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Material Handling System Design: A Case-Study in Bosch Rexroth Japan

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MASTER THESIS 2013

PRODUCTION DEVELOPMENT AND MANAGEMENT

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This thesis work has been carried out at the School of Engineering in Jönköping in the subject area Production Development and Management. The thesis work is a part of Master of Science program Production System. The authors take full responsibility for opinions, conclusions and findings presented.

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Abstract

In today's fierce competitive global markets, customers are demanding adjustable lot sizes, shorter lead times, higher quality and flexibility; in short, they want it all. In order to stay competitive in the market, companies need to attain both customer satisfaction and cost reduction in production operations. Material Handling Systems (MHS) is the place to accomplish this goal, since they have a direct impact on production. Therefore, the aim of this study was to design an in-house MHS that could be efficient for the production it serves.

With this intention, a case-study has been conducted in Bosch Rexroth Japan. During the study, the information gathered through various sources; interviews, observations and measurements. Further, the gathered data is evaluated according to main pillars of the theoretical framework, which includes design principles and physical elements, information and software, human and management.

By analyzing the findings from literature review and empirical study, first problems and challenges related to MHSs are identified. Thereafter, possible features that the system should posses are elicited and a design is built out of the selected features.

To conclude, the results show that the success is not solely depending on system's physical attributes; on the contrary, it is more related to rapid and accurate information sharing within the system. Another vital element is the interaction between system and the people, who are utilizing and operating the system. In general terms, the research took MHS design problems from one-dimensional equipment selection processes and enriches them by adding information sharing, human and management angles to design steps.

Key Words

Material handling system, Just- in-time material supply, Milkrun, AGV, Information flow

Acknowledgments

We would like to take a moment to express our gratitude to those who were supported and encouraged us along this thesis study. First of all, we would like to thank our supervisor Lars Brinkmann at Bosch Rexroth Japan for giving us this great opportunity. Without his guidance, never ending support and enthusiasm, this study would simply not have been accomplished. Secondly, we would like to express our deepest gratitude to Katsuharu Tabe for his continuous collaboration, insightful comments and suggestions. Our discussions were inspirational and without them this study would not be in the level as it is today. Furthermore, we want to express our genuine gratefulness to all the people in Newlog project group and Bosch Rexroth Japan for their support and remarkable hospitality, which made this journey unforgettable. We also want to use this opportunity to thank our supervisor Per Hilletofth for his guidance and support during this thesis. His comments enrich this thesis and inspired us along this thesis.

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1. Introduction

In this chapter background of the research, problem formulation, purpose and research questions will be presented. Afterwards, the scope and delimitations will be stated and an outline of the thesis will be given in the end.

1.1 Background

Today's fierce competitive global markets, short product life cycles, and increased customer expectations have forced organizations to recognize the vital importance of investing and focusing on their logistics systems in terms of gaining competitive advantages (Christopher, 2005; Bramel&Simchi-Levi, 1997). Lowe (2002) defines logistics as planning, implementing, and controlling of transportation activities and storage of goods; including services with related information, from the point of origin to point of use to meet customer requirements. Jonsson and Mattsson (2005) exemplify logistics as an open system which has exchanges with its surroundings, and in order to perform these exchanges a logistics system should manage three flows; material, information and monetary. According to Harrison and Hoek (2011), material flow is the transportation of physical goods from initial source to customer, while information flow is generating data, so that material flow can be accurately controlled and planned.

The definitions of logistics involve activities that ensure the necessary material is available at the right place and at the right time. Gourdin (2001) identifies some of these activities and states that a logistics system can consist of several different functional elements, such as storage and material handling, transportation, information processing, demand forecasting, production planning, and so forth. Further, Christopher (2005) introduces a total system viewpoint, which consists of different sub-systems that shares the same goal; satisfying the needs of the next customer in the supply chain. Each sub-system; material supply, production, and distribution monitor and control the material flow by various value-adding activities.

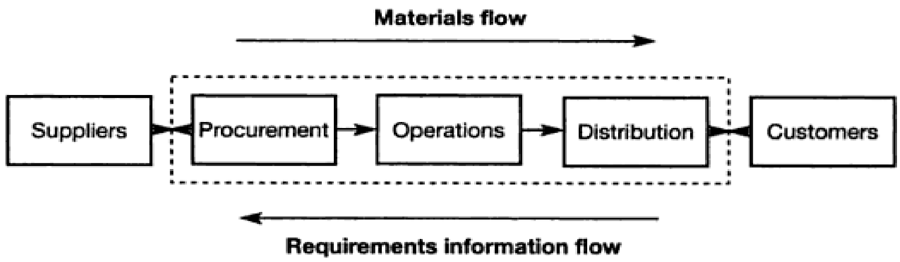


Figure: 1.1 Logistics management process (Christopher, 2005)

The challenges in logistics management can be categorized under strategic, tactical and operational levels, but the centre of these challenges is the need of connecting suppliers with company's own processes, and then with customers in an efficient way. Goldsby and

Martichenko (2005) shed light on the importance of eliminating *waste* regarding to accomplish this goal. *Wastes* can be found in every step of the logistics activities, since most of the organizations have a natural tendency to create them. By process mapping through the supply chain, it is possible to differentiate value adding and non-value adding activities and; thereby, reduce the variation while increasing speed and magnitude of the chain (Goldsby & Martichenko, 2005; Harrison & Hoek, 2011). Further, Goldsby and Martichenko (2005) denote logistics *wastes* as following; inventory, transportation, space and facilities, time, packaging, administration, and knowledge. On the other hand, Harrison and Hoek (2011) focused on logistics *wastes* from *lean* point of view such as overproduction, unnecessary motion, defects etc. Despite different definitions of *wastes,* logisticians can draw from these approaches to design their own, tailored solutions in terms of eliminating *waste* through the supply chain.

The challenges in logistics share similar traits, notwithstanding the scale of the focus area, more explicitly company's internal logistics systems have alike characteristics; and therefore, alike challenges as its external logistics systems. The heart of logistics is managing inventory levels; in global supply chains the challenge is decreasing inventory levels at retailers and warehouses, while in company-scale it is lowering buffer levels by decreasing variation in the system; in any term, from customer demand to supplier delivery, and attaining a smooth, just-in-time material flow (Goldsby&Martichenko, 2005). Even though inventory management plays an important role for eliminating *waste* from the supply chain, half of the logistics costs are coming from transportation. Meyers (1993) emphasizes the importance of efficient Material Handling Systems (MHS) for companies. By assuring *right* product to the *right* place at the *right* time in the *right* quantity and condition, companies not only can decrease their operational costs, but also can eliminate/decrease unnecessary buffers within the shop floor. Nevertheless, material and information flow are highly intertwined in logistics, and for that reason information link is the keystone for efficient MHS (Meyers, 1993; Jonsson & Mattsson, 2005). According to Goldsby and Martichenko (2005), companies can be under a real threat, if material supply and production sections do not have an efficient communication link between each other; especially in cases of high variety in schedule changes and unexpected material shortages.

1.2 Problem Formulation

Customers are demanding smaller lot sizes, shorter lead times and higher quality; in other words they want it all. By streamlining material flow companies can increase productivity and delivery performance dramatically, which is the only way to stay competitive in the global market (Allred, 1996). However, smoothening material flow, especially in assembly areas, is not an easy job. In manufacturing plants, assembly areas usually contain storages of components that will be assembled soon and supply of these components is usually problematic regarding limited spaces in workstations. Correspondingly, it is also important to replace the consumed materials in convenient time intervals to keep the assembly lines running. Domingo *et al.* (2007) point out that companies are suffering from the trade-off between material supply to assembly lines with high delivery performance or keeping buffer levels low on the shop floor. Allred (1996) argued that when workstations or point-of-uses cannot get the material they need, when they need it, productivity drops dramatically and it is commonly the largest single cause of factory inefficiency.

Transportation of materials to the assembly workstations and collection of finished products is one of the areas that create *waste* within the company, and by improving in-house MHS, just-in-time (JIT) material supply and decreased work-in-progress inventory can be attained (Sanchez & Perez, 2001; Allred, 1996). However, solely improving MHS's performance is not the ultimate solution for companies. Kaipia (2009) marks the importance of information sharing that supports material flow. Flexible material flow needs frequent updates based on accurate information, without it, *waste* is created in form of excess inventories. Thereby, a coordinative information link between material supply and production departments is one of the prerequisites of achieving an efficient in-house MHS.

Even though importance of selecting a suitable MHS has frequently been addressed in the literature, most of the in-house MHS design frameworks merely include only equipment selection processes and/or scheduling of the system. Very few papers in the literature present models and discuss MHS problems from a broad point of view that includes different aspects that can eliminate MHS's dilemma between high delivery performance or low buffer levels on the shop floor (Lins, 1998).

To be able to investigate mentioned areas in a real life situation, a case company, Bosch Rexroth Japan, has been selected and it will be presented in the following section.

1.3 Company and Case Description

Bosch Rexroth (BRJP) located in Tsuchiura, Japan is currently suffering from fluctuations in customer demand while on the other hand, the recent business environment requires an increase in company's delivery performance to sustain competitive in the market. Therefore, similar to other Bosch Rexroth plants around the world, BRJP started a project, called as NEWLOG, to cope with the challenges in global supply chain by integrating material and information flows effectively and attaining improved and standardized logistic processes.

The project has the overall targets of increasing delivery performance while maintaining low inventory levels, thereby, decreasing logistic costs. NEWLOG project (Figure 1.2) will cover 10 different sub-projects which consider the whole supply chain from suppliers to customers, and this thesis work is carried out in co-operation with one of the sub-projects; Material Supply.

Figure: 1.2 Newlog Project Description (Bosch Rexroth Group, 2012)

The primary goal of Material Supply project is to reach %100 delivery performance across the plant through continuous material flow. Several additional targets are attaining storage level reduction and inventory transparency, separation of value adding and non-value adding internal logistics activities, reduced handling effort with standardized transport devices, and improved information link between parties of material supply.

Inefficiency in the current internal material supply system (IMSS) entails huge cost and customer dissatisfaction for BRJP. This inefficiency in the IMSS can be analyzed under three main categories; non-fixed assembly schedule caused by suppliers' low delivery performance, material handling inefficiency resulted by high operation cost and massive manual transportation on the shop floor, and lack of information link between material supply and production departments. Additionally, mentioned problems above cause increased buffer levels and queues before production processes which make the situation even more critical since, Tsuchiura plant is already suffering from lack of space on the shop floor.

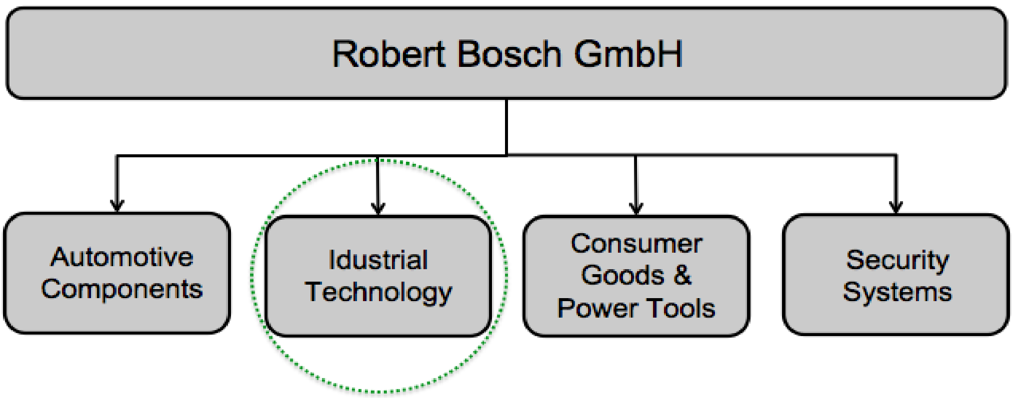


Figure: 1.3 Divisions of Bosch Group (Bosch Rexroth Group, 2012)

Therefore, it has a great importance for Material supply project in BRJP to solve these issues by designing a new material supply system for the plant, which as a result can bring higher delivery performance, while maintaining lower inventory levels.

Bosch Rexroth as it also can be observed in the Figure 1.3 is a part of Bosch Group and is operating in the technological fields such as industrial machinery, factory automation, construction machinery, and renewable energy. The company has production units in more than 25 countries and additionally sales units in 80 countries. Bosch Rexroth Corporation in Japan established first in 2005 but the company was operating since 1934 under the name of Uchida Manufacturing. There are over 900 employees, both blue and white color, working in Tsuchiura Plant. The production in BRJP is mainly focused in piston pump, piston motor and valve but the company is also the manufacturer of power unit and gear pump/motor. The share of each production area can be seen in the following Figure 1.4.

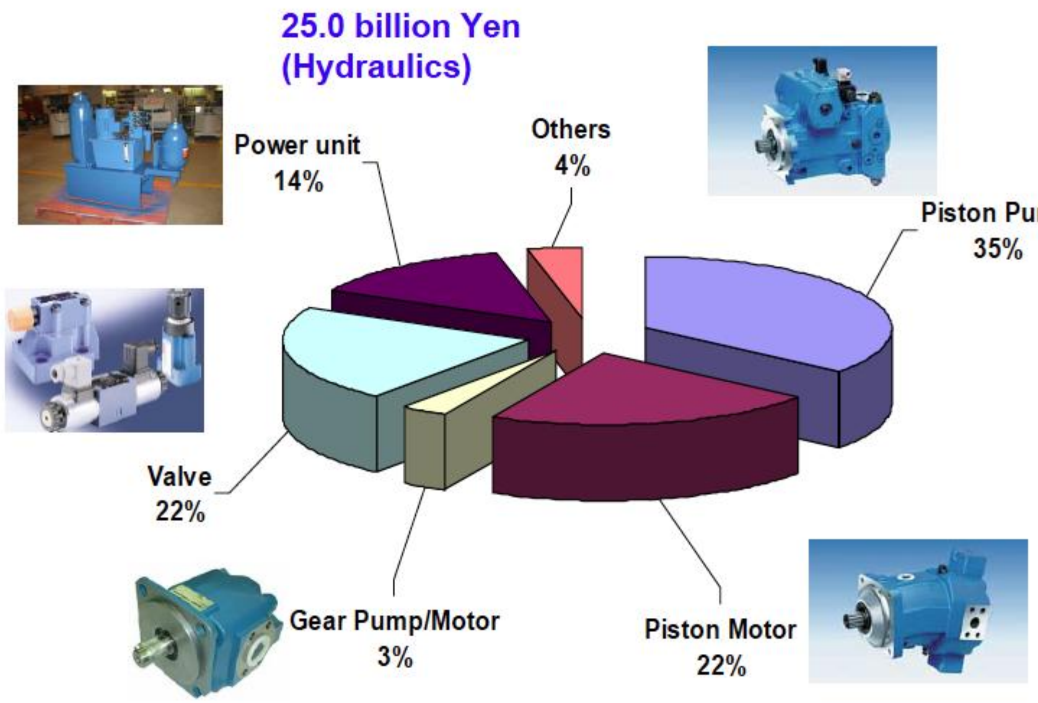


Figure: 1.4 Sales shares of Tsuchiura Plant (Bosch Rexroth Group, 2012)

Due to time limitation, the project focused on assembly section for axial piston unites. There are eight models in this category that can be seen in Figure 1.5. And among these models A6VM, which contained all steps in material supply from warehouses to testing, painting and finally packing was chosen.

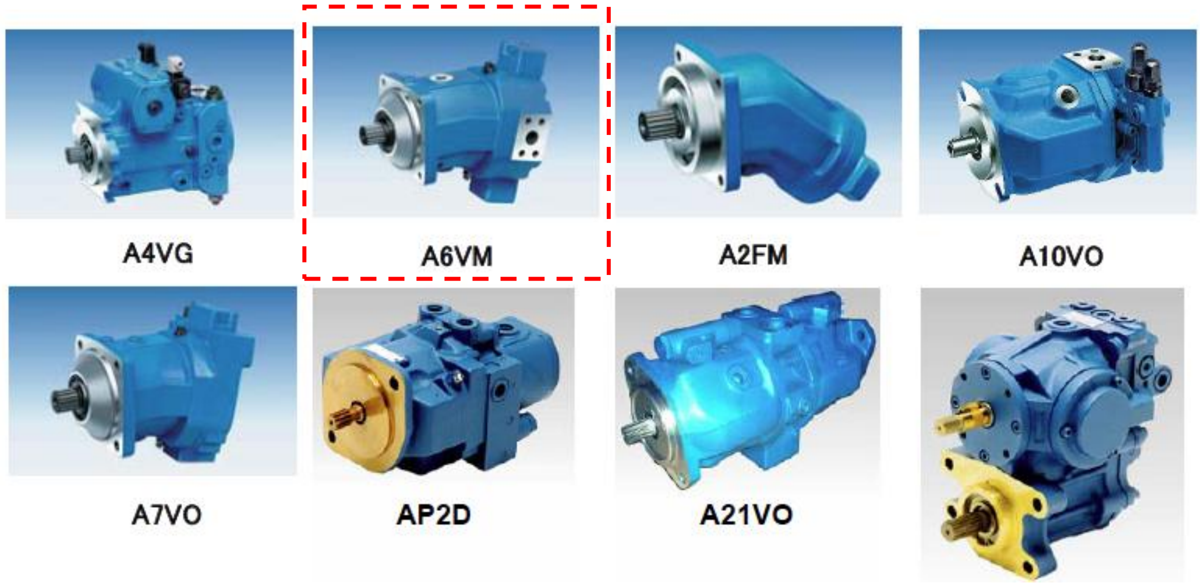


Figure: 1.5 Axial Piston Models (Bosch Rexroth Group, 2012)

1.4 Purpose and Research Questions

In background and problem formulation sections, several problems within companies' in-house logistics systems are introduced regarding different aspects such as inventory levels, MHSs, information link, and so forth. Further MHS's dilemma between high delivery performance and low buffer levels is stated and referred as one of the biggest causes of factory inefficiency. In addition, it is argued that how to overcome this dilemma is largely neglected in MHS design literature. Hence, the purpose of this thesis is:

To investigate how an in-house material handling system could be design to assure high delivery performance while maintaining low buffer levels

In order to achieve this purpose, three research questions have been formed:

RQ1.*What problems and challenges affect the delivery performance and buffer levels in an in-house material handling system?*

The first research question intends to investigate possible challenges and problems that are associated with in-house material handling system. Identified problems will be limited according to their impact on delivery performance and buffer levels on the shop floor.

RQ2.*What material handling system concepts/features can overcome the identified problems and challenges?*

The second research question is designed to elicit different material handling system concepts/features from literature that can overcome identified problems.

RQ3. *Which features should be selected for an in-house material handling system to assure high delivery performance and low buffer?*

The third research question aims to build a design for an in-house material handling system, in order to assure high delivery performance and low buffer levels. Features of the design will be selected among the ones mentioned under research question two.

1.4 Delimitations

Since this thesis work is limited to 30 credits (i.e., 20 weeks full study) and designing a new material supply system is dependent on many different variables, the problem will be narrowed down to decrease its complexity. Hence, design of the new material supply system will only cover the area between internal warehouses and assembly lines, and will exclude the parts related to suppliers and customers. In addition, the project aims to create a pilot design for in-house MHSs with the purpose of increasing delivery performance and decreasing buffer levels on the shop floor. For this reason, a product group that includes every step of material handling process has been chosen to conduct this study.

Furthermore, the research questions will look into the examined area from different perspective in order to demonstrate a clear picture about possible improvements in an in-house MHS. First, possible problems and challenges in MHS environment will be analyzed in theory and their related reflections will be found in the case company. Later, before building up a new MHS design according to identified problems, different concepts and features will be investigated in order to find near-optimal solutions. And finally, a new system will be designed out of selected features.

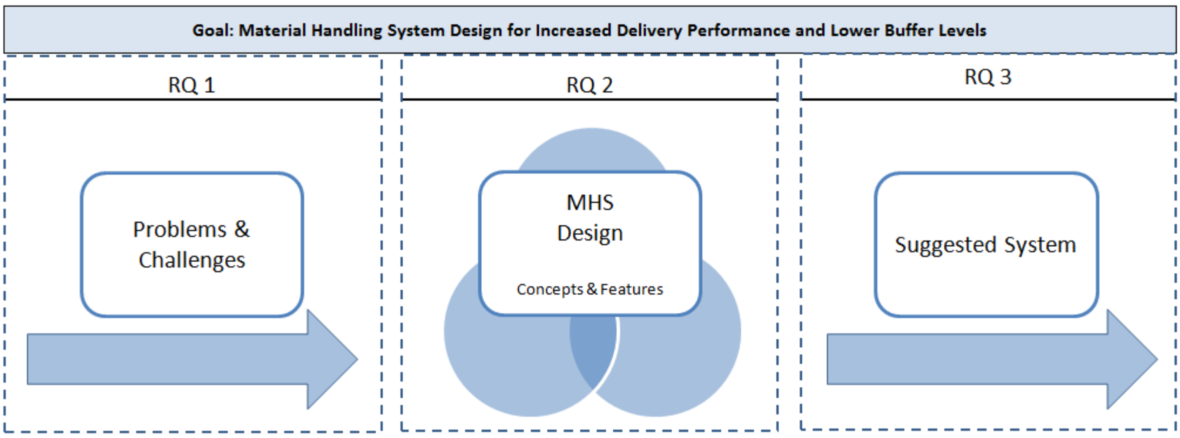


Figure 1.6: Scope of the thesis project

Additionally, all suggestions are conceptual and have been proposed according to their ability to contribute the overall target disregarding from their suitability for facilitated implementations. The design of the new material supply system will only be used and tested in one company and it is limited to the requirements set by the company. Granted that the layout of the shop floor, which the new system will be designed for, is already given and cannot be changed, and all suggestions will be formed according to this given condition.

1.5 Outline

This thesis is organized as following:

Chapter 2 – Theoretical Framework

In this chapter, different theories in the field of MHSs are connected to have a deeper understanding on the subject. The chapter covers subjects on identifying MHS problems/challenges and associated concepts in order to eliminate them.

Chapter 3 –Methodology

This chapter provides information on the methods used in this thesis work. Explanation of research process and method is given along with data collection and analysis techniques. Finally, quality of the research is evaluated.

Chapter 4 – Case Description and Design Process

This chapter explains case company's environment and different phases of MHS design process.

Chapter 5 – Results and Analysis

In this chapter, empirical findings from case company are presented. Further, based on a case-study, gathered data is analyzed and arisen research questions are answered.

Chapter 6 – Discussion

This chapter discusses the obtained results of this study and states the limitations of the research. Thereafter, theoretical and practical implications that indicate overall contribution of the research will be presented.

Chapter 7 – Conclusion and further research

In this chapter, conclusions are drawn based on results obtained, and further research suggestions are purposed.

2. Theoretical Framework

In this chapter the theories that are relevant to fulfil purpose of this study will be highlighted in order to provide a deeper understanding on the research field. Theoretical framework will investigate the problems/challenges and concepts/features related to MHSs.

2.1 Components of the Theoretical Framework

The theoretical framework of this thesis is divided into two main parts, and it is illustrated in Figure 2.1. In Section 2.2 before investigating MHS features and concepts, how a well-functioning MHS should operate will be defined in terms of having a clear picture of the desired target. Moreover, possible problems and challenges that can disrupt the system will be explored among relevant literature. Identified problems will be elaborated according to their direct and/or indirect impact on delivery performance and buffer levels on the shop floor.

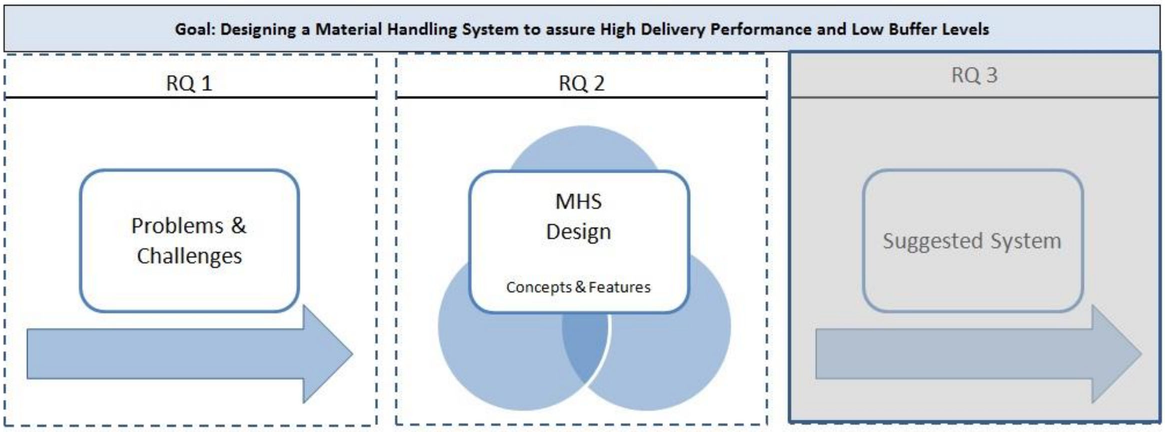


Figure 2.1 Components of Theoretical Framework (excluding gray areas)

In addition, theory part will discuss MHS design concepts from different aspects and levels in Section 2.3. Further, several features related to MHS will be elaborated according to Hassan's (2010) MHS design framework. Chosen features, in terms of fulfilling purpose of this study, will be categorized under three main pillars; design principles & physical elements, information & software, and human & management.

2.2 Problems and Challenges related to Material Handling Systems

Tompkins et al. (1996) emphasize the importance of understanding the requirements of a MHS before coming up with different solutions to improve it. To be able to find out what can be the potential problems or which factors can cause inefficiency in an internal MHS, it is essential to know how a well-functioning internal MHS operates and what sorts of internal and external factors can have an impact on the system.

Tompkins et al. (1996) shed lights on that MHS is much more than only handling materials. It is a comprehensive concept that involves the movement, storage, control, and protection of material with the aim of providing time and place utility. However, there is no unique definition that can cover all the features and activities in an internal MHS. Several researchers have been defined the concept of internal MHS from their point of view. The following represents some of the definitions of MHS:

- For Magad and Amos (1995) in-house MHS is the art and science of moving, storing, protecting and controlling material.
- Internal MHS is about providing the right amount of material, at the right time, at the right place and with the right method(s) (Kulwiec, 1985).
- Mattsson (2012) defines in-plant MHS as a system that has material and immaterial exchanges inside a factory where different departments and features are involved and working together to create value for the end-users. He points out that despite suppliers and customers are not involved in an in-house MHS, they do belong to the system's environment and can have huge impacts on its effectiveness.
- In Ballou's (1992) definition, in-facility MHS is a physical process of moving raw materials in small quantities over relatively short distances.

In the light of definitions above, it can be stated that internal MHS is a physical process inside of a factory between different departments with material and non-material exchanges (Stock & Lambert, 2001).

In Materials Handling Handbook, Mulcahy (1998) mentions several purposes that product transportation concepts should achieve:

- To provide proper material and information flow
- To ensure possible lowest operation costs
- To ensure on-time and accurate delivery
- To minimize material damage and employee injury
- Reuse of the load-carrying surface and also material identification at any time

In addition to that, Tompkins *et al.* (1996) enumerate nine factors that are essential to be fulfilled in order to eliminate material handling problems from shop floor:

- *Right Amount:* The concept of just-in-time inventory management emphasizes the importance of holding the right amount of material both in manufacturing and distribution.
- *Right Material:* An accurate identification system is necessary in order to pick and deliver the right material to the lines.
- *Right Condition:* The quality of the delivered material should fulfil the desired expectations without damages/defects.
- *Right Sequence:* The impact of the sequence of activities performed in a material handling operation is very evident. Therefore, it is important to move, store, protect, and control materials in the right sequence.

- *Right Orientation:* Physical orientation of materials represents a significant portion of people's activities both in manufacturing and distribution. Therefore, regaining the orientation of material will save valuable time.
- *Right Place:* The necessary material should be delivered at the point of use which can save undesired movements.
- *Right Time:* The need for the material handling system to move, store, protect, and control materials at the right time is increasingly important due to time-based competition.
- *Right Cost:* Right cost does not necessarily mean that a firm should decrease the cost of MHS. On the contrary, the system should be designed with competitive advantages, so it can be a revenue enhancer rather than a cost contributor.
- *Right Methods:* To perform all the mentioned points above in a right way, it is necessary to use the right methods.

Hassan (2006) denotes that without a well-designed MHS production could encounter delays, production time and cost could increase owing to unnecessary movement of products within the facility, and also products could get damaged or contaminated. On the other hand, a well-designed MHS would improve manufacturing and logistics operations, enhance delivery performance and quality on the shop floor, and also reduce work-in-progress inventories.

Table 2.1: Possible Problems and Challenges related to Material Handling Systems

Problems / Challenges	References
Delivey Precision - by eliminating unnecessary movements of products within the facility, products can be delivered at the right time, at the right place and in the right sequence - insufficient MH would cause production delays and increase production times	Mulhacy (1998), Hassan (2006), and Tompkins et al. (1996)
Inventory Levels - Holding the right amount of material both in manufacturing and distribution - Just-in-time inventory management - Decreased work-in-progress material	Hassan (2006) and Tompkins et al. (1996)
Operation Costs - to ensure possibly lowest operation costs the system should be designed in a way that it can enhance revenue rather than be a cost contributor	Mulhacy (1998), Hassan (2006), and Tompkins et al. (1996)
Delivery Quality - quality on the shop floor can be achieved by receiving right material, in right condition, and with right methods	Hassan (2006) and Tompkins et al. (1996)
Information Flow - providing proper material and information flow - accurate material identification systems - real time information	Mulhacy (1998)
Safety - minimize employee injury - Protect products from getting damaged or being contaminated	Mulhacy (1998) and Hassan (2006)

Several problems and challenges that are related to MHS are summarized according to different categories in the table above. Even though balancing between high delivery performance and low buffer levels is the main challenge of MHSs, other categories— operation costs, delivery quality, information flow and safety— are considered also in terms of their impact on overall MHS's efficiency.

Mentioned problems will be elaborated more in detail regarding to case company's environment in the analysis chapter of this thesis.

2.3 Material Handling System Concepts

In literature several researchers approach MHS design issues from different aspects. Tompkins *et al.* (1996) clarify the ideal Material Handling System from three different perspectives; theoretical, ultimate and technologically workable. The theoretical ideal MHS is a perfect system with zero cost, quality defects, safety hazards, wasted space and no management inefficiency. On the other hand, an ultimate ideal system is probably achievable at some point in future, but Tompkins *et al.* (1996) mark that lack of available technology is the reason that the system is not achievable at the present time. The technologically workable ideal system is a system that the required technology is available; however, some factors such as cost might be an obstacle in the way of installing some components. In the end, Tomkins *et al.* (1996) recommend companies to implement a cost effective system that is able to work at the present time without any obstacle for its successful implementation. Figure below shows the ideal systems approach (Nadler, 1965).

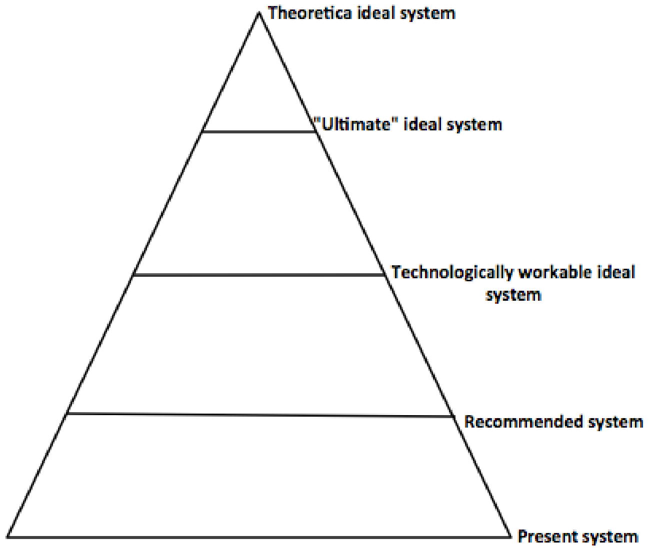


Figure 2.2: The ideal system approach (Nadler, 1965)

In most methodologies, MHS design concepts are categorized according to three different approaches (Welgama & Gibson, 1996).

- *Layout is already given;* determine or improve the material handling system
- *Material handling system is already given;* determine or improve the layout
- *Neither the handling system nor the layout are given;* determine or improve both.

However, the result for first and second approaches is highly depending on the given part of the problem, since material handling systems and facility layout are interrelated. Design of material handling systems is directly related to movement of material between the locations in the plant, and facility layout determines these locations; thereby, a flow path design with an existing layout have already loss a degree of freedom in order to attain overall optimal solution. Deciding pick-up and drop-off points is the crucial intersection between two approaches (Chittratanawat & Noble, 1999).

According to Chittratanawat and Noble (1999), material handling systems are fundamental factors for any problem related to manufacturing such as inventory levels, scheduling and production planning, delivery performance. Hence, MHS should be the first place to investigate for reducing operational costs and improving production systems. Typical factors that can affect design of MHSs are *cost*, *distance* and *material flow*; however; distance and material flow are key elements for pre-design, while cost is taken into consideration during selecting between design options (Chittratanawat & Noble, 1999).

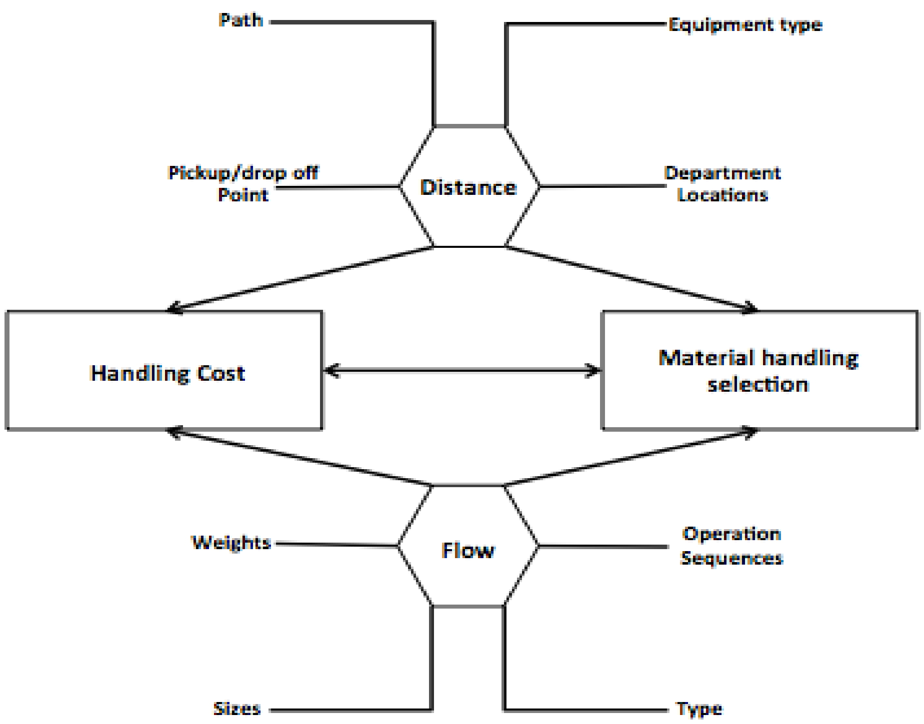


Figure 2.3: Interaction between distance and flow Chittratanawat and Noble (1999)

Chittratanawat and Noble (1999) classify MHS design elements into two main headings; distance and flow. Distance is the actual length between pick-up and drop-off points; and therefore, it directly affects material handling costs. Furthermore, issues related to distance decomposed into sub-problems, for instance, path routing, selection of material pick-up/drop-off points, type of equipment and department locations. Material flow can be described as the magnitude of the flow between locations and it also concerns factors related to material itself such as weight, size, type and operational sequence of the material. Interactions between these elements are illustrated above (Figure 2.3).

Hassan (2010) blueprints a framework that defines the steps that have to be taken during MHS design. Design process of MHS is a complex problem and it should be decomposed into smaller sub-systems. According to Hassan (2010), MHS consists of hardware, software, human and management sub-systems that work together to perform all activities related to material handling. Hardware is the largest sub-system and includes several physical elements such as equipment for transfer, storage, identification etc. Software ensures the communication link between hardware elements, but also the material handling system with its environment. Finally, human and management sub-system addresses operations of MHS, and aims to function it efficiently regarding company's manufacturing strategies.

After decomposing the problem into smaller steps, objectives of the MHS should be specified according to requirements and conditions of the overall system that MHS will operate under, and characteristics and inputs of its environment. Environment and its elements of the MHS, which it will operate in, should be identified in earlier phases of design, since it interacts, provides input and affects the MHS. Elements of external environment include suppliers, customers, regulations (e.g. safety constraints) where on the other hand, internal environment consist characteristics of the facility such as physical layout, type of production, type of industry and facility (Hassan, 2010).

Table 2.2: Different Approaches/Features in literature related to MHS design

Different Approaches / Features in Material Handling	References
Ideal system approach -Different perspectives of MHS: theoretical, ultimate, technologically workable, recommended, present	Tomkins et al. (1996)
Facility Layout approach - Design for eachother	Murther and Webster (1995)
Distance and Flow features - Material flow path and material attributes	Chittratanawat and Noble (1999)
Six-step engineering MHS design process	Tomkins et al. (1996)
MHS design framework - Hardware, software, human and management sub-systems	Hassan (2010)

As it can be summarized in Table 2.2, there are many different approaches for conceptual design of MHSs. In this study, students formed the theoretical framework based on the mentioned approaches. The figure below takes conceptual design in a more detailed level and illustrates different features that affect MHS and their relations with the system. In the following parts of this chapter, these features will be introduced and elaborated regarding to context of this thesis.

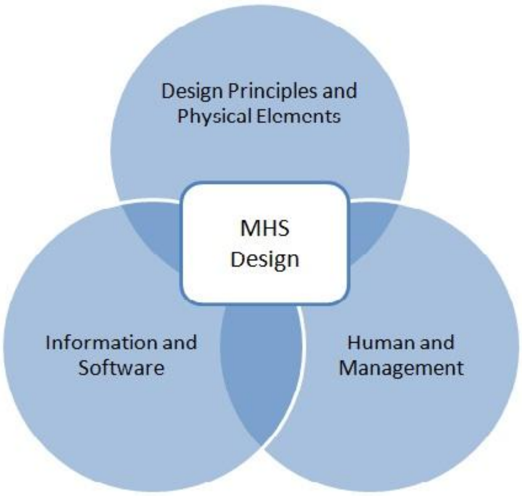


Figure 2.4 Material Handling System Design

2.2.1 Design Principles and Physical Elements

There are twenty fundamental guidelines and principles that can be used to effectively plan and control material handling. Originally these principles have been formed by College-Committee on Material Handling in Pittsburgh USA in 1990, and later these principles have been used and modified by several authors like Tompkins *et al.* (1996), Nyman (1992), and Coyle *et al.* (2008). The table below shows the principles with their definitions.

Table2.3: Fundamental MHS design principles (Tompkins *et al*., 1996)

Principles	**The definition according to Coyle et al. (2008)**
1. Planning Principle	Plan all material handling and storage activities in order to achieve maximum overall operating efficiency.
2. System Principle	Integrate these activities into a coordinated system of operations, including receiving, inspection, storage, production, assembly, packaging, warehousing, shipping and transportation.
3. Materials Flow Principle	Provide an operation sequence and equipment layout that optimizes materials flow.
4. Simplification Principle	Simplify handling by reducing, eliminating, or combining unnecessary movements and equipment.
5. Gravity Principle	Utilize gravity to move material wherever it is possible.
6. Space Utilization Principle	Make effective utilization of all cubic space.
7. Unit Size Principle	Increase the quantity, size, or weight of unit loads or their flow rates.
8. Mechanization Principle	Mechanize handling operations.
9. Automation Principle	Provide automation that includes production, handling, and storage functions
10.Equipment Selection Principle	While selecting handling equipment, all aspects like material handling, movement and the used methods should be considered.
11. Standardization Principle	Standardize the handling methods as well as types and size of handling equipment.
12. Adaptability Principle	Use the methods and equipment that can adapt to the widest variety of tasks and applications, except where the special methods and equipment are necessary.
13. Deadweight principle	Avoid unnecessary run of equipment and machines.
14. Utilization Principle	Plan for maximum utilization of handling equipment and labour.
15. Maintenance Principle	Plan for preventive maintenance and schedule repairs of all handling equipment.
16. Obsolescence Principle	Replace the obsolete handling methods and equipment when more efficient ones in order to improve the operations.
17. Control Principle	Use material handling activities to control the production, inventory and order handling.
18. Capacity Principle	Use handling equipment to improve production capacity
19. Performance Principle	Determine the handling performance effectiveness in terms of expense per unit handled.
20. Safety Principle	Provide suitable methods and equipment for safe handling.

Mulcahy (1998) enumerates several number of material handling design parameters that need to be taken into account while forming an in-house product transportation concept. These design parameters can be listed as:

- *Product dimension, size and form:* Length, width, height, shape, weight, and volume; small item, container, pallet/unit size, liquid, sheets etc.
- *Product characteristics:* Crushability or fragility of the products, protection methods, special conditions etc.
- *Original, final position of the material and travel path:* Horizontal or vertical movement, fixed or variable travel path, distance of the path, number and type of the turns along the path, elevation differences etc.
- *Physical constraints:* Layout obstacles, safety issues, hazards that can occur during the transit
- *Transportation equipment:* Non-powered (human/gravity), powered (forklift), automatic controlled (AGV), degree of mechanization desired
- *Product loading/unloading methods:* Automatic or manual delivery
- *Product flow:* Amount needed, continuous or intermittent
- *Workstations:* Number and location of pick-up/drop-off points
- *Product delivery frequency:* Batch sizes, average number of production orders, based on schedule or based on demand product delivery
- *Production constraints:* Operation hours, operators, available labor skills etc.
- *Integration with other equipment and systems*
- *Degree of control required*

In modern Material Handling literature, numerous transportation concepts are presented (Mulcahy, 1998). However, in this thesis regarding to delimitations and suitability to case company's environment, only unit-load, above-floor, horizontal movement transportation concepts will be elaborated.

2.2.1.1 Non-powered Horizontal Transportation Concepts

In several cases regarding to operational constraints and requirements, materials can be transported with manual power or gravity force between two facility locations. Despite its clear disadvantages such as safety hazards, employee injuries (Arora & Shinde, 2007); non-powered product transportations can be favourable under some constraints:

- Low delivery frequency and short distances make it uneconomical to use powered transportation equipment.
- The facility, layout, or other products do not permit powered equipment.
- Number of qualified labor is limited or labor wage rate is low
- In-house maintenance skills are limited
- The product has an irregular shape that makes it impossible to get handled by powered transportation equipment

Various manual power transportation equipment can be exemplified as platform-trucks, hand-pallet trucks, skid trucks, and etc.

2.2.1.2 Powered Horizontal Transportation Concepts

Forklift Truck

Forklift trucks are powered material handling equipment to transport pallets and unit-loads across a variable travel path between two warehouse or plant locations (Mulcahy, 1998; Arora & Shinde, 2007). Despite their widely usage in industry; in-house forklift transportation concepts have several disadvantages (Mulcahy, 1998):

- Employee operated
- Most frequently handles only one pallet
- Increased safety hazards for facility, equipment or products
- Has low productivity on the return trip to the dispatch station
- Not cost-effective

Milkruns

Mulcahy (1998) states when in-house transportation distance is over 300 ft and the unit-load volume is low to medium with a varied travel distance and several loading/unloading points, the powered tractor with a series of carts is considered as a cost-effective concept. The concept is widely known as "*milkrun*" and Baudin (2004) defines it as organizing pickups and deliveries at fixed times along fixed routes for moving small quantities of large number of items both between and within plants with short, predictable lead times and without multiplying transportation costs. Milkrun concept, as illustrated in the figure below, can be applied to different levels of company's operations such as in outbound, inbound, and in-plant logistics. By the same token, Matzka *et al.* (2009) explains the term milkrun as transportation of goods on a pre-determined route in regular and frequent time intervals. If the demand cannot be satisfied immediately, the point of need has to wait until the next milkrun tour to receive materials. According to Domingo *et al.* (2007), lean rate of a production site is the ratio between value-adding time and dock-to-dock time, and milkrun system can improve this rate significantly. Milkrun reordering system is a transport system for the horizontal movement of materials by automated guided vehicles, in-plant trucks, forklifts etc. with a defined path and fixed timetable. The system is established through the production lines to pick up empty packages and supply full packages to designated points, and if there are no parts to pick up or supply, then the vehicle continues on its route (Domingo *et al.,* 2007).

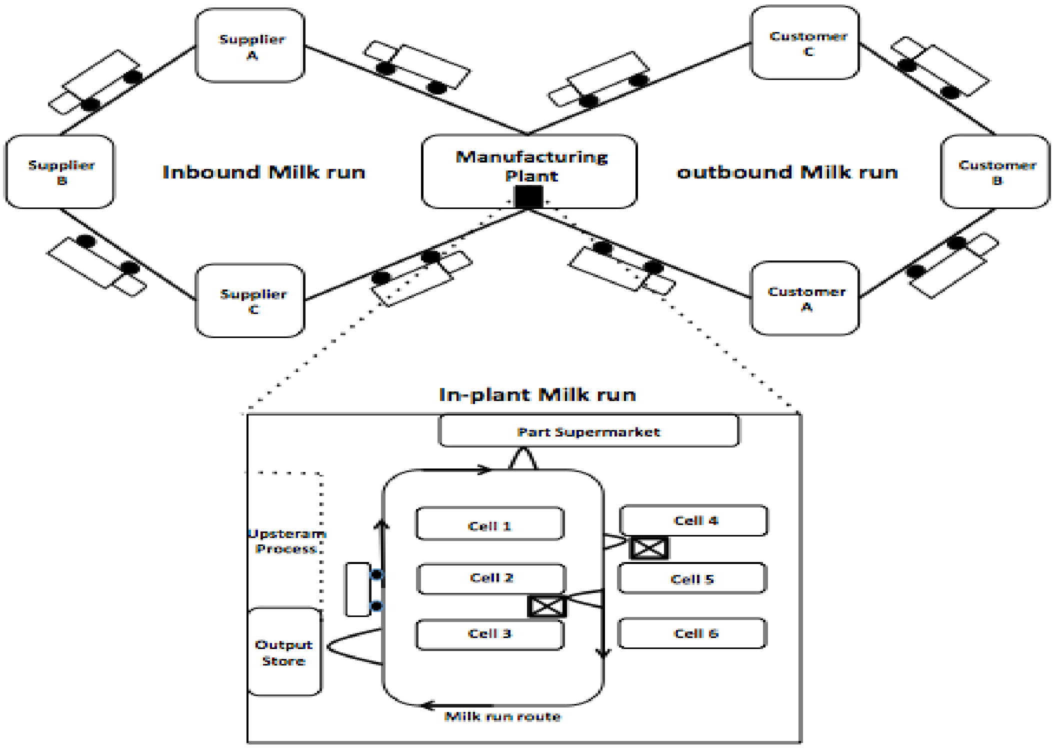


Figure 2.5: External and Internal Milkrun (Baudin, 2004)

Baudin (2004) argues that using most traditional methods on the shop floor such as dispatching the materials by forklifts are contradicting with lean manufacturing principles, since they are costly, contain safety hazard and can be operated only by specially trained drivers, and also by restricting forklifts manufacturing density can be increased by 70%. Working principle of forklifts is similar to taxis, whereas milkruns with pushcarts have the same working principle as buses and subways. Baudin (2004) illustrates this issue with an example; unless there is no concern related to cost, people uses taxis only in some certain of occasions or in emergency situations. On the other hand, buses and subways with regular intervals along fixed routes are more common to use while travelling between two fixed points every day. Furthermore, Baudin (2004) highlights that the great improvements in plant transportation can be achieved by eliminating trips within the plant rather than by reducing distances. Additional benefits of using milkrun system can be listed as following:

- Decreased inventory levels; and thereby, space requirements in production area by frequent supply in small quantities
- Stable and short replenishment time: The stocks of materials and components inside the plant are sized, so to be just large enough to support consumption until the next delivery
- Increased delivery performance: Increased productivity by supplying the right part, at the right time, in the right quantity and quality and at the right place

- Increase material supply efficiency by mixed transportation of materials and optimized transportation routes
- Increased value-adding time with standardized material and information flow

Domingo *et al.* (2007) emphasize that milkrun reduces internal logistics *wastes* in terms of unnecessary inventories and excessive movements of materials within the plant without changing the production philosophy or layout.

However, despite its widespread usage in practice, milkrun concept is largely ignored in the literature, and barely mentioned even in lean manufacturing resources (Baudin, 2004).

Automated Guided Vehicles (AGVs)

Mulcahy (1998) presents Automated Guided Vehicles (AGVs) as an alternative above-floor powered horizontal in-house pallet transportation concept. When handling high pallet volume with frequent, regular deliveries to predetermined locations; AGVs can be a good alternative to forklift and milkrun. AGVs are battery-powered, self-operated and computer controlled driverless vehicles that are guided along defined pathways by wire, magnetic or optic guidance (Kumar, 2008; Ali & Khan, 2010). AGV applications have became the essential part for manufacturing systems because of their ability to facilitate material handling, while at the same time increase productivity, improve product quality and flexibility (Egbelu, 1993). Trebilcock (2002) demonstrates benefits of using AGVs on the shop floor. First, they can eliminate the need of finding and training material handling labour force. Second, AGVs are helpful in terms of maintaining a safe shop floor environment by reducing/eliminating possible damages to facilities and products caused by forklifts. Third, AGVs bring flexibility on the shop floor; if there is a need to change layout, AGVs can be rerouted quite easily. Last but most importantly, AGVs have high delivery performance, which means they arrive exactly when they are supposed to arrive. Today's AGV systems have the ability to communicate in real time with host computer systems that can support just-in-time delivery to machines and workstations.

Ali and Khan (2010) chalk out a framework for reviewing design and implementation stages of AGVs in Flexible Manufacturing Systems (FMS) i.e., design, planning, scheduling and control (Stecke & Solberg, 1983). Problems related to design considers multiple decision factors such as flow path, number of AGV vehicles required, location of pickup and drop-off points, vehicle dispatching, and traffic control strategy. A comprehensive analysis of the manufacturing system is the key starting point to be able to predict interactions between decision factors and analyze performance impacts on the overall system. The planning phase takes conceptual design one step down in a more detailed level and deals with physical material flow, facility layout and floor conditions, which will define type of transportation equipment. Scheduling and control strategies are related to sequencing and dispatching rules and forming time tables for material supply to lines according to manufacturing strategies such as push or pull delivery systems (Ali & Khan, 2010).

2.2.2 Information and Software

Baudin (2004) defines information flow as transaction processing associated with the material flow, analysis of past activities, forecasting, planning, and scheduling of future activities. According to Coyle *et al.* (2008) information is the lifeline of every system, and also one of the important pillars in making decisions and actions effectively. In addition, to ensure that the information is valuable and useful through a material flow, it must be accessible, relevant, accurate, timely, and transferable. It has been argued by Leng and Zailani (2012) that the accuracy of information sharing will enable different departments to fulfil requests within shorter cycle times, and that is why it is considered as an important element that reflects cooperation between different sections inside or outside of a company. The most important benefit of obtaining an effective information system can be summarized as improved productivity through higher and accurate delivery performance, reduced uncertainty, and low buffer levels (Fitzpatrick & Ali, 2010). Huang *et* al. (2007) state that manufacturing shop floors suffer from lack of real-time information. Paper-based manual systems are time-consuming, prone to errors, and frequently lost or damaged. As a consequence, the information cannot accurately reflect the real-life situations and changes in the system, which makes it impossible to make accurate shop-floor decisions.

In MHSs environment, several identification and control techniques/equipment are used to collect and communicate the information to coordinate the flow of materials (Arora & Shinde, 2007) and the ones that are relevant to course of this thesis will be presented below.

Kanban

Kanban is a tool in scheduling system that was mentioned for the first time by Taichi Ohno in Lean Production and just-in-time concepts. According to its creator it is a physical information card in manufacturing plants that helps to determine what to produce, when to produce and how many units to produce (Ohno, 1988). A single implementation of kanban system might be two-bin system where parts are supplied with containers to production lines. Empty container became the *signal* itself, and indicates that it needs to be replenished, after parts are consumed by production (Hobbs, 2004).

However, nowadays many companies want to take advantage of increasingly effective computer and communication technologies (Baudin, 2004), and prefer to implement electronic kanban (e-kanban) system. E-kanbans can be easily integrated into company's enterprise resource planning (ERP) systems; and also by employing them, the common problems such as handling with manual cards, lost cards, entry errors etc. can be eliminated (Drickhamer, 2005). Additionally, embedded e-kanbans into company's software system can provide real time information on the shop floor. In material handling systems environment, kanban is used along with Just-in-time concept or two-bin systems while pulling materials of production orders from warehouses (Wang *et al.*, 2011; Kumar & Panneerselvam, 2007).

Wireless Barcode Scanners and RFID Technology

The need of quickly responding to customer requests and customizing the delivery services are becoming more and more important for companies (Fuller *et al.*, 1993; Småros *et al.,* 2000). On the other hand, Holmström and Kärkkäinen (2002) underline that many company are dealing with the same challenge; finding new solutions for more efficient information sharing; and thereupon, leaner material handling across the company borders. For this purpose, electronic information technology, for example, in forms of wireless barcode scanners and RFID technologies can be very handy. Holmström and Kärkkäinen (2002) define wireless scanner as product identification system that enables to identify a product or a part automatically without physical handling. Holmström and Kärkkäinen (2002) divide the major benefits of implementing wireless communication technology in three main categories, functional benefits through whole organization, provided visibility and increased control through the whole chain, and the possibility of restructuring the information systems infrastructure.

Similar to wireless scanners, RFID-tags are additional tools in terms of fostering information link within MHS (Knill, 1996). By implementing RFID technologies not only financial gains, but also efficiency gains can be achieved through improved productivity and visibility, higher speeds, greater accuracy and better customer service (Drum, 2009).

However, it is essential to be aware of that information system is more than computer system, for example in lean manufacturing, information system is a combination of visible management, 5S, and computer systems (Baudin, 2004).

2.2.3 Human and Management

Hassan (2010) states that human and management are essential factors for MHS designs. The term human refers to employees who will operate the system; while on the other hand, management refers how we manage the MHS according to time schedules, manufacturing constraints and principles, and so on. While designing or improving a material handling system not only physical elements, but also supportive aspects such as employee involvement and compatibility with the manufacturing system are essential, since they will affect success of the design dramatically. Below several concepts related to issue will be mentioned.

Push vs. Pull systems and JIT Concept

Baudin (2004) claims that lean manufacturing concept can be described as pull system, while it is used in the logistics domain in case of transportation of raw material or parts between plants or between lines within a plant. Pull system is about two-way communication, which means warehouses do not send anything until production lines signal that materials can be delivered. On the contrary, in push system parts are shipped as soon as they are ready without considering the condition in the production lines (Baudin, 2004). According to Pyke and Cohen's (1990) theory, push system is mostly based on forecast and centralized control whereas pull system is reactive, decentralized, and more service-oriented. Additionally, Baudin (2004) argues that pull system is commonly based on local decisions while push system allows more global decisions. Despite great advantages of pull system such as higher productivity and delivery performance, and lower buffer levels (Baudin, 2004), there are few disadvantages that should be considered during design process of a new MHS. One disadvantage that has been mentioned by Blinder (1981) and Caplin (1985) is the increased variability at the higher levels in the plant. Another drawback is the possibility of outstripping capacity at the replenishment point (Pyke & Cohen, 1990).The main reason behind employing pull system is to deliver at a time that parts can be used without any waiting, in other words JIT delivery.

American Production and Inventory Control Society (APICS) defines JIT concept as manufacturing excellence, which focuses on waste-elimination of all kinds, and continues improvements on quality and productivity. In addition, JIT concept focuses mainly on visibility, simplicity, flexibility, organization, and standardization. However, in order to eliminate waste, it is important to identify it first. Waste can be defined as all types of activities that cost money, but do not add any value to the product. Tompkins *et al.* (1996) defines the equipment, inventories, space, time, labour, handling, transportation, and paperwork as common sources of waste in an organization. Inventories for raw material are usually wasted due to several reasons; however, one of the main reasons is inefficient material handling system. Therefore, there are different solutions and techniques in JIT concept that discuss the issues related to building design, plant layout and MHS.

As a result, JIT concept suggests that the traditional method for designing the layout and MHS needs to be updated. The factors that can have an impact on MHS and its surroundings will be described below:

1. *Reduction of inventories:* Inventories can be reduced, if products are produced, purchased and delivered in small lots, production schedule is levelled appropriately, quality is improved, necessary equipment on the shop floor are maintained adequately, and most importantly parts/products are *pulled* at the right time and with the right quantity.

2. *Delivery to point-of-use:* When the parts/products are purchased and produced in small lots, they should be delivered to the point-of-use to avoid excessive inventories at consuming stations.

3. *Quality at the source:* It is essential to attain high quality in each process, which means transportation, material handling, and storage processes must deliver the parts to the next processes with the same quality condition that they receive it. In order to achieve this, the following steps are required:

- Proper packaging
- Efficient MHS and storage activities
- Teamwork and enough time to perform the operation processes without any stress

4. *Better communication:* Effective communication is one of the most vital elements of JIT concept.
5. *Total employee involvement:* Empowerment is necessary to change the traditional decision making and problem-solving approach; therefore, employee involvement is essential in all different stages from design and implementation to operation.

Employee Involvement

The success of implementing a new concept without involving related employees is almost equal to zero (Baudin, 2004). Therefore, employee-involvement and training for the achievement of an effective and efficient in-house material handling system is essential (Mulcahy, 1998). Baudin (2004) underlines that human are the key component for successful implementation, start-up, and continued operation of an in-house transportation concept or equipment. For this reason, Mulcahy (1999) claims that it is vital to increase training and motivating activities related to in-house material transportation management and employees. However, employee involvement and needs should be addressed in earlier stages of design in order the get the best results from system implementation. On the other hand, it is crucial not to forget management involvement both in functional and physical levels of implementation (Motiwalla & Thompson, 2009).

3. Methodology

In this chapter, the research methodology used to achieve purpose of this study is presented. Applied research methods, data collection and analysis techniques are introduced; and thereafter, the research quality is evaluated.

3.1 Research Process

The project was carried out from February to July 2012 in Bosch Rexroth Japan (BRJP) as a mandatory part of Production Development and Management master program in the School of Engineering at Jönköping University. The primary collaboration with the company started in November 2011 and through several telephone conferences the project scope and objectives were clarified and established (Williamson, 2002). As a next step, an initial project plan was formed in order to follow a structured procedure during the execution of the project, and attaining the project goals (Saunders *et al.,* 2000).

After establishing the primary project plan, a wide literature review in the field of MHS was made and the research questions were formed (Williamson, 2002). During this process it was essential for students to have critical minds about the contents of the literature; therefore, a process of continuous evaluation, and comparison of ideas and research findings were carried out (Williamson, 2002). In order to fulfill this purpose, and also be able to answer the research questions, various research methods and techniques were performed (Walliman, 2001). At this point, the students decided to divide the content of the project in three main categories:

1. **Design Principles and Physical Elements,**
2. **Information and Software,**
3. **Human and Management.**

The main reason of taking this decision was to have a deeper understanding in the investigated field and also attack the focused area from different perspectives (Jacobsen, 2010). For this purpose a case study needed to be performed due to two main reasons. First to identify the possible problems and second to define the potential concepts/features of MHSs. Based on the findings from the case study, a suitable concept could be suggested in order to achieve higher delivery performance while attaining lower buffer levels.

3.2 Research Approach

In order to achieve higher reliability during the research process, a combination of qualitative and quantitative research methods have been used (Marcoulides, 1998). Bryman (2007) defines quantitative research as a distinctive research strategy that emphasizes quantification in the collection and analysis of data. In addition, Kothari (2004) mentions that quantitative method is mainly based on numbers and measurements. On the other hand, qualitative method explained as qualitative phenomenon related to quality and type, and this approach examines why and how questions instead of what, where and when questions. Näslund (2002) points out content analysis, structured observations, questionnaires and surveys as methods used in quantitative approach while interviews, documentary analysis, unstructured observation can be pointed out as methods used in qualitative approach.

3.3 Research Method

In order to provide a deeper knowledge about the problems and challenges in the current in-house MHS and also to be able to suggest suitable solutions for the arisen issues a case study was conducted in this research.

3.3.1 Case Study

Case study was chosen upon two main reasons; firstly, to investigate the possible problems and challenges related to MHSs within a real-life context and secondly, because of insufficient control over the events (Yin, 2003). Another reason of choosing the case study was its flexible nature, which would allow students to use multiple data collection techniques such as; interviews, observations, measurements, and so on. The case study focused on designing a new MHS that could replace the existing forklifts on the shop floor. The project started with observations of the current system; and henceforth, different tools such as process mapping, value stream mapping, and etc. were used. However, for designing a new MHS, students needed to consider the regulations and constrains of the case company and the country where the factory was located, Japan. The company settled the initial and overall targets of the project. Besides enumerated factors the physical layout of the factory was another issue that needed to be taken into consideration. During the execution of the project, BRJP provided students the opportunity of visiting different companies such as Toyota and Nissan, which already were using milkrun and AGV as a part of their in-house MHS. In addition to students' own experiences and theoretical knowledge within the investigated area, involved employees also contributed with their ideas and suggestions during the design process.

3.4 Data collection

While carrying out the project, multiple data collection techniques were used in order to have more reliable outcomes (Williamson, 2002). Likewise, different data sources can support each other and bring strong and exciting results (Jacobsen, 2010). According to type of the data that collected, these techniques can be classified under two main categories; primary and secondary data.

3.4.1 Primary Data Collection

The aim of primary data collection in this study is to build groundwork for the analysis (Jacobsen, 2010). For this purpose, several techniques such as interview, observation, and measurement (Williamson, 2002) have been used, and will be described in following sections.

Interview

The main reason of using interview during this project was that it is a valuable tool for collecting qualitative data that can provide deeper understanding on the investigated area (Patton, 1987). The interviews helped students to gather the relevant information and analyze the current MHS in assembly section in BRJP (Säfsten, 2010). According to Williamson (2002) interviews can be divided into three categories; structured, semi-structured, and non-structured. While carrying the interviews, students tried to hold semi-structured interviews and the prepared questions were as simple, comprehensive and non-leading as possible (Jacobsen, 2010). The chosen strategy allowed the students to be more flexible and adapt the following questions depending on the given answers of the respondents (Williamson, 2002). Another reason of applying semi-structured interviews was to give the interviewees the freedom to express their own thoughts and ideas, and in this manner form a creative idea-sharing environment. An overview of the performed interviews can be observed in the table below.

Table 3.1: Overview of the performed interviews at BRJP

Department	Position
Logistics	- Overall project leader for Newlog project - Project leader for material supply sub-project
Warehouse	- Section manager - Operators
Washing	- Section manager
Assembly	- Production engineer - Production planner - Line responsible - Operators
Testing	- Section manager - Operators
Shipping	- Section manager - Operators

The interviews were performed face-to-face, which made it possible to achieve a high response rate (Williamson, 2002). The interviews carried out both in groups and individually, depending on the purpose of each interview session and the availability of the participants. The time for each interview session vary from ten minutes up to two hours depending on the subject, situation, and location. Finally, these interviews were performed under a period of six months from February to July 2012 while students were carrying out the project in BRJP.

Observation

Observation was a helpful technique that allowed students to bring a deeper understanding and knowledge about the current MHS in BRJP (Williamson, 2002; Walliman, 2001). On the other hand, this technique made it possible to gather data by watching employees' behavior, events, and noting physical characteristics in the way they exist in the current MHS in BRJP (Powell *et al.*, 1996). In this project material flow, equipment, operators' behavior, and other aspects related to MHS were observed.

Since the observations were ongoing during the whole project period, the ones that seemed to have a bigger impact on the result of this study were recorded both as videos and pictures. The purpose of recording some of the important observations was to be able to use them later in the analysis chapter, as it suggested by both Williamson (2002) and Powell *et al.* (1996). An overview of observations that took place during this study can be seen in table 3.2.

Table 3.2: Overview of the performed observations in BRJP

No	Department	Involved Employee(s)	Amount of Observation Session
1	Goods Received	- Section manager - Operators	5
2	Warehouses	- Section manager - Operators	7
3	Washing	- Section manager - Washing operators	3
4	Assembly	- Production engineer - Line responsible - Assembly operators	8
5	Testing	- Section manager - Testing operators	4
6	Shipping	- Section manager - Shipping operators	3

Before the observations, the involved employees had been informed about what the students were going to observe, and also the intention of the observations that would take place. However, the exact time for each observation session was not revealed with the purpose of maintaining high credibility and authenticity of the operators' behaviors.

Measurement

By applying this data collection technique students were able to assign numbers on objects and observations (Walliman, 2001). Measurement was an important tool for collecting the necessary data while carrying out this study. However, in order to provide accurate and high quality data during the measurement process some points such as reliability and validity of the study, interpretability of the collected data were taking into account (Kothari, 2004). Needless to say, these points were performed precise and free of errors (Walliman, 2001).

In this study, a time measurement has been carried out by using a stopwatch on the warehouse activities, travel time of material flow path, loading and unloading time of raw materials/finished goods at each station, washing of parts, and so forth. Additionally, related distances for material handling processes and other physical constrains were measured.

3.4.2 Secondary Data Collection

As it is stated earlier, the quality of the research would decrease, if only one source of data collection technique would be performed. Therefore, students agreed that it was ideal to apply different types of data sources in order to enrich the outcomes of the study (Jacobsen, 2010). Through literature review the students build a foundation that forms the main pillars of this thesis project (Walliman, 2001).Another source that has been used during this study was company's documents and database, which clarify the rules and limits that needed to be taken into consideration, while designing a new MHS. These documents were mainly related to material supply and consist of maps, daily schedule of related sections, job descriptions, and recorded data of reasons that was causing production/assembly line stops. Williamson (2002) mention that it is never safe to use secondary data without knowing its real meaning. Although students knew that by using secondary data they would save time in data collection process (Williamson, 2002), they were also aware that they could not solely rely on secondary data. With considering these two aspects, students tried to select data sources critically in the way that they would be relevant, accurate and authentic (Jacobsen, 2010).

Literature Review

The literature review during this project provided students the opportunity to identify, locate, synthesize, and analyze problems and concepts related to MHS design (Williamson, 2002). Furthermore, by using this method students tried to obtain a deeper understanding in the research field, and also a background and context for this thesis project (Walliman, 2001; Marshall & Rossman, 2006). Henceforth, a comprehensive literature review was performed in the following areas:

1. Design principles and physical elements
2. Information and software
3. Human and management

The literature review was attained from two main sources, books and databases. The books were provided mainly from University library in Jönköping and the databases used during this study were Jönköping University's database and ProQuest database. To find the relevant literature several keywords were employed, for instance, *MHS design process,* *Milkrun, AGV, just-in-time material flow, ergonomy and safety in MHS, employee involvement in MHS design.*

3.5 Data Analysis

The students were aware of the importance of using a proper data analysis strategy while performing the case study in BRJP; therefore, through continues analysis of the collected data students ensure efficient utilization of time, but also bring order, structure, and meaning to the collected data (Williamson, 2002; Lively, 1997). Since aim of gathering this data was to create a new theory, it was crucial to ensure that the collected data was supported by the existing theory (Williamson, 2002). For this purpose a data analysis process that has eight steps was followed (Williamson, 2002):

1. **Data transcription:** Typing the notes and tapes from interviews, observations, and etc. into a word processor in order to make the information more accessible and easier to analyze.
2. **Getting familiar with the gathered data:** Before breaking the gathered data into each specific category it was important for the students to have an overall understanding of the information that was collected through interviews, observations, measurements, and etc.
3. **Categorization of the collected data:** In order to make the gathered data more accessible and easier to analyze, the information was divided under three main categories; Design principles and physical elements, Information and software, Human and management.
4. **Creation of new ideas from the gathered data:** After having enough information about MHSs in general and identifying company specific challenges, the students start thinking about the data in different ways in order to provide a deeper understanding.
5. **Conceptually organizing the categories:** In this stage the students start thinking about the relationships between categories both similarities and differences.
6. **Forming tentative theories:** Taking notes and memos to create tentative hunches, ideas or theories about the collected data.
7. **Check through data for evidence that supporting the tentative theories:** Cross checking between the gathered data and the tentative theories to insure their accuracy.
8. **Generate the result of the study:** Interpretation of the analysis and insuring that the research questions have been thoroughly answered or if further analysis is needed.

3.6 Research Quality

To ensure and maintain high quality on the research and its outcomes, it was essential to have continuous quality check on the gathered data (Williamson, 2002). For this reason, different data collection techniques were used in order to eliminate or minimize the effect of biased data (Yin, 2003). On the other hand, the quality of the project could also be judged based upon two other criteria: validity and reliability (Williamson, 2002). Validity is more about measuring accuracy, whether reliability can be defined as obtaining the same results and findings through repetitive research on the same area (Williamson, 2002).

Validity

Validity can be defined in two steps: internal and external (Yin, 2003). The author defines internal validity as the quality of the research, and external validity as the generalization level of findings and results.

During this study in order to reach high validity, students tried to apply multiple data collection techniques that were supported by related literature. As it is stated by Hansson (2007) observations during a research might be affected by predetermined perception of the observers. In order to avoid this issue triangulation technique, which suggests using more than two data collection techniques, was employed during execution of the thesis work (Williamson, 2002).

Reliability

As it is stated by Williamson (2002) reliability is about accuracy of the results and findings. For achieving high reliability during the execution of this project, different data collection technique such as interviews, observation, video-record, and etc. were used. On the other hand, the information gathered from the literature review was critically and thoroughly questioned and analyzed.

4. Case Description and Design Process

This chapter elaborates case company's current situation, requirements, and future targets along with comprehensive design phases.

4.1 Material Handling System in BRJP

As it is argued before in the method chapter, case study deemed necessary not only to fulfill the aim of this research, but also provide deeper and broader knowledge in the field of MHS. For this purpose, Bosch Rexroth Corporation was chosen. The main reason for selecting this case company was that BRJP was suffering from inefficient MHS, which in turn, was causing several other hitches for the company's operations, customer satisfaction, and market share.

4.1.1 Current MHS and Related Problems and Challenges

In the existing system material movement on the shop floor is handled mostly by forklifts and manual transportation, which represents traditional approach of material handling, and is not beneficial any longer due to various reasons such as cost, high buffer levels, low delivery performance, safety and ergonomic aspects. Furthermore, in BRJP Production Control department provides the production orders separately to warehouses and assembly section; this generates push material supply delivery on the shop floor and an inefficient information sharing process, which affects both the delivery performance and buffer levels. Correspondingly, the complex products produced by BRJP require different parts from different warehouses to be delivered at different times (Figure 4.1). All above-mentioned issues put additional challenges on the current material handling system and make the situation even more difficult to handle.

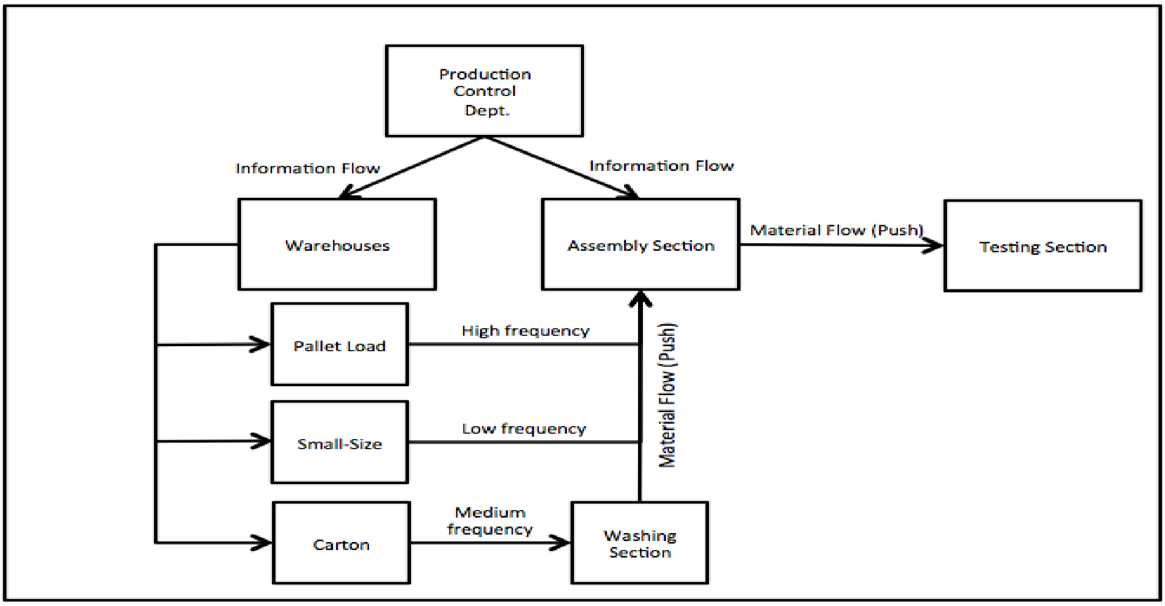


Figure 4.1: Current material delivery process in BRJP

4.1.2 The Future MHS

To manage the enumerated challenges above, BRJP proposed a project description with an objective of designing a new internal MHS where the company can attain:

- Higher delivery performance and delivery quality;
- Lower buffer levels and material handling operation costs;
- Improved information link; and
- Higher safety and ergonomics standards in material handling processes and equipment.

The new material handling system will serve two machining, one assembly, and one testing sections in the company. This made the project more detailed and hard to accomplish, and regarding to time limitation of this study, students had to decrease the complexity level of the project. Thereby, one product family, the largest product group— A6VM hydraulic pumps— that includes all steps in the material handling process has been chosen. The suggested material-handling concept for A6VM would later be used as a pilot and implemented in different sections after small adjustments (Figure 4.2).

Figure 4.2: MHS design/implementation plan

However, to be able to carry out this project and could deal with its complexity a well-structured work method seemed necessary to follow (Bellgran & Säfsten, 2010; Tompkins *et al.*, 1996). For this purpose, a combination of Bellgran and Säfsten(2010)'s a structured way of working for system development and Tompkins *et al.* (1996)'s six-phased engineering design process were used. Tomkins *et al.* (1996) emphasize the importance of following a structured procedure, while designing a new MHS or improving the already existing one. Consequently, they suggest a six-phased engineering design process. The design process consists of six following steps or phases:

1. Define the objectives and scope for the MHS
2. Investigate the requirements for moving, storing, protecting, and controlling material
3. Generate alternative designs for meeting MHS requirements
4. Evaluate the generated alternative MHS designs
5. Select the preferred design for MHS

6. Implement the selected one including training of personnel, installation, debug and start up of equipment, and periodic audits of system performance.

It is important to mention that both the working description and the principles were adopted in order to fulfill the aim of this research. Thus, the project work was divided into three main sequential phases and several sub-phases:

1. Planning phase:
   - Define the objectives and scope for the MHS
   - Plan for the MHS design
2. Preparation phase:
   - Background study
   - Investigate the requirements for designing a new MHS
3. Design phase:
   - Generate alternative-design for meeting material handling system requirements
   - Evaluate the generated alternative and select the suitable option(s)
   - Detail design of the selected MHS

4.2 Planning Phase

The purpose of having a structure way of working was to avoid or minimize the initial unexpected problems and achieve a clear structure already at the start of the project work. However, students were also aware of the fact that the plan itself would not deliver any solution rather it would lead them through the system design process (Bellgran & Säfsten, 2010).

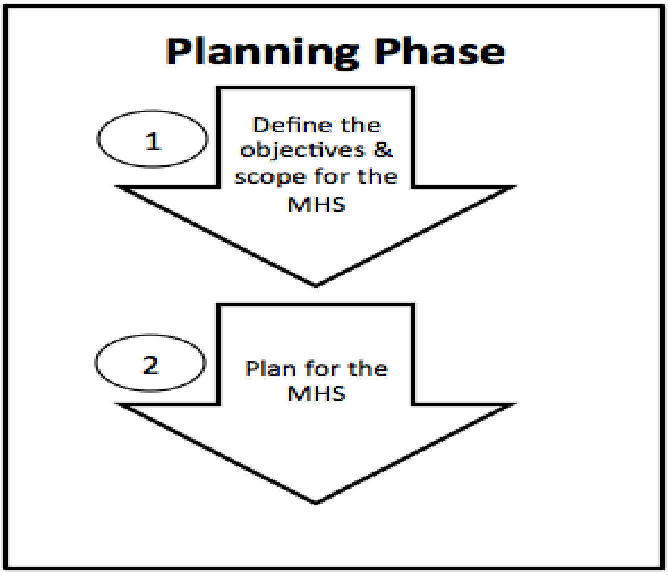


Figure 4.3: Planning Phase (Bellgran & Säfsten, 2010)

The first step in this phase was to define and clarify the preliminary objectives and scope of the project; and while being prepared, some adjustments along the way might be necessary. Through observations and interviews with involved employees an overall knowledge about the company was gathered; and further, expectations about the future material handling system were discussed. On the other hand, Bosch as a worldwide organization had predetermined rules and objectives, which also needed to be considered. Moreover, in consultation with other members in the material supply team the scope of the project was agreed upon to cover only the issues related to material handling inside of the factory.

The next step after specifying the project's preliminary objectives and scope was to create an initial plan for MHS design parameters. The overall variables, which were defined in this plan and deemed to be essential for the start of the project, enumerated as transportation concept, travel path and P/D points, transportation equipment and material characteristics, and delivery schedule respectively. Notably, to achieve the best outcomes from data collection and analysis, a reverse pyramid method was used, where all steps were interdependent and carried out in an iterative manner (Figure 4.4).

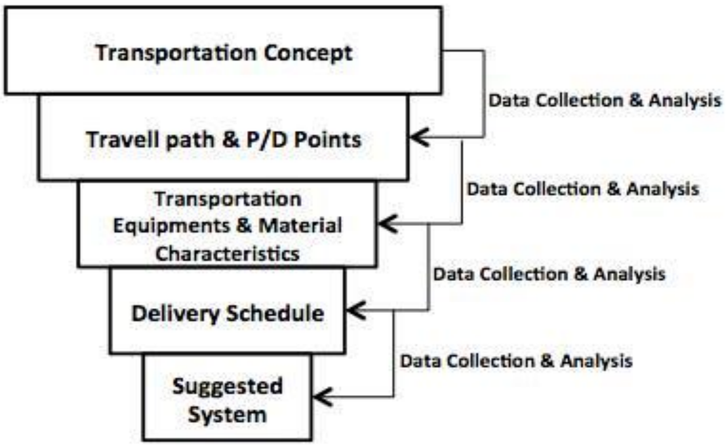


Figure 4.4: Material Handling System Design Process

4.3 Preparation Phase

The preparation phase includes two steps as it is illustrated in Figure 4.5. During background study of the project, it had a great importance for students to get familiar with the current situation in the company; more particularly in material handling area. Thus, the gathered data contained information about all internal and external factors that could have an impact on the MHS. Through different data collection techniques such as interviews, observations, measurements, etc. related information about layout and physical constraints, process times, production volume, information sharing process, and etc. was gathered. The aim of using different techniques was to increase the quality of the collected data; and thereby, achieve both high quality and accuracy on the outcome of the thesis project.

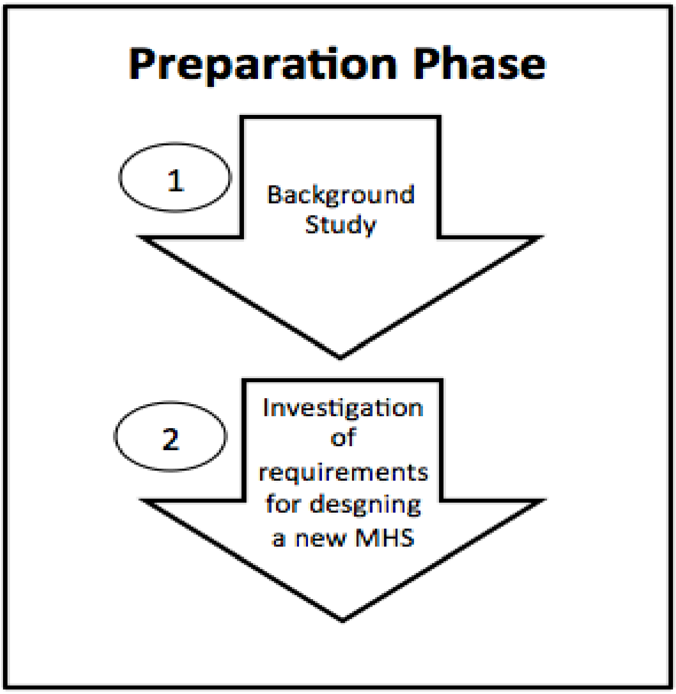


Figure 4.5: Preparation Phase

On the other hand, identifying and categorizing the possible requirements of the new MHS from company perspective was also necessary, since it needed to increase the efficiency of processes involved in this area. Hence, requirements from company side were evaluated and separated into four main groups:

1. *Delivery performance*; in terms of supplying the right materials at the right time, to the right place.
2. *Buffer levels between warehouses and assembly lines*; which needs to be eliminated totally or decreased to a lowest possible level.
3. *Ergonomic and safety issues*; needs to be improved through standardized material handling equipment.
4. *Operation costs*; should be decreased.

4.4 Design Phase

Based on the gathered data from the current MHS and pre-defined requirements on the future system the development process was started. This phase contained three steps (Figure 4.6), and was aiming to suggest a MHS, where requirements set by the company could be fulfilled in an optimal manner.

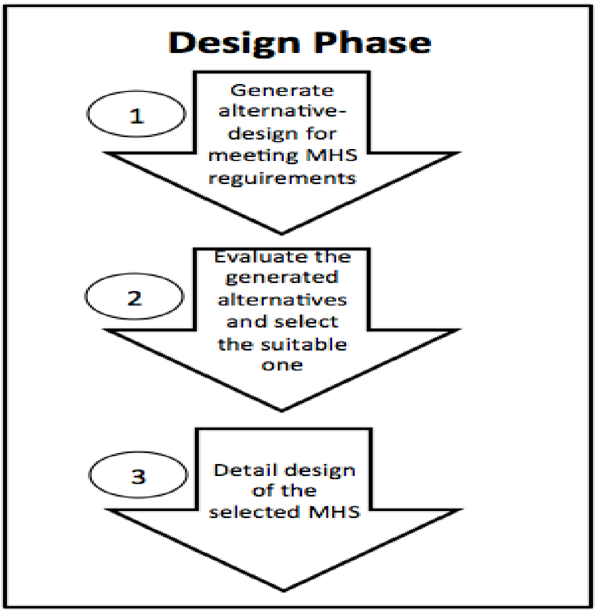


Figure 4.6: Design Phase

To attain best possible solution for the case company, different MHSs were considered and generated. However, the selection process of the optimal system needed to be handled comprehensive and carefully. For this purpose, a checklist was formed where various performance measurements were included. Additionally, to assure the accuracy of the selected system, MHS alternatives and features were evaluated through various discussions within the material supply project team, where different ideas and aspects were reflected.

As a result, based on the evaluation checklist and project-team's discussions, a MHS design was developed, which was aimed to fulfill requirements of the case company, more explicitly the following points:

- Decreased buffer levels and space efficiency between warehouses and assembly lines
- Reduction of manual material handling
- Elimination of material re-handling
- Higher delivery performance
- Higher delivery flexibility
- Information sharing efficiency
- Ergonomics improvement on the shop floor
- Standardization of work methods and MH equipment

Moreover, in the next step a detailed system solution was developed, where JIT delivery schedule and information link between warehouses and assembly lines were suggested. However, in order to find out the efficiency and effectiveness of the suggested system several trials were held on the shop floor. These trials were considered as beneficial, since they could help students to detect the possible errors in the suggested system and fixed them before they could cause any serious problems after implementation phase.

Another aspect of the performed trials was to insure the gained benefits from the suggested MHS for the case company. These benefits can be marked as:

- Communication efficiency
- Transparent information sharing
- Pull schedule and decreased buffer levels near to the assembly line and shelves
- Reduced forklift travelling time and less forklift traffic
- Reduced manual transportation
- Increased method standardization
- Decreased material handling process time and more smooth processes

Additionally, the suggested MHS had the ability to improve the ergonomics for the employees both in warehouses and assembly lines. Since the material handling equipment was adapted both for the warehouses and assembly workstations, material movement between them could be handled more smoothly and without any unnecessary lifting. On the other hand, automatic coupling/decoupling of the carts to the Milkrun vehicle/AGV decreased the manual material handling; and thereby, increased the ergonomics on the shop floor.

Table 4.1: Evaluation checklist for different MHSs (Tompkins et al., 1996; Beamon, 1998)

Performance measurements	MHS1	MHS2	…	MHS n
Delivery Performance				
MHS flexibility				
Information sharing efficiency				
Space efficiency				
Ergonomic				
Material & operators Safety				
Manual material handling				
Material re-handling				
Work method & equipment standardization				
Suitability for the existing layout				
Excessive material on hand				
Cross traffic				
Travel distance				
Tracking of material				
Vehicle utilization				
MHS cost efficiency				

5. Results and Analysis

In this chapter, the empirical data from case company is presented and research questions are analyzed based on a case-study. The findings are divided according to three main categories that are formed in the theoretical framework of this thesis.

5.1 Problems in the Current System

In this chapter, problems from case company's environment will be identified and analysed according to theoretical framework. From material handling literature, six main categories—delivery performance, buffer levels, operation costs, delivery quality, information flow, and safety—are formed. Company-oriented material handling problems will be exemplified regarding to formed categories, in terms of eliciting; and thereby; answering Research Question 1. Although the purpose of this thesis concerns only delivery performance and buffer levels, other categories are included also due to their intertwined relationship and impact on the system. The table below shows mentioned categories and problems from the case.

Table 5.1: The correlation of identified issues between theory and Case Company

Problems/Challenges	References	Identified Problems from Case Company
Delivery Performance: - By eliminating unnecessary movements of products within the facility, products can be delivered at the right time and place in the right sequence - Insufficient MH would cause production delays and increase production times	Mulhacy (1998); Hassan (2006); & Tompkins *et al*. (1996)	- Push Material Delivery - Unnecessary movements of materials - Production line stops due to material supply delays - High and unstable throughput time of material supply
Buffer Levels - Holding the right amount of material both in manufacturing and distribution - Just-in-time inventory management - Decreased work-in-progress material	Hassan (2006) & Tompkins *et al*. (1996)	- High buffer levels between warehouses and assembly - High storage levels on the shop floor
Operation Costs - To ensure possibly lowest operation costs the system should be designed in a way that it can enhance revenue rather than be a cost contributor	Mulhacy (1998); Hassan (2006);& Tompkins *et al*. (1996)	- High operation costs due to forklift running costs, forklift maintenance, forklift driver, and manual transportation
Delivery Quality - Quality on the shop floor can be achieved by receiving right material, in right condition, and with right methods	Hassan (2006) & Tompkins *et al*. (1996)	- No method standardization in Material Handling steps - Non-value adding activities
Information Flow - Providing proper material and information flow - Accurate material identification systems - Real time information	Mulhacy (1998)	- No information link between warehouses and assembly sections - Non-computerized communication with papers - No real-time information and updates
Safety - Minimize employee injury - Protect products from getting damaged or being contaminated	Mulhacy (1998) & Hassan (2006)	- No standardization of material handling equipment - Material Handling System designed without considering ergonomics - Accidents on the shop floor mainly regarding to intensive forklift traffic

5.1.1 Problems related to Delivery Performance

Recent studies indicate that the single largest cause of factory inefficiency is caused by material handling incompetence; when workstations cannot get the material they need it, and at the time they need it, productivity decreases dramatically. To investigate problems in the case company and to understand the correlation between assembly line stops and material supply to lines, an analysis has been carried out on the data that was gathered from production lines during 4 months. The root-cause-analysis (Figure 5.1) verified low delivery performance on the shop floor. More than %33 of assembly line stops are related to delayed parts which caused by inefficiency of internal material supply. Interviews revealed the fact that even though required parts are already in company's internal warehouses, their delivery to lines can be delayed regarding to miscommunication between assembly and warehouses.

As already mentioned in *Chapter 4 Case Description*, in BRJP production control (PC) department does the production planning according to customer orders, and then send the assembly schedule to assembly department, and related order-picking lists to warehouses. Materials from warehouses are *pushed* to assembly lines regarding to the assembly schedule that has been provided by PC department earlier.

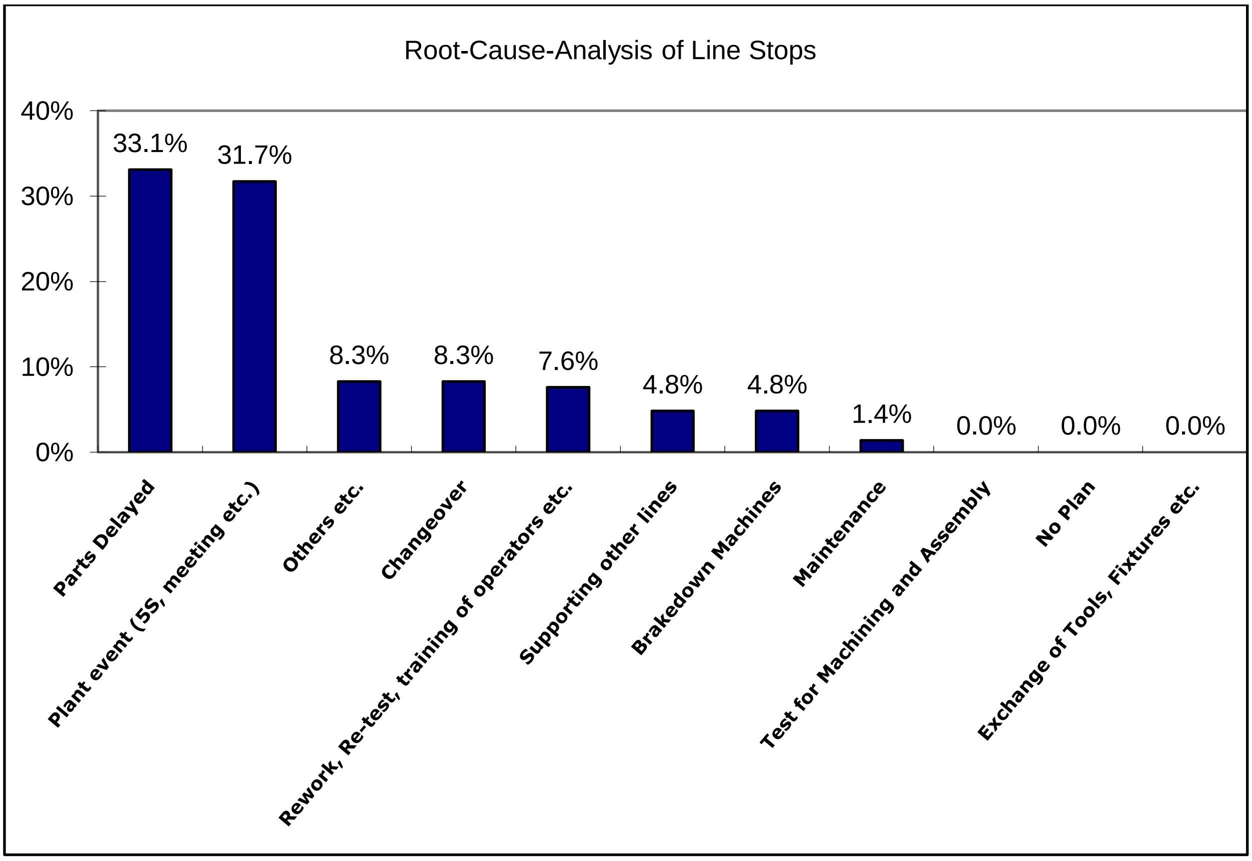


Figure 5.1 Root-Cause Analysis of Production Line Stops

However, in reality, this system does not work smoothly, since assembly schedules are changing frequently regarding to several variables such as missing parts, customer demands, and changes in shipping dates etc. In addition to that, there is no real-time information link between assembly department and warehouses to share the last minute changes and update material delivery plan to lines. Therefore, most of the time warehouses are picking and delivering the wrong orders, while the actually needed ones waiting on shelves. This incompetency of the system creates *waste* by increasing unnecessary movements of materials within the plant, decreases delivery performances, and causes production line stops.

5.1.2 Problems related to Buffer Levels

Baudin (2004) mentions material handling's dilemma between delivery performance to production lines and buffer levels on the shop floor, and states that it is challenging to attain an optimal system that balances these two criteria. Domingo *et al.* (2007) point out that in production facilities, sometimes parts are not delivered fast enough, while at other times they are accumulated for hours near to workstations or on temporary shelves. The analysis has been conducted on the case company showed that apart from its negative effect on delivery performance, *push* material delivery schedule increases buffer levels next to assembly lines on the shop floor as well, and also between warehouses and assembly. Because of the space suffering on the shop floor, wrong/early delivered orders are taken back to shelves —between assembly and warehouses— where they will wait to be re-delivered to the lines. Through observations and measurements, it has been found that pallet-size products can wait up to a week on the shelves to be re-delivered to assembly lines while on the other hand, waiting time to assembly for small and medium size parts can be even more.

5.1.3 Problems related to Operation Costs

Material handling system is the first place to reduce manufacturing costs and increase production efficiency. Therefore, minimizing handling costs is the core aim of most MHS design project (Chittratanawat & Noble, 1999; Hassan, 2010). In BRJP, material dispatching is done by forklifts, which increase operation costs drastically. Like Baudin (2004) pointed out before, to operate forklifts well trained, skilled operators are necessary. This issue was the biggest burden on BRJP's material handling system in terms of cost, since in Japan employee salaries are extremely high. Another factor related to forklift cost was the travel distance of materials. When materials are dispatched to workstations by forklifts similar to taxis, instead of getting transported in a ring system with regular frequency, travel distances; and thereby, handling costs are increasing (Baudin, 2004). In the case company, two different warehouse sections and washing section are sending materials to assembly lines by forklifts and manual transportation, which is another cost contributor regarding to employee salaries. Apart from manual transportation and forklift running cost, forklift maintenance costs are observed as another cost contributor. However, their effect on the system can be taken into less consideration or even completely neglected in this project, since other material handling dispatchers such as AGVs also have maintenance costs.

5.1.4 Problems related to Delivery Quality

As already argued by Tompkins *et al.* (1996), quality on the shop floor can be achieved by receiving right material, in right conditions and with right methods. Correspondingly, enhancing material delivery quality and performance is depending on using right methods with standardized steps. Therefore, in order to observe material handling steps and measure process times, time-motion studies along with value stream mapping have been carried out for order-picking and material delivery processes (Figure 5.2). Studies were conducted and repeated several times in seven different warehouse sections for pallet load, carton, and small size products. During the observations, the biggest problem that had been identified was lack of standardization in material handling processes which prevents to attain stable throughput time of material supply and creates *waste*; and thereby; makes material delivery schedule inefficient.

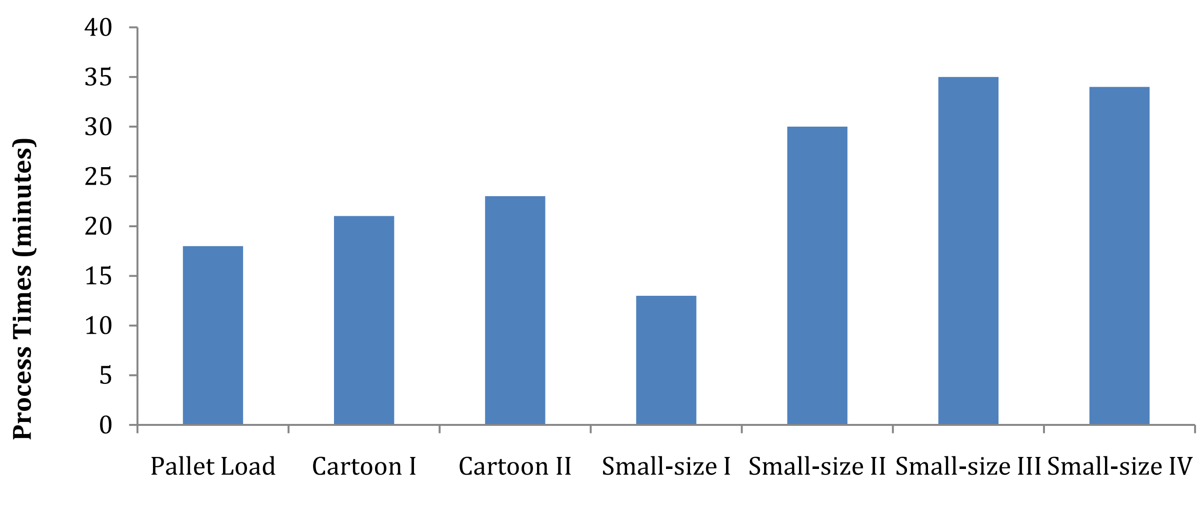
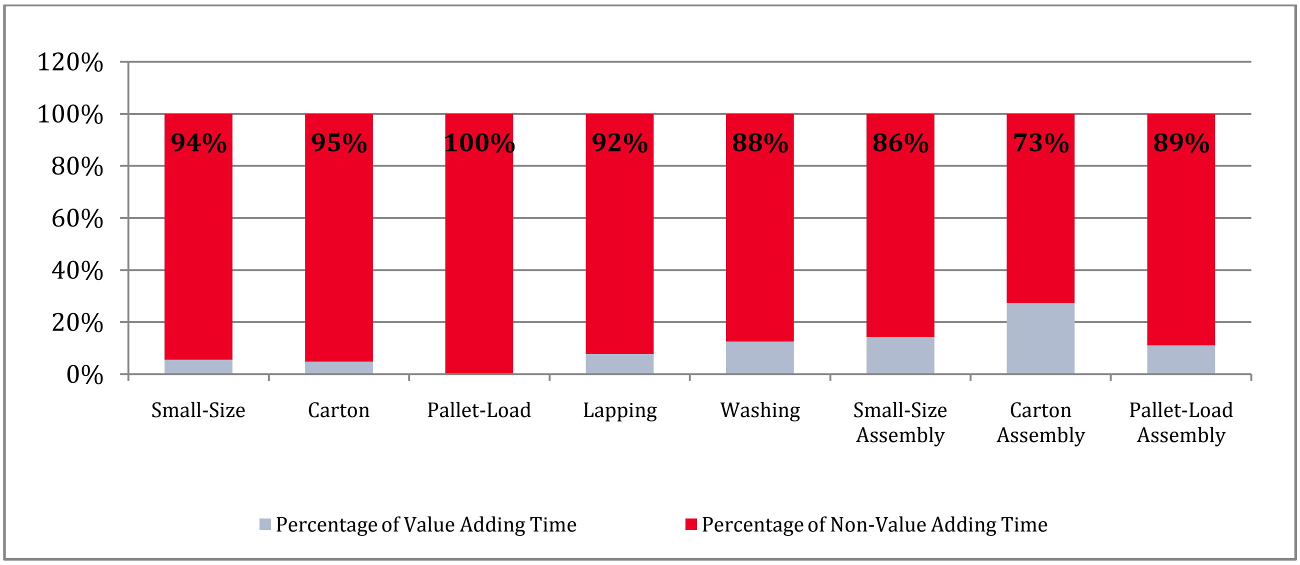


Figure 5.2 Average Process Times for Order-Picking and Material Dispatching

In the Figure above average process times for order-picking and material dispatching to lines can be seen. As easily can be realized, process times show significant variations in different warehouses which is an indicator of lack of standardization.

For further investigations and tracking down the *waste* in different process steps, customer orders have been followed, and analyzed according to value adding and non-value adding activities. Process steps were observed by process mapping and value-stream mapping techniques, and finally categorized for small-size, carton, and pallet-load products. In the Figure below, non-value adding activities represent waiting times; specifically after order-picking while waiting to be delivered to following processes or next to workstations as temporary buffers. Besides creating *waste* indirectly, when combined with other factors such as push material delivery schedule and lack of real-time information on the shop floor, lack of standardization increases buffer levels also.



	Order-Picking			Preparatory Processes		Assembly			Total Sum
	Small-Size	Carton	Pallet-Load	Lapping	Washing	Small-Size	Carton	Pallet-Load	
Value Adding (hours)	1	1	0	1	1	2	3	2	
Non-Value Adding (hours)	17	20	20	12	7	12	8	16	123
Total Time (hours)	18	21	20	13	8	14	11	18	

Figure 5.3 Value adding vs. Non-value adding Material Handling Processes

5.1.5 Problems related to Information Flow

Stevenson and Spring (2007) stated that accurate and real-time information is the key component for eliminating the inefficiencies from MHS; and henceforth, facilitating the overall material flow in plants (Fitzpatrick & Ali, 2010). Lins (1998) describes information systems as octopuses that have tentacles can reach everywhere within the organization; and by the same token, can impact buffer levels directly. As already discussed before, during interviews and observations it has been understood that there is no real-time information link between assembly department and warehouses in BRJP. Information sharing between departments is carried out during daily meetings and it is based on non-computerized communication with papers. When it is considered with BRJP's fast-pace environment with every minute changing variables, for instance, missing parts from suppliers, shipping dates to customers, assembly schedules, and urge to be flexible, incompetent information link is the main cause of not only low assembly delivery performance, but also high buffer levels on the shop floor.

5.1.6 Problems related to Safety and Ergonomics

Vallet (1999) emphasizes that by enhancing employee safety and ergonomics through material handling equipment, productivity on the shop floor can be increased significantly. Hassan (2006) points out the importance of safety while designing MHS, and states that overall safety and ergonomics define system's success and they should not be neglected. During the interviews that are carried out in BRJP, it has been noted down that MHS was designed without considering ergonomics criteria. Before designing the new system, a catalogue of existing material handling equipment was created, and more than 100 different transportation carts were documented. Besides lack of standardization of transportation carts, heights of workstations show variances up to 20 cm which indicates lack ergonomics principles on the shop floor. Further, Vallet (1999) states that lack of ergonomics can cause employee injuries and accidents on the shop floor. Similarly, during the interviews in the case company, it has been stated that there were several accidents in recent years especially related to intensive forklift traffic. Documented accidents involve damaged fixtures and equipment, damaged products, and even employee injury.

5.2 Material Handling System Design Features and Concepts

Through comprehensive literature review the problems related to material handling systems were described; moreover, via observations, interviews, and other data collection techniques the existing issues in the material handling system in the case company were identified. In the following step, the problems brought up by different researchers in the literature were linked with a real-life context. This method helped students to obtain a clearer view about the situation, and also facilitated the way by that mentioned problems could be solved. However, in this section the categorized problems will be connected with the appropriate concepts and/or features (Table 5.2) and the alternative solutions will be suggested so that they could form a MHS with the aim of increased delivery performance and decreased buffer levels.

Table 5.2: The connection between identified problems related to MHS and appropriate concepts and/or features

No.	Identified Issues in the Case Company	Appropriate Concepts and/or Features
1	**Delivery Performance:** -*Push* Material Delivery -Unnecessary movements of materials -Production line stops due to material supply delays -High and unstable throughput time of material supply	• Pull system (Pyke & Cohen, 1990; Ghrayeb *et al*., 2009) • JIT Concept(Ghrayeb *et al*., 2009; Soni, 1992) • Standardized Wok Methods(Whitemore, 2008; Bloss & Pillai, 2001) • AGV (Hall *et al*., 2001)
2	**Buffer Levels:** -High buffer levels between warehouses and assembly -High storage levels on the shop floor	• Pull System (Pyke & Cohen, 1990; Ghrayeb *et al*., 2009) • JIT Concept(Ghrayeb et al., 2009; Soni, 1992) • Real-time Information Sharing (Bloss & Pillai, 2001; Pyke & Cohen, 1990)
3	**Operation Costs:** -High operation costs due to forklift running costs, forklift maintenance, forklift drivers, and manual transportation	• Cost effective MHS (Tompkins *et al*., 1996; Murther & Webster, 1995; Beason, 1999) • Milkrun & AGV (Beason, 1999)
4	**Delivery Quality:** -No method standardization in Material Handling steps -Non-value adding activities	• Standardized Work Methods (Münstermann et al., 2010; Hassan, 2010) • Elimination of non-value-adding activities (Münstermann et al., 2010; Hassan, 2010)
5	**Information Flow:** -No information link between Warehouses and Assembly Sections -Non-computerized communication with papers -No real-time information and updates	• Computerized Communication System (Attaran, 2003; Leng & Zailani, 2012) • E-Kanban, Wireless Scanner (Kärkkäinen&Holmström, 2002; Michel, 2006) • RFID (Knill, 1996) • Real-time Information Sharing (Lindau, 1994; Ward & Zhou, 2006) • AGV (Knill, 1996)
6	**Safety:** -No standardization of material handling equipment -Material Handling System designed without considering ergonomics -Accidents on the shop floor mainly regarding to intensive forklift traffic	• Standardized MH equipment (Vallet, 1999; Hassan, 2010) • Total employee Involvement (Labar, 1995; Figura, 1996) • AGV(Napolitano, 2012)

5.2.1 How to Attain High Delivery Performance and Low Buffer Levels

As it is described earlier, the material supply in the case company was based on push delivery system. This caused various issues such as higher buffer levels, unnecessary movement of products, production line stops, inefficient usage of shop floor area, and etc. To cope with these problems several methods like pull system, JIT concept, standardized working methods, and so forth were recommended.

Above all other factors, real-time information sharing is fundamental to increase the delivery performance and achieve lower buffer levels on shop floor. Thereupon, organizations should be aware of importance of the local information, which has tremendous impact on the companies' business processes both inside as well as outside (Pyke & Cohen, 1990). Bloss and Pillai (2001) state that rapid information sharing has a huge impact on both delivery performance and buffer levels. Moreover, in a pull-based material handling system local information provides ability to pull the necessary parts; and thereby, avoid the undesirable activities in the shop floor (Pyke & Cohen, 1990). On the other hand, the necessary parts will not be delivered as long as the request has not been sent; which increases the space efficiency. Pyke and Cohen (1990) state that it is difficult to imagine a pure pull-based material handling system; therefore, a hybrid pull/push system (Figure 5.4) will be more efficient and effective. Combining these two systems makes it possible that they cover each other's weaknesses and strengths, which will lead to a more beneficial system with higher performance (Ghrayeb *et al.*, 2009). It is important to realize that to get the best result out of this system, JIT concept is vital. The combination of hybrid push/pull system and JIT concept will enable companies to keep the buffer levels low, while reacting fast to demand on the shop floor (Ghrayeb *et al.*, 2009; Soni, 1992). Just-in-time concept eliminates the variability in processes and ensures high quality and reliability in delivery performance. Moreover, JIT concept visualises the ineffectiveness and inefficiency within the processes and increases their quality by eliminating all kinds of *wastes* (Soni, 1992).

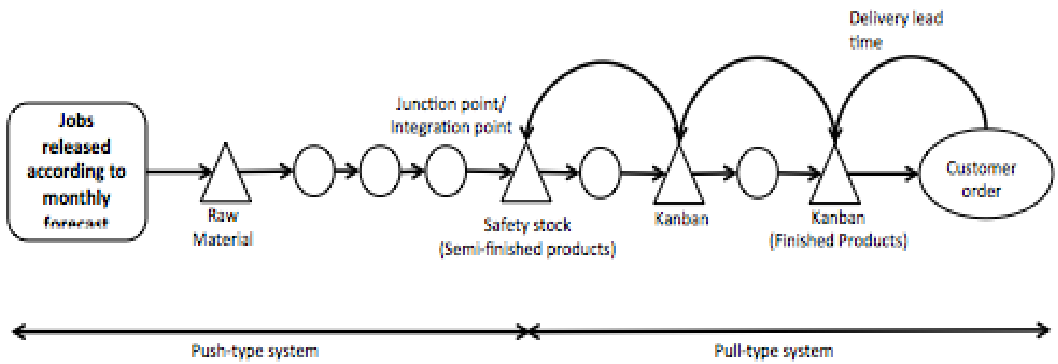


Figure 5.4: A generic hybrid push/pull manufacturing system (Ghrayeb et al., 2009)

However, as Taiichi Ohno pointed out no improvement can be achieved without standard (Whitemore, 2008). If everyone would perform the job in his or her own way the outcome would be unpredictable and as a result the lean principles such as pull system would not be applicable (Whitemore, 2008). With standard methods the abnormality in the systems and processes becomes more visible, variation will be decreased and unnecessary movement gets eliminated. Bloss and Pillai (2001) describe standardized work as a detailed, documented and visual system, which has been developed with contribution from involved employees. Furthermore, standardized work method has standard document, standard work sheet, time observation sheet, capacity sheet, and etc. (Whitemore, 2008).

The last piece that would complete this system is the actual physical movement of these parts to related stations. At the present time, many companies are still using forklifts to supply parts from warehouses to production lines or between the lines, but it has been realised that this approach is neither safe nor beneficial any longer (Hall *et al.*, 2001). The challenge is to make material handling system more flexible, efficient, effective, and safer in order to achieve higher delivery performance and lower buffer levels (Hall *et al.*, 2001). To accomplish all the goals mentioned above, Automated Guided Vehicle (AGV) system was suggested (Hall *et al.*, 2001). The author defines the AGV system as a main tool in point-of-use delivery and storage in manufacturing plants. He continues that the advantages with this system are flexibility, space utilization, safety, and overall operation cost. Furthermore, AGV not only minimizes physical obstacles from the shop floor, but also shares the aisle-area with other users. By implementing AGV system, parts will be moved from machine to machine instead of returning to storage area between the operations. Accordingly, number of product movement as well as in-process inventory will be decreased (Hall *et al.*, 2001). Another key point is safety level of AGV is considered very high, since it is equipped with various warning tools and it can eliminate human errors from the shop floor. On the negative side, their purchasing cost is quite high; therefore, they should obtain high utilization rates via multiple shifts (Hall *et al.*, 2001).

5.2.2 How to Decrease Operation Costs

A well-structured material handling system would help manufacturing companies to increase their productivity, improve quality of the products, and above all reduce operation costs (Hassan, 2010). To be able to reduce operation costs in a MHS, it is vital to define the cost sources. Beason (1999) categorizes them as damaged products, damaged trailers, high labour force, long travel distances, and multiple product handling. Moreover, Castenholz (1949) points out that in many cases the actual cost of material handling is buried under labour costs.

However, for cost reduction several factors such as product type, distance between stations, delivery frequency and quantity, and storage locations are prominent (Castenholz, 1949). These factors will not only result in elimination of direct labour, but also will increase the productive time for other employees. Furthermore, by using a pre-defined and well-equipped travelling path the total driving distance will be decreased, and many accidents and unnecessary activities can be avoided (Beason, 1999). Another option for reducing manual material handling is automatically loading and unloading parts or finished goods on the material carriers at the stations. In that case, both time and labour force could be used more effectively. In the final analysis, by implementing Milkrun and AGV system companies can increase safety, cleanness, efficiency, eliminate product damage, and lower maintenance costs comparing to forklifts (Beason, 1999).

5.2.3 How to Increase Delivery Quality

The main purpose of material handling systems is to deliver the right material in the right quantity to the right location and at the right time (Tompkins *et al.*, 1996), to fulfil this aim the system needs to be equipped with well-structured and well-defined processes and guidelines (Hassan, 2010). One possible way to attain this goal is process standardization (Münstermann *et al.*, 2010). Process has been described as a group of related activities performed to reach a desirable outcome (Davenport & Short, 1990), whereas standards stand for documents with predefined activities, rules, and guidelines for repetitive usage in order to achieve the best outcome in a given context (ISO, 1996). To obtain a standardized work process the following framework can be practiced (Hassan, 2010):

- Decomposition of the processes into simple sub-processes,
- Specify objectives and requirements for each sub-process,
- Identify and define the necessary activities that need to be performed in each sub-process,
- Evaluate the process as a unit and insure that the sub-processes are well functioning together.

Table 5.3: The benefits of standardized work process (Münstermann & Weitzel, 2008)

No.	Benefit	Description
1	Improved process performance	• Reduced cycle time • Reduced process cost • Increased process quality
2	Improved customer confidence	• Reduced probability of making mistakes • Cope with the increased process complexity • Increased performance quality and reliability
3	Enhance readiness	• Increased flexibility to regularly changes
4	Simplified and increased communication/transparency /measurability	• Simplified communication among departments • High transparency of process-activities • Flexibility in allocation of employees and performing the tasks due to process standardization

The first benefit of standardized work process is that the steps are simpler to perform and can be operated with shorter cycle times; moreover, process standardization has a direct positive impact on the process quality and cost (Münstermann *et al.*, 2010). Additional benefits with standardized work process can be observed in the table below:

In essence, through standardized work process, transparency and control over processes increase, which makes non-value adding activities more visible; so that, they can be eliminated. However, both external and internal factors that might have a negative impact on MHS should be considered and removed as much as possible (Hassan, 2010).

5.2.4 How to Increase Efficiency of the Information Flow

Nowadays manufacturing companies are seeking for higher flexibility, improved quality, lower operation cost, and decreased operation lead-time in order to stay competitive in the market (Lindau *et al.*, 1994), and these requirements already start at the shop floor (Attaran, 2003). To fulfil this purpose, real-time information sharing becomes more and more crucial (Lindau *et al.*, 1994). In addition, the real-time information sharing is more vital when the demand fluctuation is high (Kaipia & Hartiala, 2006). Second, it has been realized that without real-time information the work in process (WIP) increases dramatically and space efficiency gets affected negatively (Lindau, 1994).

However, the suggestion is to integrate information technology with production processes in order to facilitate communication between different sections and update operators with the latest changes about the schedule (Attaran, 2003). Information technology provides data, information, and knowledge to organizations, individuals, and processes; and for that purpose it uses different tools such as computers, software applications, and telecommunications (Attaran, 2003). In manufacturing companies this capability is utilized for production scheduling and control, process modelling, material handling, and so forth (Lewis & Talalayesvsky, 1997).

It is argued that information sharing should be relevant and accurate, and the data exchanging between sections and departments must be handled in a manner that the provided information would come in use (Kaipia & Hartiala, 2006). In the case of material handling, the information flow should distribute the data mainly related to material delivery status and available materials in the inventory (Leng & Zailani, 2012). Another aspect regarding information is that the amount of data should be just enough to take care of the related tasks; in this manner employees will not get confused (Liker, 2009). In the literature, directions of material and information flows are stated as opposite, where the information is sent from customer to manufacturer and the material from manufacturer to customer. However, Lewis and Talalayesvsky (1997) state that the best result will be obtained by keeping the information flow in both directions.

To facilitate the information sharing process various techniques and tools can be used. In this thesis project e-kanban, wireless scanner and RFID technologies, which could make the information sharing more efficient, were suggested. Besides the ability to eliminate massive paperwork on the shop floor, e-kanban has positive effect on inventory reduction, on-time delivery and visibility. But the most compelling evidence is that embedding e-kanban into ERP/SAP system in the company, information sharing capability might be enhanced revolutionary (Michel, 2006). Secondly, wireless scanners are mentioned as a revolution in warehousing, granted that the products can be stored and found easily wherever they are needed; thereby, space utilization will increase dramatically (Kärkkäinen & Holmström, 2002). In addition, the combination of RFID technologies with AGVs provides manufacturing plants the ability to track the information about each transportation cart along with its related loading and unloading points; and thus, will bring more efficiency to activities on the shop floor (Knill, 1996).

Leng and Zailani (2012) denote that computerized communication system is the key ingredient for companies to attain improved information sharing. According to Ward and Zhou (2006), computer systems allow organizations to handle real-time information, be more flexible, and manage more functions and features simultaneously, which would lead to increased on-time delivery and reduced buffer levels. Nevertheless, organizations should be aware of that integrating information technology and production processes, and eliminating manual process steps is an enormous work, which requires time, money, and effort (Leng & Zailani, 2012).

5.2.5 How to Improve Safety and Ergonomics

Employee injuries and product damages related to MHS in manufacturing plants are tremendous and bring huge compensation costs to companies (Labar, 1995). These issues arise basically from employee actions in different material handling operations and incompatible material handling equipment; notwithstanding, new computer-driven devices give a hope to resolve these problems and improve ergonomics in MHS (Nash, 2002). Figura (1996) states that product damages and employee injuries could be easily controlled and even eliminated completely with very low prices comparing to how much companies are paying for these issues in compensation.

It is important that safety and ergonomics related issues would be taken into account already in designing phase of MHS (Deierlein, 1999; Hassan, 2010). In addition, it is strongly recommended that a MHS should be simple and formed for more safety, efficiency, and productivity (Deierlein, 1999; Brodie, 2005). On the other hand, the new material handling equipment should give the operators the ability to avoid heavy lifts, unnecessary movement, and be more productive instead of being involved in manual material handling operations (Vallet, 1999). For instance AGVs are developed to increase safety and ergonomics, minimize product damage, and reduce labour (Napolitano, 2012), and another example is adjustable tables that make materials easily accessible to the operators and increase ergonomics on the shop floor (Labar, 1995). Further, Labar (1995) underlines that the improvements in MHSs are required to focus two main areas:

- Employee involvement in identifying and modifying the potential tasks with high safety risk; and
- Introducing new equipment and procedures that improves the safety and ergonomics on the shop floor.

Through safety and ergonomics improvements companies will not only prevent occupational injury, but also achieve lower workers compensation cost, reduced material handling related damages, higher quality, and increased productivity (Ling, *et al.*, 1992; Vallet, 1999; Figura, 1996). However, as it stated earlier employee involvement is the core element of safety and ergonomics improvements, since they are the ones that are using equipment and performing the job (Figura, 1996; Labar, 1995). Without their contribution the success of preventing the injury and product damages are near to zero (Labar, 1995).

5.3 New System Design

In this section a future system design will be presented according to findings from Research Question 1 and 2. All given suggestions are interrelated and share the same goal; to create a MHS design that could eliminate identified problems from literature and empirical findings. Since MHS is directly related to movement of materials, and in terms of having a *working system*, physical elements are the most prominent parts (Chittratanawat & Noble, 1999). They form a backbone for the whole design and determine main principles and constraints of the system.

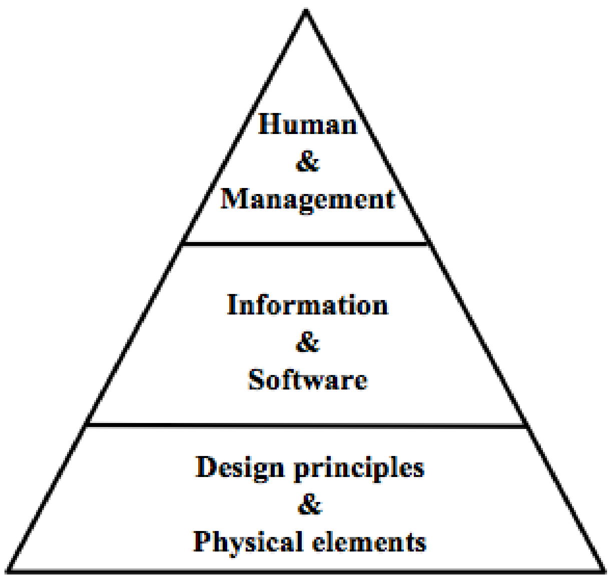


Figure 5.5: MHS design steps

The next step of the design is Information and Software, which can assure that the designed system is working effective; in simpler words, "doing the right things". Finally, the last step of the design—Human and Management— aims to bring efficiency to the overall by improving methods and “doing things right” (Sink & Tuttle, 1989).

5.3.1 Design Principles and Physical Elements

Physical elements of MHS include transportation concept, pick-up and drop-off points, travel path, and transportation equipment. During the design process mentioned physical elements are categorized into sub-problems and solved separately. Even though there are many approaches to reach optimal solutions for these sub-problems, there is no clear evidence that combining them will lead to an optimized solution for the whole system (Chittratanawat & Noble, 1999). However, in terms of decreasing the problem’s complexity and being able to attain a solution in the end, decomposing the whole system into smaller sub-problems was necessary.

Transportation Concept

In theory part of this thesis four transportation concepts; manual, forklift, milkrun, AGV; have been presented in terms of their compatibility with the existing production system and its constraints. During the analysis disadvantages of manual and forklift transportation which are currently adopted by the company have been discussed comprehensively, and therefore; they will not be taken into account for new system design. Remaining two concepts are elaborated and tested in company’s real life environment (Figure 5.6). In terms of decreasing the problems complexity, the tests were physically limited between internal warehouses and assembly section.

Figure 5.6: Pictures from Milkrun and AGV trials at BRJP

Empirical findings from the trials indicated several benefits that can be gained through by adapting each concept separately and they can be seen in the Table 5.4.

Table 5.4: The benefits that can be gained by adapting different transportation concepts

Milkrun Concept	AGV Concept
Less traffic on the shop floor	Secured delivery precision
Less product travel distance and decreased costs depending on that	Human factor minimized
Compatible with existing transportation carts	Increased safety
Easy product loading / unloading	No labour cost
	Ease to operate in narrow aisles and turning points
	Ability to integrate with information systems

At this point of the research, students decided to merge two transportation concepts; and embedded AGVs as transportation vehicles into Milkrun; in terms of obtaining benefits from each. Using AGVs instead of classical transportation vehicles such as in-plant trucks or forklifts etc., increased delivery performance drastically, since their arrival time can be programmed exactly without any disturbances such as human factor (Trebilcock, 2002). Another significant benefit of AGVs is that they can be connected with computers, wireless scanners, and other software tools. Through RFID implementations on AGV carts, it is possible to track material movements precisely, and decrease response times in case of emergencies or failures (Kempfer, 2006; Knill, 1996). Additionally, RFID attached AGVs can communicate with host systems and makes it possible to deliver materials just in time to workstations or point-of-needs. Their ability to increase delivery performance and support to real-time information on the shop floor were the two main reasons why AGVs are preferred as transportation vehicles. Embedding them into Milkrun concept made it possible to keep mentioned benefits without increasing product travel distances and traffic on the shop floor.

Travel Path and Pick-up/Drop-off Points

Prior to establish a new MHS concept on the shop floor, it was necessary to do a flow analysis and determine material pick-up and drop-off points (P/D stations) for A6VM product group.

The first challenge was deciding number of P/D stations which involves the trade-off between handling effort for stopping the transportation equipment against possible increment in walking distances; and thereby, in manual transportation and operation costs. With this dilemma in mind, all points that are sending and/or receiving material, for instance, warehouses, supermarkets on the shop floor, machining, assembly and testing lines, transfer points between lines, full and empty transportation carts stock area were identified. Afterwards, identified points were joined together to locate P/D stations according to physical constraints such as aisle widths, dangerous spots, walking distances to point-of-uses, and also average consumption volume on the workstations.

In end, six P/D stations have been chosen (Figure 5.7) for A6VM product group:

A.01 Machining parts transfer point

A.02 Warehouse 1: pallet-load products

A.03 Waiting Area: short-term waiting for empty/full transportation carts, transportation equipment

A.04 Warehouse 2: small and carton-sized products

A.05 Assembly line

A.06 Product testing line

Figure 5.7: Pictures from Assembly P/D stations

The second challenge was establishing the travel path, since it is discussed before travel path determines the distances that affect material handling costs most (Beason, 1999; Chittratanawat & Noble, 1999). First thing to remember is travel path should include all stations and be a closed loop, if possible, but at the same time it should decrease empty and loaded travel distances for vehicles (Beamon, 1998). Besides concerning variables related to operational costs, travel path should be designed in a way that can increase safety on the shop floor, and eliminate accidents related to material handling. Therefore, travel path should not have two-way traffic, unnecessary turns or crossroads, and be as straight as possible. Location of turning points, drive radius of the vehicle, ground conditions and visualization on the road are other key points that need to be taken into account.

From case company's environment several points related to travel path are investigated and analyzed in an iterative manner according to design parameters that are described by Mulcahy (1998).

- Products will follow a horizontal path along the shop floor without elevation differences
- Travel path is fixed
- Travel path has narrow aisles and four sharp turns.
- Layout is fixed and cannot be changed
- High product, equipment, and employee safety is mandatory

After considering all mentioned points an initial travel path has established which includes all P/D points (Appendix B) and several signs and marks that indicate P/D points have been replaced on the shop floor. P/D point signs include stop name, related product picture, list of materials will be delivered/picked, route and location of the stop on the route, and an escalation plan that will be follow under certain situations such as in case of accident, material and/or quality failures, lack of material etc (Figure 5.8).

Figure 5.8: Pictures from P/D station signs and placement on the shop floor

Transportation Equipment

During the analysis it has been identified that safety and ergonomics aspects have not been considered adequately in the existing system, and in addition to that there is no standardization for transportation carts. Therefore, the next step of the process was designing transportation carts, which will be used with AGVs in future. Products are analyzed according to their dimension, size, form, and characteristics; and new transportation carts were designed (Figure 5.9) based on identified specifications (Table 5.5). During the design existing transportation carts were also considered since, it might be cost-efficient to use them after some modifications.

Table 5.5: Considered product characteristics

Product Characteristics	
Weight (kg)	16 -64
Length (mm)	282 – 423
Height (mm)	302 – 384
Width (mm)	146 – 226
Size	Small, Carton, Pallet-load
Some products require special protection against dust, oil, and etc.	

Carts were equipped with automatic coupling/de-coupling option, which gave the ability to AGVs load and unload them without human effort while running on the shop floor. Additionally, all new designed carts and existing assembly workstations have been modified according to safety and ergonomics considerations due to eliminate human and product damages.

Figure 5.9: Pictures of designed cart prototypes (CAD picture of carton size products cart, Carton size products card, Pallet-load size products cart, Small size products cart respectively)

5.3.2 Information and Software

Information and Software pillar establishes the connection between the other remaining pillars. In other words, it will provide right information that can assure right products will be carried at the right time according to schedule that has generated. As already stated by many researchers, real-time information sharing is crucial to attain delivery performance as well as lover inventory levels (Pyke & Cohen, 1990; Bloss & Pillai, 2001). In this project e-kanban, wireless scanners and RFID technology were used as supportive tools to facilitate information sharing.

Kanban

In the designed MHS, e-kanban will be implemented into company's ERP/SAP system to provide computerized communication between parties of the system in terms of supporting JIT and pull material delivery. Instead of Production Control department, assembly sections will generate material lists of production orders, which are based on real-time information and send to warehouses through e-kanbans. Materials will be prepared according to lists specifically, and will be transported to assembly lines by AGVs. Changing the tools of the information link from papers to computers and its direction will bring crucial benefits to attain inventory reduction and delivery performance on the shop floor (Ward & Zhou, 2006).

Wireless Scanners and RFID Technology

Besides e-kanban, wireless scanners and RFID tags were additional tools that were chosen to improve information flow between warehouses and assembly lines by tracking the information about each material and their loading/unloading points (Knill, 1996).

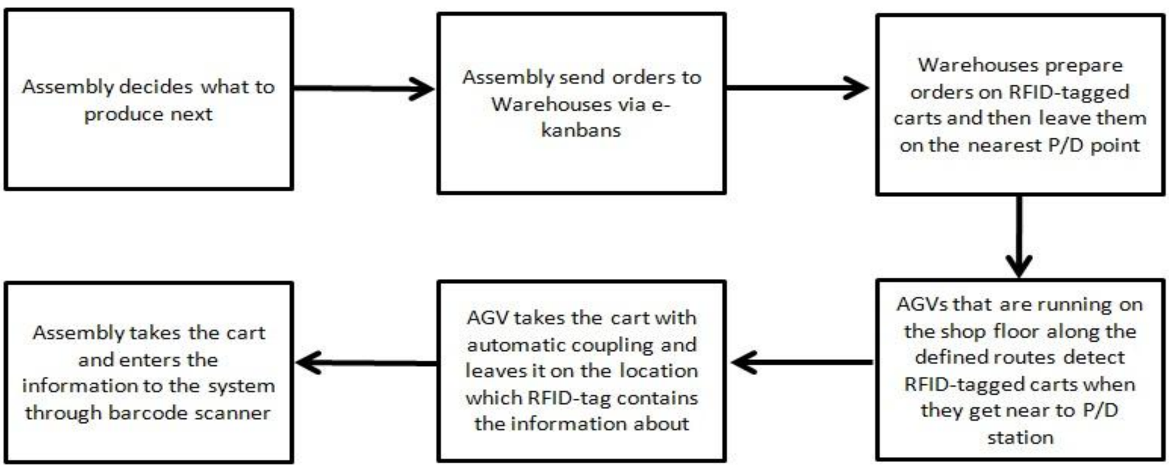


Figure 5.10: Illustration of Future Information System

As an illustration how these tools can be connected with each other and utilized; wireless scanners can be used after picking of materials, which their orders are sent through e-kanbans, and they can provide information about materials' location and status. Moreover, AGVs that are running in Milkrun routes can decide to stop on the bus station or not, depending on if there is a material waiting. For that purpose, RFID-tags can be embedded onto transportation carts to make them visible by AGVs. Transportation carts can communicate through wireless network, and control where AGVs should go and drop/pick-up materials from which stations. Above Figure 5.10 demonstrates an example how the processes will function in reality.

5.3.3 Human and Management

Any MHS's success is not solely related to its physical attributes; on the contrary, it is highly depending on how and by whom it is operated (Allred, 1996). The last step of the Material Handling System design determines the outcome of the whole system; and therefore, it has a huge importance. Human and Management pillar streamlines material flow by right scheduling delivery of the materials; and for that purpose, it uses several methods and principles such as push/pull hybrid systems, JIT concept, standardizing working methods and eliminating non-value adding activities, and total employee improvement.

Scheduling of MHS

Prior to scheduling deliveries of designed MHS, it was necessary to classify materials according to their sizes and delivery frequencies to assembly lines. During the observations three material groups; pallet-load, carton, small-size, and different schedules needed to be formed according to their requirements and constraints have been defined (Figure 5.11).

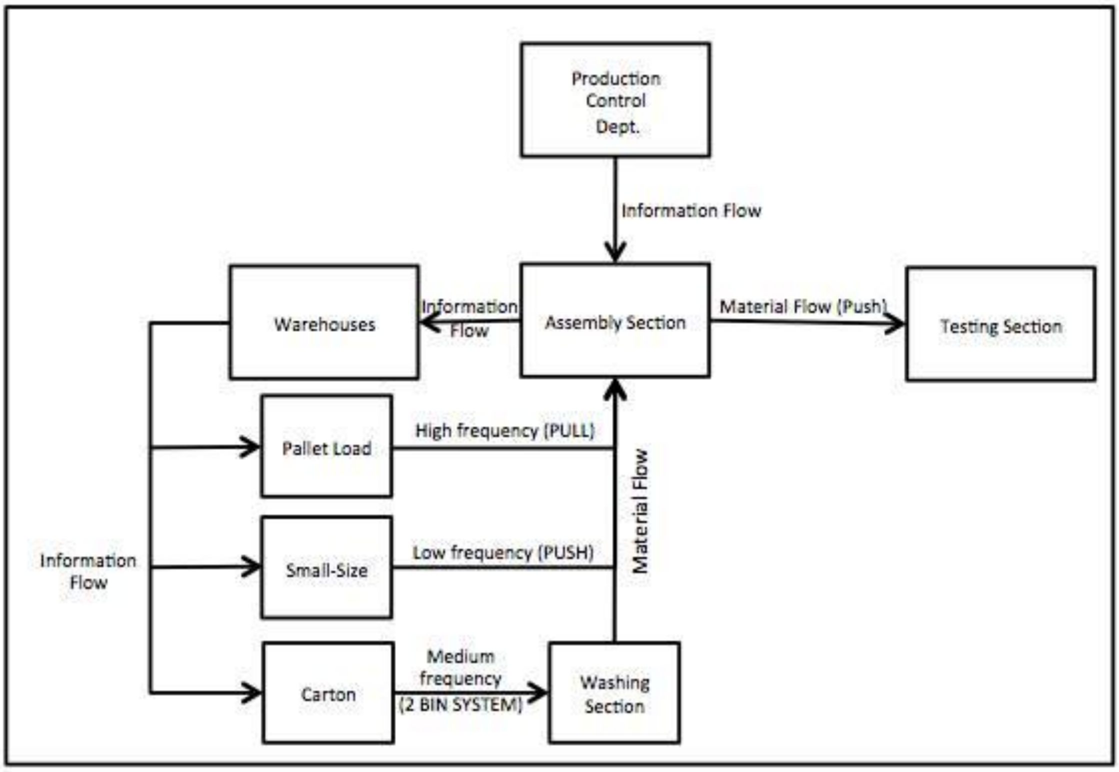


Figure 5.11: Future material delivery process in BRJP

Pallet-load

Pallet-load size materials were the main sources of high buffer levels and space inefficiency on the shop floor. Therefore, JIT concept is adopted for their delivery schedule to enhance MHS's quality and reliability on the shop floor (Ghrayeb et al., 2009; Soni, 1992). As an illustration; warehouses will prepare materials of productions orders and deliver them directly after assembly lines "pulled" them through e-kanbans. As a consequence, waste of unnecessary product movements will be eliminated in addition to storage level reductions.

Carton

Due to their material characteristics, carton size products need to be washed before they are shipped to assembly and washing section follows same exact order sequence as assembly department, but 4-6 hours prior. Since carton size materials were relatively small and their frequency were lower than pallet-load products, for delivering washing parts two-bin system is employed. AGVs that are running on the shop floor will take materials from washing in carts and supply to assembly as soon as there is an empty space. Not to mention, there will be no oversupplies and assembly will never run out of materials, since systems' ability to cope with uncertainties will increase.

Small-size

Small- size items have a very low delivery frequency, once in a day for all production orders, but their process times for order picking are the highest. Thereupon, it was more meaningful to form their delivery schedule based on push system and deliver to assembly lines before the production starts.

Standardized Working Methods and Improving the System

After delivery schedules have been formed for Milkrun, it was important to create standard guidelines and methods that everyone can follow and work in the same way for system's overall success (Whitemore, 2008). However, as already mentioned before, it was important to involve users of the system in early stages as well, in terms of many aspects such as safety, ergonomics, work performances, and so on (Bloss & Pillai, 2001; Labar, 1995; Figura, 1996). Therefore, standard work descriptions have been prepared with collaboration with other employees through the whole design process.

6. Discussion

In this chapter, results that are obtained from the study and methods in order to reach them will be discussed. Additionally, limitations of the research will be presented along with its theoretical and practical implications.

6.1 Discussion of Analysis and Result

The starting point of this research has arisen from the question; how should a MHS be designed in a way that it can be more efficient and effective for the production system it serves. During the comprehensive literature review it has been noticed that the trade-off between high delivery performance from internal warehouses to production lines and keeping buffer levels low on the shop floor is the main source of MHS inefficiency (Meyers, 1993; Goldsby & Martichenko, 2005; Domingo *et al.*, 2007). Hence, authors of this research found it meaningful to direct course of this study to investigate possible features of an in-house MHS, which can overcome, mentioned inefficiencies and to build a system design out of selected features.

To accomplish this goal three research questions have been formed:

RQ1.*What problems and challenges affect the delivery performance and buffer levels in-house material handling system?*

RQ2.*What material handling system concepts/features can overcome the identified problems and challenges?*

RQ3.*Which features should be selected for an in-house material handling system to assure high delivery performance and low buffer?*

Similar to every improvement process, it was necessary to understand problems and dysfunctional elements within the system before starting with anything (Tompkins *et al.*, 1996). Therefore, the first research question has been formulated and investigated in the case company according to problems that are drawn out from literature. Even though delivery performance and buffer levels were the main problem sources and triggers of this research, four other category; operation costs, delivery quality, information flow, safety and ergonomics; were also selected as inefficiency causes regarding to their intertwined relation with MHS inefficiency. Evidently, the results obtained from company supported the theoretical background of the study and formed a solid base that the further research builds upon.

After revealing and categorizing the hidden problems that relies in the system, the next step that has been taken to answer the second research question was investigating possible solutions for each problem. Hence, a comprehensive literature review has been carried out in terms of finding partial improvement solutions to the parts of the system.

Despite several researchers approach this problem from different angles and levels, there was no structured and detailed framework that includes physical and non-physical elements at the same time and combines them in order to increase MHS efficiency.

Correspondingly, the framework presented by Hassan (2010) has inspired the main outline of this study. However, it needed to be modified and enriched with different aspects. The third research question brings every elements of the design together and represents a general walkthrough. The findings from this research verified Allred (1996); even though physical elements of the MHS are vital, they are not enough to ensure system's efficiency. On the contrary, overall efficiency of the system is more depending on its management principles and information sharing within it.

To sum up, findings of this thesis successfully addressed problems within MHS and presented a detailed design that can increase the efficiency by eliminating *high delivery performance* or *low buffer levels* dilemma from the shop floor. The generated design not only considers physical equipment, but also includes information sharing, human and management aspects.

6.2 Limitations of the Research

The focus of the thesis work was mainly based on the issues related to delivery performance and buffer levels in an in-house material handling system and also the negative effects caused by these problems. One of the initial limitations for this project was that the external factors such as supplier delivery performance, product quality, and etc., which might have impacts on performance of the MHS, were excluded due to time limitation for this study. On the other hand, the internal factors included in this research were only the ones that had direct influence on the focused areas.

Another limitation was that the developed system could be tested only in one manufacturing company. In addition, the environment where the new MHS aimed to be implemented was already given, a factor that strongly affected the way in which the system was developed. Moreover, the students had to take the company's rules and restrictions into consideration while designing the new MHS.

The overall validity and reliability of the research could be more enriched if several case companies and different production environments could be included. However, it is important to mention that the case company is an international organization and one of the leading companies in their field. Furthermore, additional factors, both internal and external, could be examined in order to achieve a more accurate result out of this study. Nevertheless, for this purpose extended time period for data collection and data analysis was required.

6.3 Discussion of the Methods

In order to fulfil the aim of this research and also be able to answer the research questions, a structured way of working deemed to be necessary and essential. For this intention, the students established a primary project plan, while being prepared for the possible changes during the execution road. The primary plan could be used as a guideline to carry out this study. Moreover, since the subject of the thesis, milkrun, was quite undiscovered for the students of this project, a broad literature review in the field of MHSs was performed in three categories; design principles and physical elements, information and software, human and management. In addition, to increase the validity and reliability of the project various data collection and data analysis techniques were used. Each method will be discussed further under a separate sub-heading.

6.3.1 Case Study

After considering different methods and techniques for obtaining a deeper and better understanding about the subject of the thesis work, the students found case study as a useful tool to examine the problems related to MHS in a real-life context. Before performing the case study, the issues mentioned in the literature had been thoroughly investigated. At this point, students were curious to see the connection between the theory and the real world. Moreover, as it is pointed out before, milkrun was an undiscovered subject for the students and the control over the situation did not seem to be enough (Yin, 2003); therefore, studying a MHS while it was in operation would bring further knowledge and clearness on the investigated area. Nevertheless, this method also would allow the students to use various data collection techniques such as interviews, observations, measurements, and etc.

The interviews performed in this study were divided into each specific subject and held as a semi-structured type. It implies that the students had initially prepared some questions for each interview, but the interviews were carried out more as discussions. The idea of performing the interviews in a semi-structure manner was to create an environment where the interviewees could have the possibility to express their own thoughts and ideas while the students could have the chance to be more flexible and form the following questions depending on the given answers from the participants. However, the language barrier was an issue during the interviews and might have affected the outcome of the held interviews. To deal with this concern multiple data collection sources were used, besides the students tried to have a critical mind about the received data.

In addition to provide a clearer image of the current MHS in BRJP, performing other data collection methods also seemed to be crucial. Therefore, observations of the material handling activities and time and distance measurement on the shop floor were applied. These tools helped students to gather the necessary data, which could not be collected through the interviews, such as measuring the travel distance for milkrun train, the distances between different milkrun stations or time measurement of related processes in order to create an accurate milkrun schedule. On the other hand, the focus of the observations was both on the activities of the current MHS, and also how a milkrun or AGV system should be operated when it was in action. For this purpose, the case company provided students with the opportunity to visit the Toyota, Nagoya and Nissan, Iwaki facilities in Japan.

To be able to generate possible solutions for the enumerated problems of MHS, case-study was chosen. The great advantage of applying a case-study in this project was the structured way of working. Moreover, case-study gave the students the ability to merge the solutions gathered from various researchers through a comprehensive literature review and create a pattern that could be used for the aim of this study. The drawback with the case-study was that it was more about what needs to be done, not how to be done; however, to cover this issue the students followed Williamson's (2002) eight steps data analysis process.

6.3.2 Validity and Reliability of the Research

To increase the validity and reliability of the report different data collection techniques were applied; however, the appropriateness and functionality of the applied methods might be questioned. Though, the students believed that by using multiple data collection sources, triangulation, and a comprehensive literature review the inner validity of the project would be insured. Additionally, the authors of the thesis believe that the core findings and results would be similar; even if the gathered data could vary depending on other researchers will carry out the same study.

To insure the external validity and generalization of the result, the research was started with an extensive literature review in the field of MHS. This procedure helped the authors to discover the lack of a general framework for designing an in-house material handling system. Previously, various researchers had been focused on a specific part of MHS but no one had looked into it as a whole unit. At this point, the authors decided to divide the system into three sub-categories (Hassan, 2010):

1- Design principles and physical elements;
2- Information and software;
3- Human and management.

Students were convinced that this method would not only bring a better and deeper understanding in the investigated field but also all the involved elements in a MHS would be thoroughly examined. However, the developed MHS could only be examined in one manufacturing company, which uncovers the fact that the system needs further examinations in different production environments in order to achieve a maturity level. On the contrary, the case company was an international organization and had already implemented similar MHS in their other production facilities around the world. Moreover, the developed MHS has influenced by ideas and experiments from similar production facilities such as Toyota in Nagoya and Nissan in Iwaki, both in Japan, Bosch in Elchingen Germany, and Bosch Rexroth in Bursa Turkey.

To insure the accuracy of the findings and results, applying different data collection and data analysis methods were necessary. Besides, the interviews and observations were recorded as voice, video clips and pictures and transcribed in order to avoid biased information. However, one main problem faced during the data collection process was the language barrier. The official language of the country was Japanese and the main documentations in Bosch were in German; this issue prolonged the process of data collection. To overcome this concern and assure the performance of the collected data, the triangulation method was applied and a process of data comparison between data collection sources was carried out. Furthermore, the accuracy of the findings also was matched with previous researches.

6.4 Implications of the Research

This research identified, explained and discussed problems that could make a MHS inefficient and ineffective. Further, the authors examined and described the possible solutions for each arisen issue in order to achieve higher delivery performance and lower buffer levels on a manufacturing shop floor. The core findings of this project points out the importance of an effective communication between involved departments and real-time information sharing. Besides, other elements such as what needs to be considered during the MHS design process and how the system should be managed or handled were discussed. The research has also identified and analysed several other factors that could have negative impact on the performance of a MHS; these elements were identified as operation cost, delivery quality, and safety.

The main practical implication of this research is that manufacturing companies need to pay more attention to MHS on their shop floor because this is the place that both cost reduction and customer satisfaction could be achieved at the same time. In order to attain a cost effective MHS, besides all physical elements and system management, information sharing in both directions between warehouses and production/assembly lines is required. Furthermore, increased safety for both employees and products in the material handling activities is another practical implication of this thesis work.

The main theoretical implication of this thesis project is that there is a requirement from manufacturing side to investigate and explore how an efficient MHS could contribute to companies' overall business target, in terms of cost reduction and higher customer satisfaction. In this research the authors developed a framework that contains all main elements and the interactions between them, which are necessary to design and maintain a MHS on a manufacturing shop floor. It is essential to point out that the developed framework requires further investigation and more expansion in the investigated area.

7. Conclusion and Further Research

This chapter presents conclusions and critique of the thesis work. Further, suggestions on future research will be given according to possible improvements of the research.

7.1 Conclusion

This research established the fact that a MHS consists of three main pillars; design principles and physical elements, information and software, human and management, which are equally important in order to achieve a well functioning MHS on a manufacturing shop floor. Moreover, based on the comprehensive literature review and case company investigation the existing issues with the traditional MHS (manual transportation & forklift transportation) were identified and categorized as; delivery performance, buffer levels, operation costs, delivery quality, information flow, and safety. To cope with the mentioned problems above various methods and techniques such as JIT concept, standardized work methods, hybrid pull/push system, AGV system, and etc. were suggested. However, the core element in an effective and efficient MHS was pointed out as real-time information sharing. The latter fact enables companies to rapidly react to different requests and changes on the shop floor area; and thereby, to obtain increased delivery performance and decreased buffer levels. It was also clearly argued that by integrating information technology with production processes many undesirable material-handling activities could be easily avoided, in addition, the companies would be able to attain increased space efficiency on the production/assembly area and decreased work in process (WIP).

Another vital element in developing a new MHS was pointed out as interaction between the new system and its surroundings, particularly, the interaction between the system and people, who are utilizing and operating the system. Therefore, employee involvement and employee training was mentioned as a key component for achieving an effective and efficient MHS. Organizations already have been realized that without employee involvement the success of any system implementation is almost near to zero. However, these needs and contributions should be addressed and defined in earlier stages in order to attain the best outcome of the developed system. On the other hand, companies should not forget the importance of management involvement and support in all stages from design to implementation of a MHS, both in functional and physical levels.

The thesis project also revealed that the main benefits gathered from the new MHS (Milk run) could be enumerated as higher delivery performance, lower buffer levels, decreased operation costs, enhanced real-time information sharing, increased delivery quality and safety. In addition, it was shown that these benefits could be more fruitful, if the variability within the MHS processes could be eliminated or decreased. For this purpose, JIT concept and standardized work methods were proposed in order to visualize the ineffectiveness and inefficiency within the MHS processes.

Finally, different MHSs were considered and discussed. They were mentioned as theoretical, ultimate, and technologically workable. However, the suggestion was that companies should focus on and implement a MHS that is cost effective and is able to function at the present time without any obstacle and failure.

7.1.1 Generalization of the Findings and Suggestions

This research has been carried out in a way that its findings and suggestions also could be practiced and implemented in other companies with similar situation. The concepts, methods, and theories mentioned and proposed in this study are general and well tested. This study has combined methods and theories form Lean Production, TQM, production logistics, and etc. together with related practical techniques to form a framework that could be suitable to develop a new MHS for manufacturing companies. The main goal of the designed framework is to achieve increased delivery performance and decreased buffer levels on the production shop floor.

However, a thorough analysis of the current MHS is essential before applying any of the suggested methods and techniques in this research. For this purpose process mapping could be a useful tool; moreover, there are other data collection techniques such as interviews, observations, measurements, and etc. that could be used to insure the accuracy of the gathered data. To create a better image of the current situation it is necessary to identify the possible problems within the existing MHS as well as constrains and available resources on the shop floor area. On the other hand, clarifying the goals of the new MHS and what the company wants to achieve with this new system is also of great importance.

What this study considers as vital factor and a key element for the success of any MHS is real-time information sharing. Without well-structured and well functioning information system, which could be able to update the involved sections with the latest information at the right time, an effective and efficient MHS is not possible. In addition, a process of continues improvement should be carried out in order to address and fix the possible errors within the new system; and thereby, increase the outcomes.

7.2 Further Research

This research described, analysed, proposed, and discussed the issues and related solutions with a MHS (in-plant milk run) in a manufacturing company. The main focus of this project was on the factors that had the ability to make a MHS inefficient and ineffective, which would result in lower delivery performance and higher buffer levels. Therefore, it is considered that the research questions were answered; and thereby, the purpose of this study was fulfilled. However, to enrich the outcomes of this research it could be expanded to include more case companies as well as different production environments.

Besides the internal factors considered, investigated, and analysed in this research, which could have negative impacts on the performance of a MHS, there are other external factors that are strongly interrelated with the effectiveness and efficiency of a MHS. Due to time limitation for this study these elements were excluded but they could be interesting topics for further research in this area. In a broader picture it could be stated that the performance of an in-house MHS is depending on the quality of the required materials as well as their existence in the warehouses. To insure on time delivery of the necessary parts from suppliers an external milk run, between the company and its suppliers, could be connected with the existing in-plant milk run. This could be another interesting topic for further research. The same procedure could be applied between the company and its distributors and customers.

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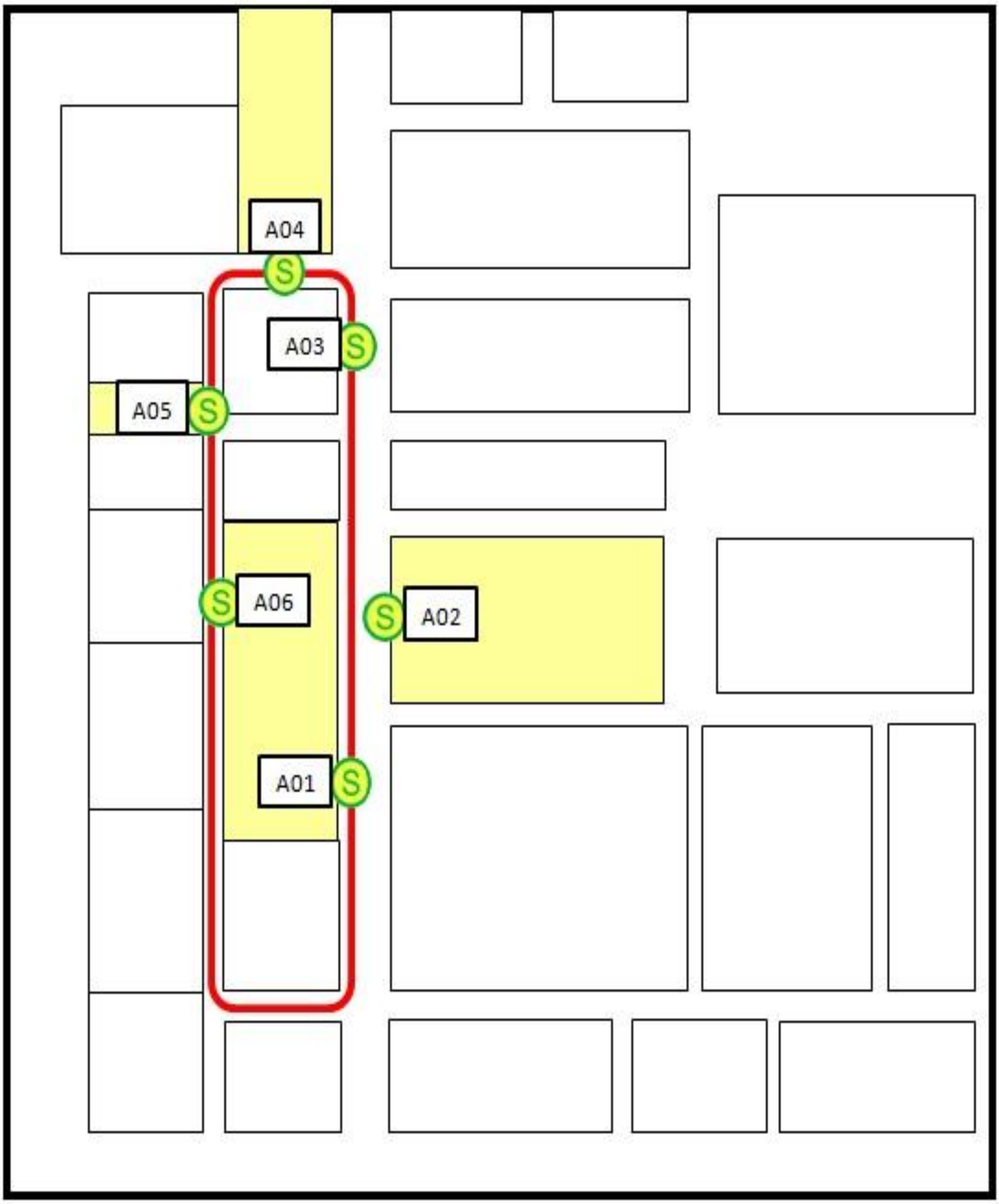
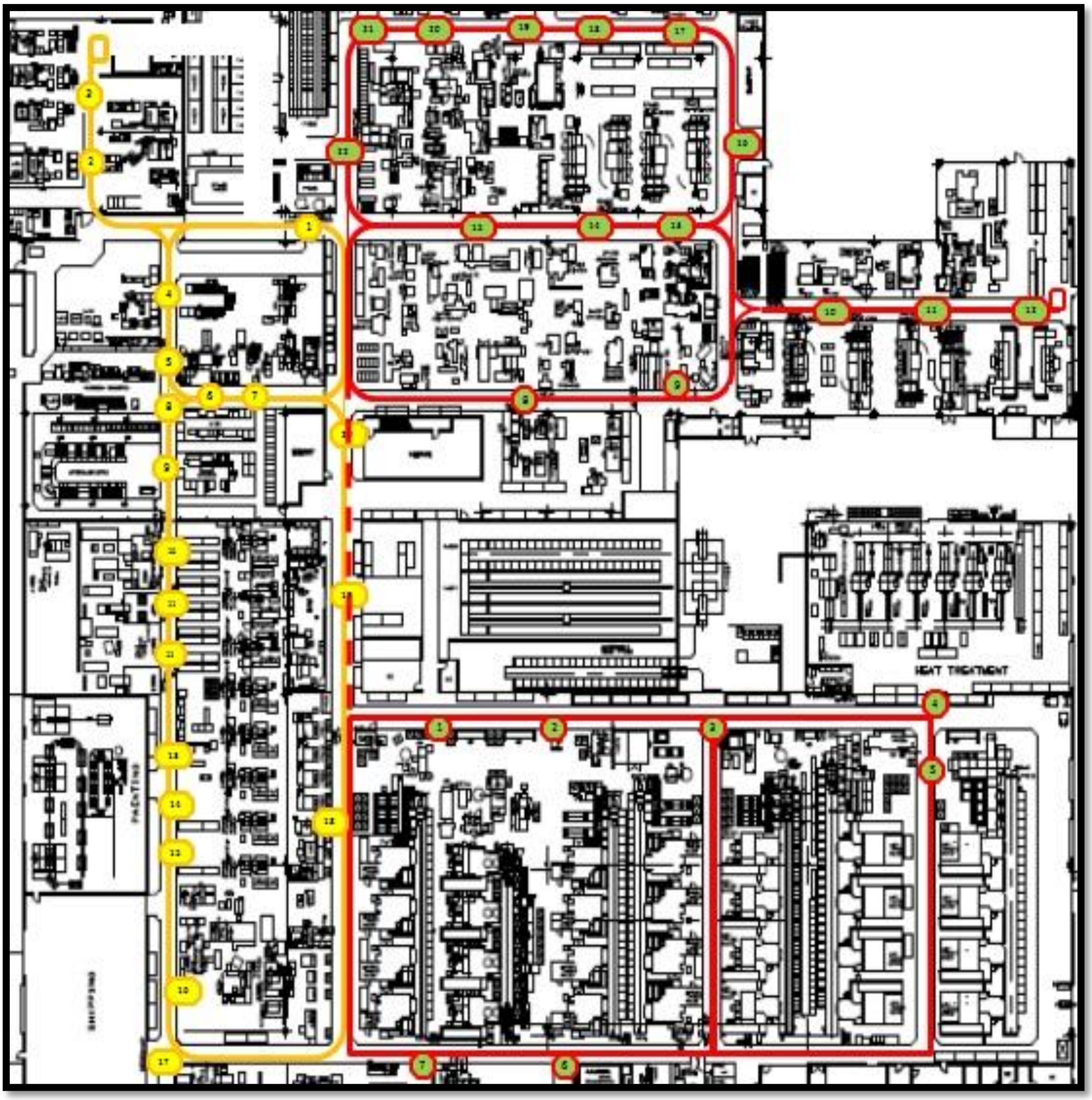
Appendix

Appendix A: Established Milkrun Route



Appendix B: Future Milkrun Route



Appendix C: Established Milkrun Schedule

Milkrun Trial Schedule

Milkrun Delivery Time	Assembly Schedule	Warehouse I (Pallet-load)									Warehouse II (Cartoon)						Warehouse III (Small)		
		Part Names																	
		Order No.	Size	Qty	Order No.	Size	Qty	Order No.	Size	Qty	Order No.	Size	Qty	Order No.	Size	Qty	Order No.	Size	Qty
08:00																			
08:30																			
09:00																			
09:30																			
10:00																			
10:30																			
11:00																			
11:30																			
12:00								Lunch Break											
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