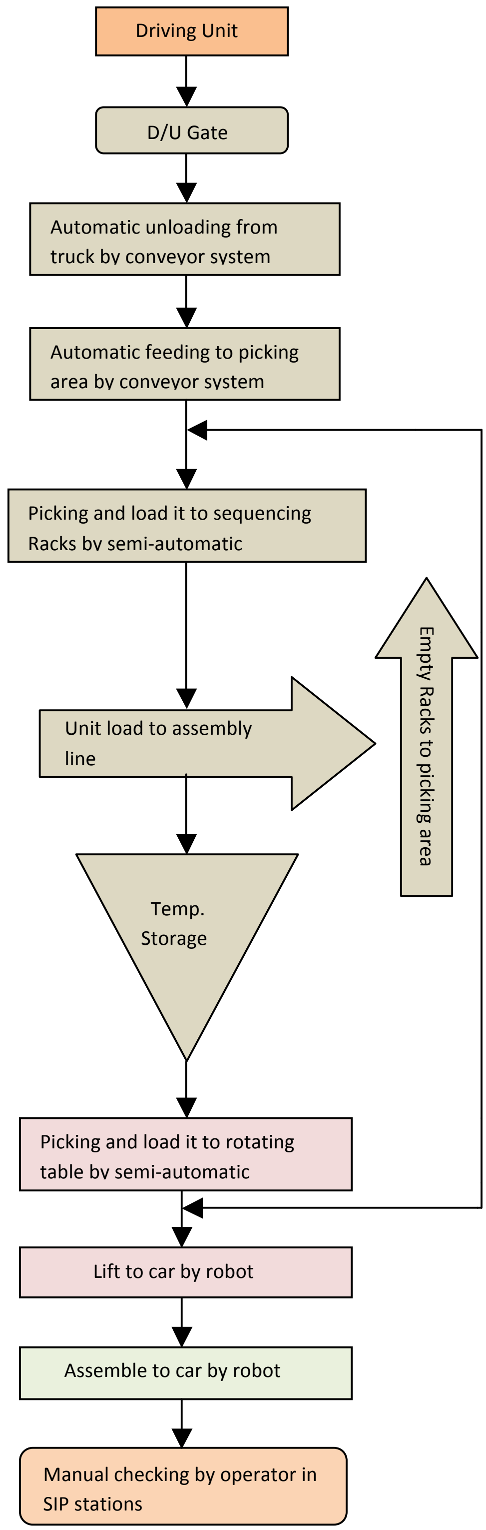
2. Generalize flowchart of external sequencing flow

External sequencing components: Door Panel, Headlining, Front Seat and Back Seat




A
Lifting and load it to automatic machine by manually
Assemble to car by machine
A
Lift to car by manually
Assemble to car by hand tool
TC_ID control for right torque
A
Lift to car by semi-automatic
Seat belt assembly by Manually
Assemble to car by machine
TC_ID control for right torque

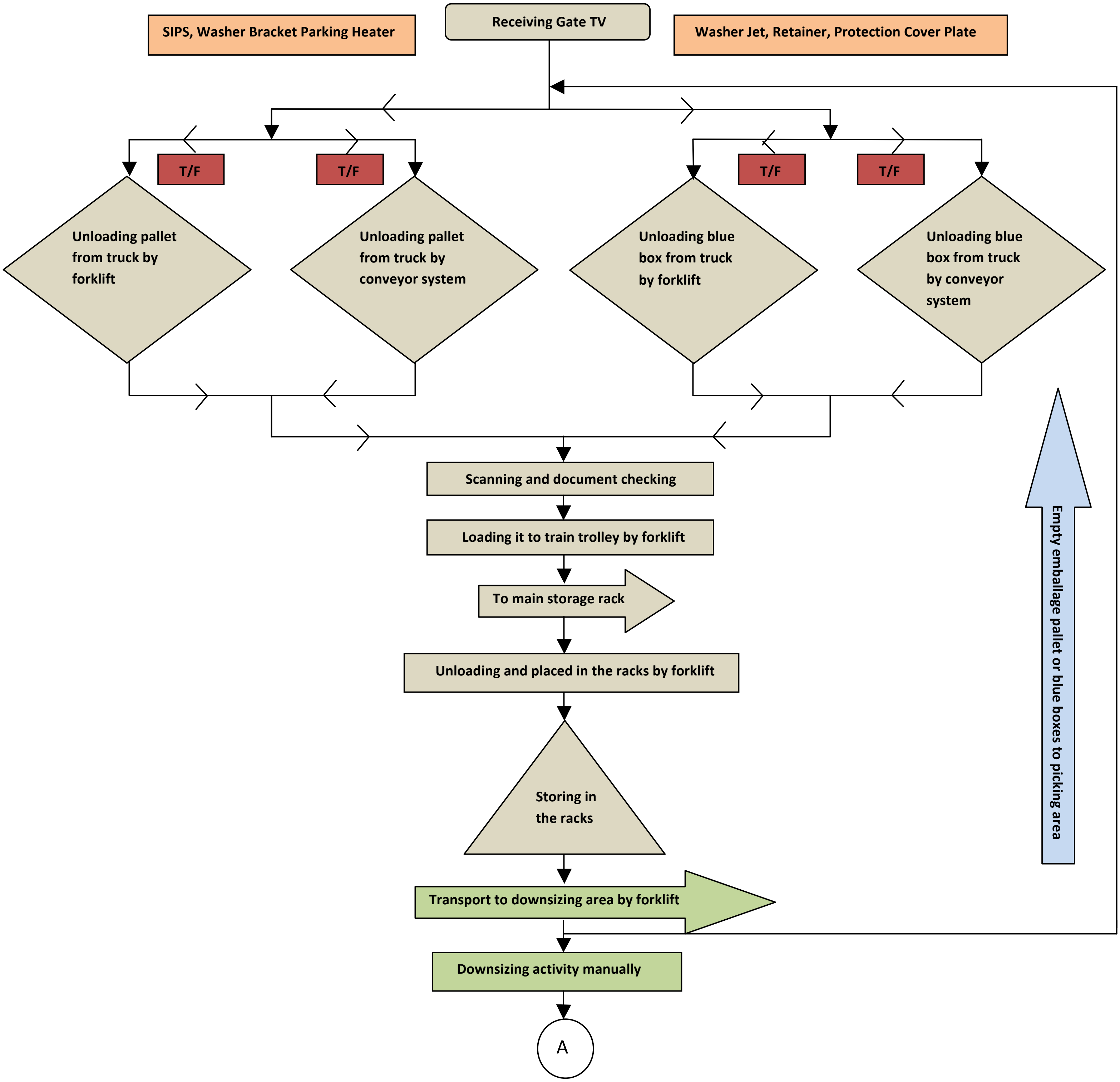
External Sequencing Components: Driving Unit

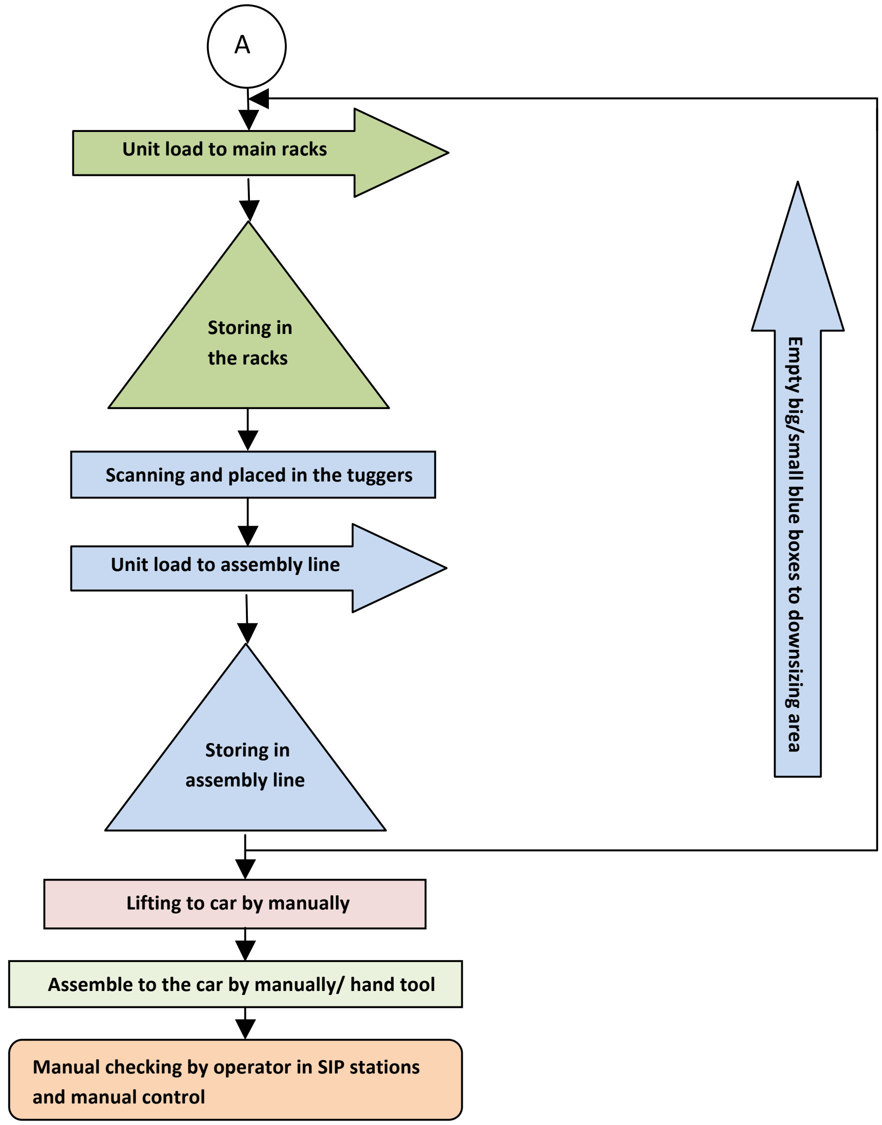


- **Component name**
- **Transport**
- **Lift to car**
- **Assembly**
- **Control station**

3. Generalize flowchart of downsizing flow

Downsizing components: Washer Jet, Retainer, Protection Cover Plate, SIPS and Washer Bracket Parking Heater

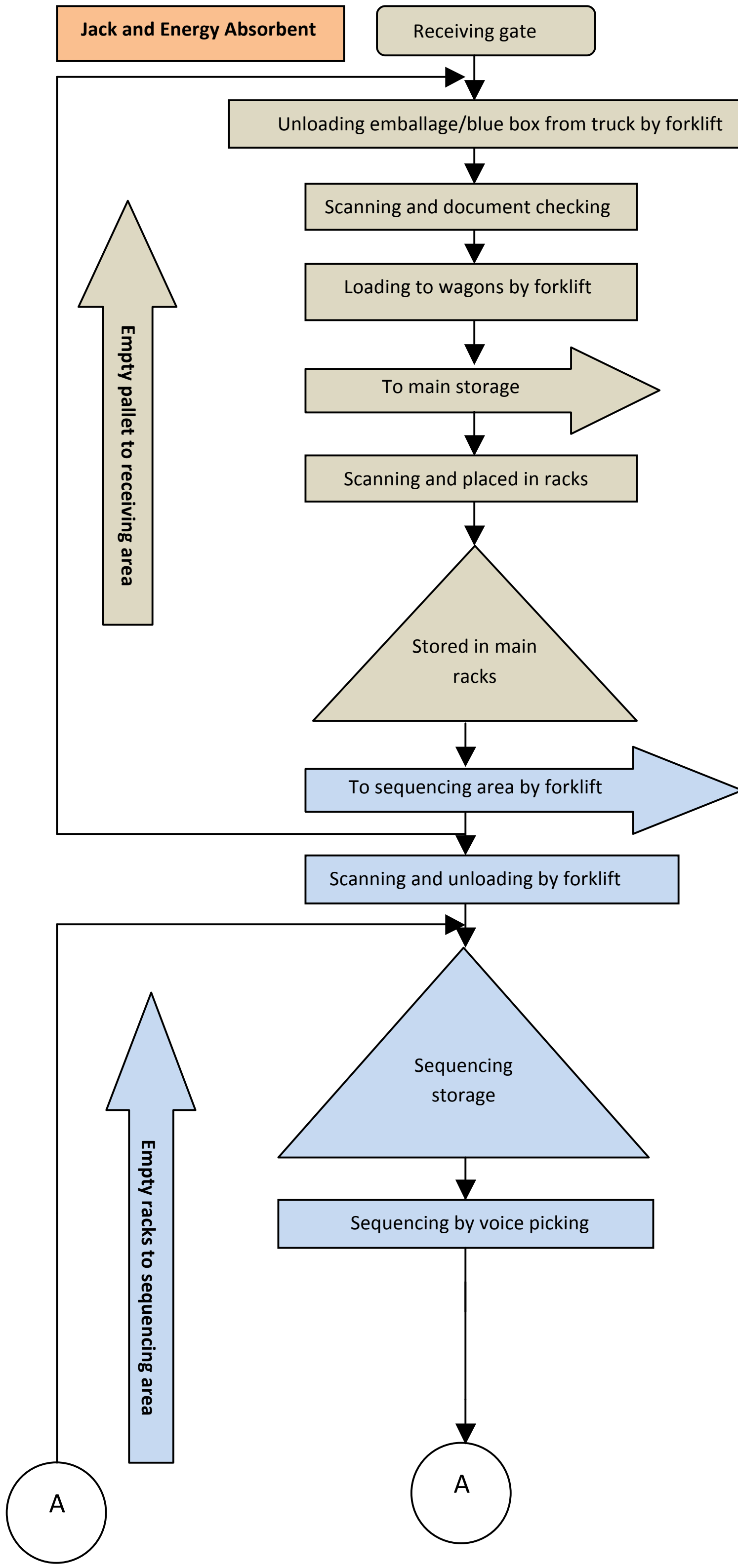


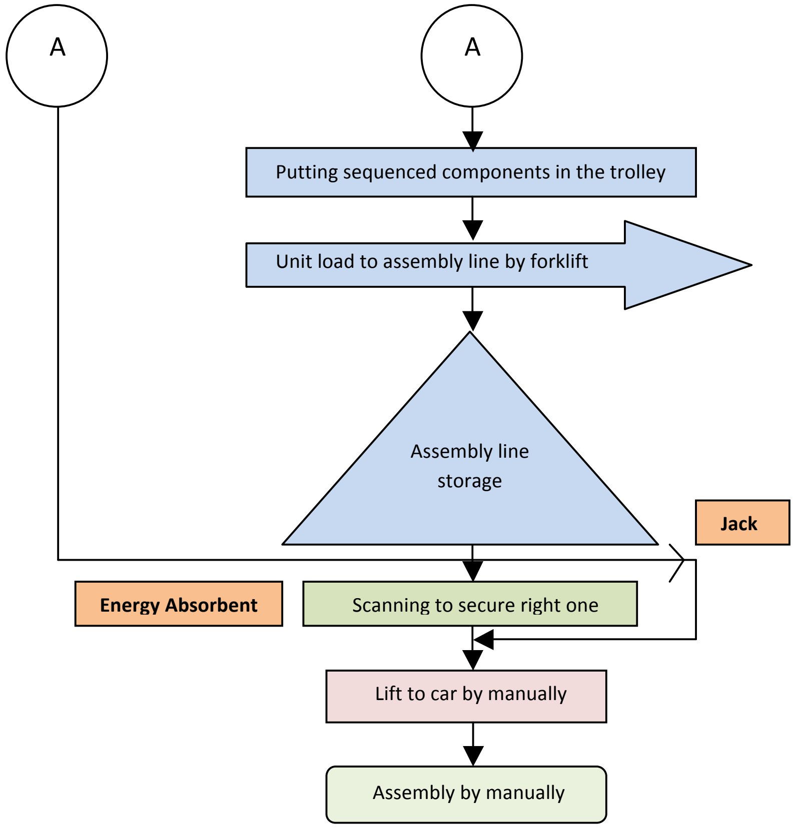

A
Unit load to main racks
Storing in the racks
Scanning and placed in the tuggers
Unit load to assembly line
Storing in assembly line
Lifting to car by manually
Assemble to the car by manually/ hand tool
Manual checking by operator in SIP stations and manual control
Empty big/small blue boxes to downsizing area

- **True or False**
- **Component name**
- **Transport**
- **Re-packing**
- **Replenishment**
- **Lift to car**
- **Assembly**
- **Control station**

4. Generalize flowchart of internal sequencing flow for validation components

Validation components: Jack and Energy Absorbent

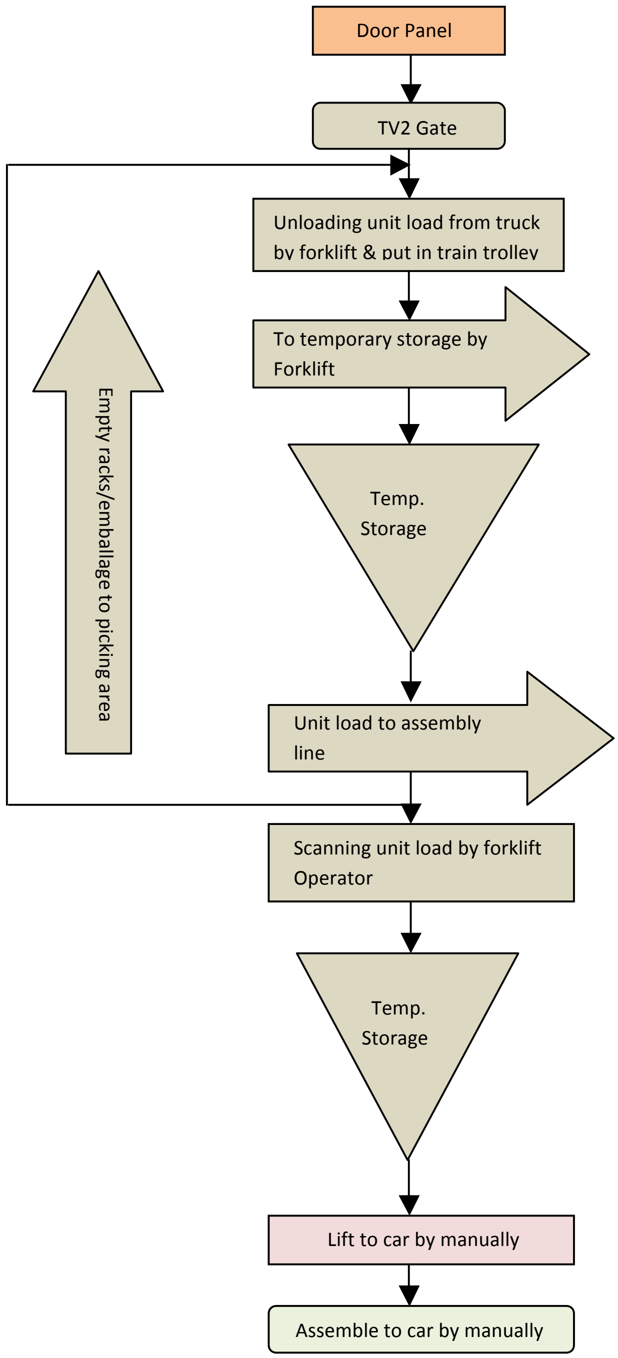



A
A
Putting sequenced components in the trolley
Unit load to assembly line by forklift
Assembly line storage
Jack
Energy Absorbent
Scanning to secure right one
Lift to car by manually
Assembly by manually

- **True or False**
- **Component name**
- **Transport**
- **Replenishment**
- **Securing right article mounted**
- **Lift to car**
- **Assembly**

5. Generalize flowchart of external sequencing flow for validation components

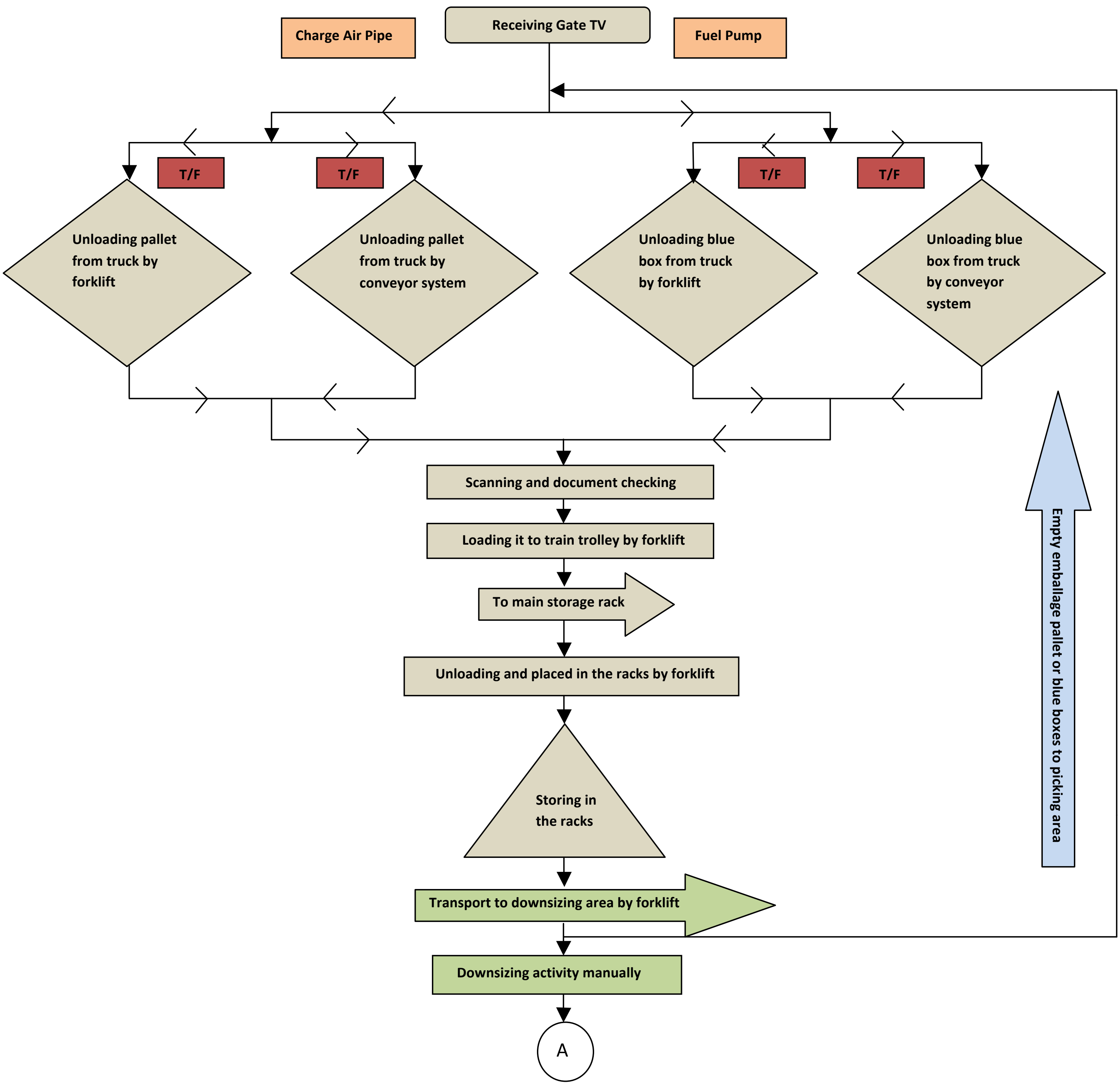
Validation component: Rear Carpet

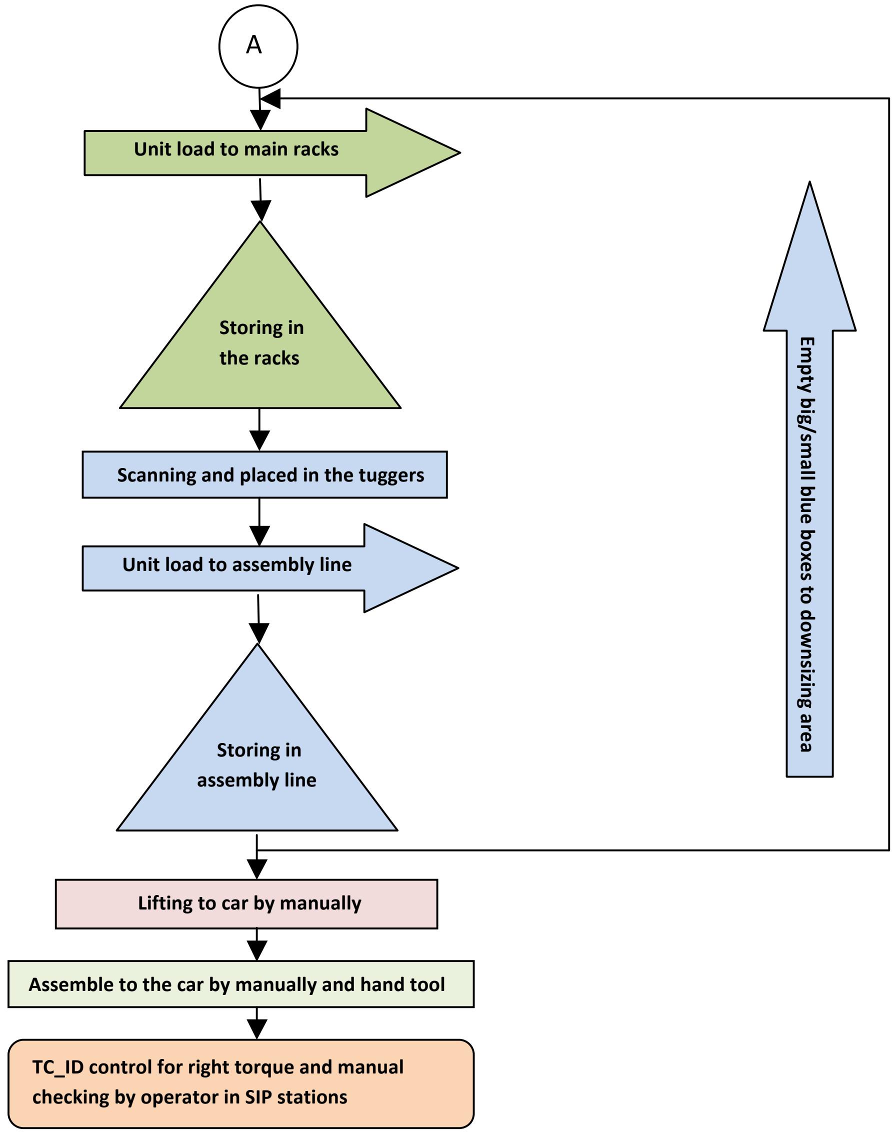


(orange)	-	**Component name**
(tan)	-	**Transport**
(pink)	-	**Lift to car**
(light green)	-	**Assembly**

6. Generalize flowchart of downsizing flow for validation components

Validation components: Fuel Pump and Charge Air Pipe




A
Unit load to main racks
Storing in the racks
Scanning and placed in the tuggers
Unit load to assembly line
Storing in assembly line
Empty big/small blue boxes to downsizing area
Lifting to car by manually
Assemble to the car by manually and hand tool
TC_ID control for right torque and manual checking by operator in SIP stations

- True or False
- Component name
- Transport
- Re-packing
- Replenishment
- Lift to car
- Assembly
- Control station

Appendix B

1. Cost Model Sheet

Component Name	Internal Transport			Re-packing			Replenishment			Securing Right Article Mounted	
AC Compressor	Principles	Unit load	Cost (SEK)	Principles	Unit load	Cost (SEK)	Principles	Unit load	Cost (SEK)	Principles	Cost (SEK)
	Combitainer	[redacted]	[redacted]	Not Needed	[redacted]	[redacted]	Batch	[redacted]	[redacted]	Scanning	[redacted]

Summary of Cost Results								
Steps	Internal Transport	Re-Packing	Replenishment	S R A M	Lifting to Car	Assembly	Control	Total Cost (SEK)
Cost in each steps (SEK)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Note

Lift to car	If there are two principles in lifting select both M3 & M4 from dropdown, if not just select a principle in M3 and no need in M4
Assembly	If there are more than one principle in assembly select acccording to that in column R else select no need

Lift to Car				Assembly					Control Station		Flow Total Cost in SEK
Lifting time	Investment on lifting	Depreciation time	Cost (SEK)	Principles	Assm. time	Investment on assembly	Depreciation time	Cost (SEK)	Principles	Cost (SEK)	
[redacted]	[redacted]	[redacted]	[redacted]	Manual	[redacted]	[redacted]	[redacted]	[redacted]	Self Control	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	Hand Tool	[redacted]	[redacted]	[redacted]	[redacted]			[redacted]
				No Need	[redacted]	[redacted]	[redacted]	[redacted]			[redacted]

1.1 Internal Transport Individual Sheet

Internal Transport							
Activities	Activity duration in min	Labor cost per min in SEK	Fork lift rent per min in SEK	Maintenance /service cost per min in SEK	Emballage cost in SEK	Total cost in SEK	Total activity cost for different emballage in SEK
Unloading from truck, scanning, loading to wagons of full box by forklift	[redacted]						
Unloading from truck, scanning, loading to wagons/automatic storage of full pallet by forklift	[redacted]						
Unloading from truck, scanning, loading to wagons of full combitainer by forklift	[redacted]						
Transporting full box from receiving area to main storage by forklift wagons	[redacted]						
Transporting full pallet from receiving area to main storage by forklift wagons	[redacted]						
Transporting full combitainer from receiving area to main storage by forklift wagons	[redacted]						
Placing box from wagons to storing racks	[redacted]						
Placing pallet from wagons to storing racks	[redacted]						
Placing combitainer from wagons to storing racks	[redacted]						
Unloading from truck and loading to wagons of full external sequence rack by forklift	[redacted]						
Transporting rack/external sequenced components to assembly line temporary storage	[redacted]						
Returning empty racks and loading to truck for external sequencing	[redacted]						
Rental cost of box	[redacted]						
Rental cost of pallet	[redacted]						
Rental cost of Combitainers	[redacted]						
Cost of external sequencing racks	[redacted]						
Total activity cost for box	[redacted]						
Total activity cost for pallet	[redacted]						
Total activity cost for combitainer	[redacted]						
Total activity cost for external sequencing racks	[redacted]						

1.2 Re-packing Individual Sheet

Downsizing /Re-packing							
Activities	Activity time in min	Labor cost per min in SEK	Equipment cost/rent per min in SEK	Maintenance /service cost per unit time in SEK	Consumables and box service cost in SEK	Total cost in SEK	Total activity cost for emballage in SEK
Transporting emballage from storing rack to downsizing area by forklift	[redacted]						
Downsizing manually to required quantity	[redacted]						
Placing re-packed boxes to storing rack	[redacted]						
Transporting empty big boxes to receiving area	[redacted]						
ID Sticker in the box	[redacted]						
Total activity cost for box	[redacted]						
Total activity cost for not needed	[redacted]						

1.3 Replenishment Individual Sheet

Replenishment							
Activities	Activity time in min	Labor cost per min in SEK	Equipment cost/rent per min in SEK	Maintenance /service cost per min in SEK	Rack/kit cost in SEK	Total cost in SEK	Total activity cost in SEK
Shifting Emballages from storing rack to sequencing area by forklift	[redacted]						
Sequencing components manually by voice picking							
Kitting components manually by voice picking							
Transporting sequenced to assembly line by forklift							
Returning empty sequencing rack to sequencing area							
Transporting empty emballages from sequencing area to receiving area and load to truck							
Transporting full small box from down size store to assembly line							
Returning empty small box to downsize area							
Transporting full pallet from main store to assembly line, and replace to the assembly line							
Batching from pallet to rack in the assembly line							
Returning empty pallet from assembly line to receiving area and load to truck							
Replenshing external sequenced rack from line temporary storage to picking area							
Total activity cost for box							
Total activity cost for pallet							
Total activity cost for batching							
Total activity cost for sequencing							
Total activity cost for kitting							
Total activity cost for external sequencing rack							

1.4 Securing Right Articles Mounted Individual Sheet

Securing right articles mounted					
Activity	Activity Time in min	Labor cost per min in SEK	Equipment cost per min in SEK	Maintenance cost per min in SEK	Activity total cost in SEK
Checking Specification	[redacted]				
Checking and pressing pick to light button					
Scanning to confirm the component					

1.5 Lift to Car Individual Sheet

Principle1	Lifting to car				
Activity	Activity Time in min	Labor cost per min in SEK	Robot/ machine cost per min in SEK	Maintenance cost per min in SEK	Activity total cost in SEK
Lifting component to car manually	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Lifting component to car by semi-automatic	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Lifting component to car by robot	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Principle2					
Activity	Activity Time in min	Labor cost per min in SEK	Robot/ machine cost per min in SEK	Maintenance cost per min in SEK	Activity total cost in SEK
Lifting component to car manually	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Lifting component to car by semi-automatic	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Lifting component to car by robot	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

1.6 Assembly Individual Sheet

Principle 1	Assembly				
Activity	Activity time in min	Labor cost per min in SEK	Robot/ machine/hand tool cost per min in SEK	Maintenance/service cost per min in SEK	Activity total cost in SEK
Assembling to final product manually	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by hand tool	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by machine	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by robot	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Principle 2					
Activity	Activity time in min	Labor cost per min in SEK	Robot/machine/hand tool cost per min in SEK	Maintenance/service cost per min in SEK	Activity total cost in SEK
Assembling to final product manually	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by hand tool	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by machine	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by robot	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Principle 3					
Activity	Activity time in min	Labor cost per min in SEK	Robot/machine/hand tool cost per min in SEK	Maintenance/service cost per min in SEK	Activity total cost in SEK
Assembling to final product manually	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by hand tool	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by machine	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Assembling to final product by robot	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

1.7 Control Station Individual Sheet

Control station					
Activity	Activity Time in min	Labor cost per min in SEK	Equipment cost per min in SEK	Maintenance/service cost per minute in SEK	Total activity cost in SEK
Self control	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Manual control	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
SIP control	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Measurement programs,CC1 control	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Vision camera control	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]