JDE packaging material warehouse strategy and process redesign: improving efficiency by reducing variability

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Executive summary

The Netherlands is experiencing a shortage of labor, resulting in high labor costs and the desire to reduce labor need. To achieve this labor need reduction, companies can choose to use automation to reduce the need of labor in production. This drive to advanced automation is further propelled by developments known as industry 4.0, an important aspect of which is automated warehousing. In automated warehouses, storage decisions can be made by algorithms, movement of pallets to and from storage locations can be done robotically and registration of inventory locations and movements can be done registered digitally using scanners. However, implementing these automations can cause new strains on efficiency when humans do not interact properly with the robots that took over part of the activities in the factory. This has given rise to the need of research to determine where these strains of efficiency originate and what can be done to improve efficiency.

The packaging department of the KBU ("koffiebranderij Utrecht") has recently undergone exactly such an automation advancement by installing a automated warehouse for packaging materials and a autonomous guided vehicle to transport materials to and from that warehouse. However, this automation performs suboptimally. It is the goal of this thesis to find the issues that occur in and around the automated warehouse and the autonomous guided vehicle and to design solutions for the identified issues. The goal of this should be to reduce labor waste and decrease lead time of packaging materials to the assembly lines. The design objective of this thesis is as follows: design a warehousing strategy and process for JDE packaging materials.

By thoroughly studying the issues that arise in this specific case, a light can be shed on the types of problems that manufacturers might face in these transitions and the proper actions they may take to mitigate these issues. Having a clear insight in the problems faced in these transitions can help improve efficiency for the packaging of coffee in Utrecht, cutting costs and improving productivity. In a broader sense it can act as a guide to other factories that are pursuing automation of their warehousing. This will prevent efficiency loss due to human-robotic interactions in those factories.

The automated warehouse for packaging materials is a combination of conveyors, lifts, satellites and storage racks that can store pallets up to 9 rows deep. The pallets that are stored here contain a varied portfolio of materials. These include materials that move very quickly, usually being retrieved within days and representing large quantities in the warehouse, but also specific materials that are only used once every few months that are present in limited quantity. Although many activities have been automated, including most movements of materials, decision making on locations, the activities still have to be instigated by human to a large extend. Reducing the need for human control of automation requires the system to be very stable. This means that material needs and consumption have to be highly predictable. This is not the case due to changing market demand, last minute decisions from various management layers and erogenous ordering.

The root-cause was based on a combination of regression analysis, descriptive statistics and semi-structured interviews. The root-cause analysis showed x main areas where issues arose. The first area where issues occur is ordering of materials. Issues are wrong ordering of materials which cause a strain on the warehouse, increasing lead time and causing extra

work for those responsible for clearing away these pallets. Concentration of activity is the next main issue that was identified. The fact that in some parts of the day activity of both PMW and AGV means that lead time rises and more work is necessary than in less busy hours. This is due to the fact that in busy hours the AGV might be unavailable, meaning manual pickups are required. Queues form in both PMW and AGV in these busy hours causing further lead time increase. Another area where issues have been identified is allocation. Allocation concerns the algorithm that determines in what storage rack a pallet should be moved. Here it has become apparent that the current algorithm do not yield the results in terms of lead time that could be achieved with other algorithms. Shuffling is the process of moving pallets around within PMW, not to retrieve them, but to change the orientation of the pallets to enable quicker retrieval later. These shuffling rules are very unclear for warehouse operators, who consequently do not match their own activities properly to shuffling activities. Input is the process where pallets are put into the warehouse, either material deliveries from the dock, or used pallets from the production floor. Issues here concern administrative activities not being conducted well, and poor execution of tasks causing malfunctions later on in the process. The malfunctions are poorly addressed which further causes extra work and lead time increases.

The causes of these problems have also been studied and have been structured to form 5 main causes, supported by a flurry of root causes. These 5 main themes of causes of problems are: Control, People, Process, Information and external causes. Each of these causes are root of one or more of the issues that have been identified.

The control causes are causes that can be found in the controls of the automations that are implemented in the KBU. The most prominent of which is the inefficient allocation algorithm that controls PMW.

People cause problems throughout the system, this includes ordering wrong materials, blocking robotic movements, poor checks causing malfunctions and feedback not finding it’s way to the proper recipient.

Information, or rather the lack thereof causes problems in decision making by both people and machines. This includes good insight in status of malfunctions for people who have to decide on robot usage, but also poor insight in future material flows in allocation algorithms.

Processes have been analyzed and showed that there is a large disconnect between the work as imagined (by management) and the work as done (how it actually happens on the workfloor). Furthermore it shows that in many activities in the warehousing system have impact on other activities, but the people and machines conducting these activities have no real knowledge of the effects they cause. This is because the effects only become apparent: After the initial activity (for example malfunctions due to poor entry), elsewhere in the factory (for example double ordering) or only are visible digitally (for example the allocation algorithm).

External factors are sometimes the cause of issues, when for example materials have to be changed suddenly due to a planning change. However, these existence of last-minute planning changes also disables a lot of opportunities when designing in this warehousing system.

Seven functions that are in need of redesign have been identified based on the FRAM analysis. These are functions that vary much in quality and therefore influence the overall performance. Redesign alternatives have therefore been tailored to reduce this variability and therewith create stable quality thus improving overall performance. The study specifically emphasize the importance of feedback in nearly every activity and function in the system. This is due to the fact that the automation makes it that effects of human actions are often not visible or apparent to the worker who conducted the activity, but does need to reflect on their own work.

Three sets of potential solutions have been designed that can help solve part of the issues and their causes that have been identified. The first set focusses on solving the identified problems as well as possible with limited funds. This includes feedback loops that have to be performed by workers amongst themselves, in regular meetings. This alternative is suboptimal in performance, since only part of the variability is reduced. However, it is possible to implement this alternative at very low financial costs for the company.

The second option focusses on investments in further automation of activities in and around the warehousing in the KBU. This requires big investments but will also yield greater results in lead time reduction and labor saving. Importantly, this solution works 2 ways. Firstly, activities will, where possible, be transferred from workers to machines thus reducing the amount of labor that is required. Secondly, these new machines won’t exhibit the level of variance in their work that the workers currently show. One example is a scanning machine that will take over the task of checking the wrapping of inbound pallets. It will allow the warehouse operator to unload trucks in less time and will detect more poorly wrapped pallets. In this design, feedback is automatically acquired and shared with workers.

The third design has been evaluated and found to be the best fit for the objectives (lead time reduction, labor waste reduction and affordability) that have been established. This design focuses on using production planning to optimize and integrate logistical activities in and around PMW and AGV based on the production plan. A trade-off that has to be made here in comparison to the other design alternatives, is that flexibility is reduced: the production plan can no longer be changed last minute as currently happens often and freely. In exchange for this, efficiency will go up and lead time for packaging materials and labor waste will be reduced as much as possible. In this design, feedback will be much less important since many of the activities that were in need of feedback mechanisms have been automated, such as establishing material orders.

This study has shown important areas to pay attention to when designing in automated warehousing systems. Furthermore it has shown that the human factor can greatly influence the performance of automated warehousing. By implementing the design that was proposed JDE can meaningfully decrease lead time of packaging materials and reduce labor waste in and around the KBU packaging material warehouse.

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Chapter 1: Introduction & background

1.1 Introduction

Global supply chains are evolving at a very high pace, not seen since age of digitization and the industrial revolution (Radivojević and Milosavljević, 2019). To keep up with supply chain developments, manufacturing firms are rapidly converting their factories to become more efficient. This is done by increasingly automizing activities within the factories. These manufacturing transitions amount to a new type of manufacturing industry, referred to as Industry 4.0 or smart industry, where all aspects are automated and can autonomously function and communicate (Ali and Phan, 2022). Alongside these developments, companies also face the challenge of maintaining a reliable and resilient supply chain (Ozdemir et al., 2022). An important way to improve the reliability and resilience of supply chains is strategic warehousing (Anca, 2019, Shaikh et al., 2020). Warehousing concerns the storage of goods. This does not only include finished products, but also pertains to the materials needed for packaging these products. The warehousing of packaging materials is a crucial and often overlooked cornerstone of the production process.

Despite the importance of packaging in the production process, we lack insight into the control strategies for warehousing packaging materials. Especially when designed specifically for the needs of companies, including the impacts on efficiency, finances and social sustainability for stakeholders within the company. A crucial marker of efficiency of automated warehousing is lead time. Lead time refers to the time required by the automated warehouse to store or retrieve an item. Lead time has important impacts on the three pillars of sustainability: economic sustainability, environmental sustainability and social sustainability (also known as people, planet, profit) (Ranjbari et al., 2021).

High lead times have a significant negative impact on economic sustainability in the FMCG industry. Economic sustainability refers to the ability of companies to balance their profitability with responsible production practices, supply chain management, and minimizing negative environmental and social impacts (Imperatives, 1987). Lower warehouse lead times due to automating the warehousing process will cause fewer delays in production processes thus ensuring increased productivity, which is vital to maintaining profitability (Storm and Naastepad, 2013). Increasing productivity is especially important considering the recent labor shortages and rising inflation (Causa et al., 2022).

Environmental sustainability can be increased by decreasing lead times. Factories use a base amount of power per hour (Panagiotopoulou et al., 2021). When production is delayed due to slow warehouse lead times, the factory will consume more power for the time of the delay, without any production. In addition, power is required to move pallets through the warehouse. When allocation and relocation is not conducted optimally, more movements are required, thus using more power. This power consumption is environmentally wasteful.

Low lead times have a positive influence on social sustainability. When lead times are high, workers will be idle, thereby increasing the chance of unpredictable behavior, and with that, increasing the probability of accidents. When delays occur the workload increases, which can cause unsafe behavior (Hofstra et al., 2018). Low lead time ensure that workers can continue their labor quickly, thus preventing delays. This will increase worker productivity, which is more fulfilling, as well as increasing production thus enabling higher wages (Ciccullo et al., 2018).

When a warehousing strategy is designed to lower lead times, it is important to consider that tailoring it to a specific factory and workforce is crucial for sustainable stakeholder interrelations in the warehouse. This can importantly reduce resentments between stakeholders for instance. Namely, when a new system is implemented, it is not always clear which responsibilities lie with which stakeholders. Moreover, a poor design can further lead to further malfunctions and inefficiencies causing irritation and subsequently through that pushback against change from workers longing for the old situation, where (new) problems were not present.

Automated warehouses come in many different forms, each with advantages and disadvantages. The variation mainly lies in the intensity of storage, meaning the number of stock keeping units (SKU) per square meter. Higher intensity storage typically utilizes space more efficiently, but makes storage and retrieval less efficient due to increased complexity. To facilitate storage and retrieval, automated warehouses can for instance be constructed with conveyor belts, cranes or retrieval lanes between each rack. Although this requires more space, it does make all stored objects highly accessible. Another option is to create either double or multi-deep racks, with SKU’s stored behind each other, thereby decreasing the need for lanes and thus space, but creating the problem that SKU’s could be blocked by SKU’s that are stored in the same rack.

In the context of automatic warehouses, JDE forms an important example. JDE is a leading company in the fast-moving consumer goods (FMCG) sector and has installed an automatic warehouse for packaging materials in their coffee factory in Utrecht in 2018. This warehouse automatically transports, stores and retrieves pallets using conveyor belts, satellites and lifts, and stores pallets in storage lanes, all across 7 floors of warehouse. In addition to this, an autonomous guided vehicle transports pallets between the warehouse and the Senseo production lines. However, these innovations are yet to be utilized in a way that decreases the currently suboptimal, hence problematic, lead times. Furthermore, the new innovations carry little support amongst workers, who need to be enthused for the positive change that these innovations can bring. This problem demands a redesign of the warehouse strategy. This strategy is to include pallet allocation, reshuffling and picking within the warehouse; complemented with recommendations for procedural changes for operations that are closely related to warehouse operations. Important considerations here include the requirement of human activity in the system, the production planning, the layout and capacity of the warehouse, and the intensity of operations throughout the day.

1.2 Literature review

1.2.1 Autonomous vehicle storage/retrieval system

Autonomous Vehicle Storage/Retrieval Systems (AVS/RS) revolutionize the way warehouses handle and manage goods by integrating advanced technology, automation, and smart logistics (Roy et al., 2012). These systems are designed to optimize the storage and retrieval processes, improving efficiency, reducing costs, and enhancing overall warehouse performance. AVS/RS leverage cutting-edge technologies, including rail-guided satellites and lifts, to further enhance their capabilities and provide efficient solutions for various warehouse environments.

Azadeh et al. (2019) describe the concept of AVS/RS and other robotic storage. At the core of AVS/RS lies the concept of autonomous vehicles, which are self-guided vehicles designed to transport goods within the warehouse. These vehicles navigate autonomously through the facility, guided by advanced sensors, algorithms, and control systems (Zhou et al., 2017). By eliminating the need for human intervention in routine material handling tasks, AVS/RS significantly improve operational efficiency, productivity, and safety (Halawa et al., 2020). Additionally, AVS/RS often include lifts and rail-guided satellites. These satellites facilitate horizontal movements within the warehouse across a dedicated rail system, and the lifts provide vertical movements to allow multiple floor warehouse layouts. Due to its precise positioning and navigation capabilities, the transport of goods can happen with great accuracy and efficiency. Moreover, the use of robotics and sensors allow for the use of deep-lane storage, storing more goods per square meter than single-lane designs. Due to the tracking and automation, it is possible to find pallets that are at the back of a row, and retrieve them using robotics. Although retrieval of back-row pallets is still time consuming, it no longer requires human labor.

When it comes to the control of Autonomous Vehicle Storage/Retrieval Systems (AVS/RS), there are various aspects to consider, including centralized control systems, real-time monitoring, and intelligent decision-making algorithms. These elements work together to ensure the smooth and efficient operation of the system. To optimize the performance of AVS/RS, intelligent decision-making algorithms are employed (Zhang et al., 2021). These algorithms utilize the real-time data collected by the control system to make smart decisions and efficiently allocate resources. For example, they can determine the optimal route for an autonomous vehicle to minimize travel time (Lehmann and Hußmann, 2022) or dynamically adjust the allocation of goods based on demand and priority (Zou et al., 2019). By leveraging advanced algorithms, the control system can continuously optimize the operation of the AVS/RS, improving efficiency and responsiveness.

The control system also handles scheduling and task assignment within the AVS/RS. It manages the allocation of tasks to autonomous vehicles and rail-guided satellites, considering factors such as priority, proximity, and vehicle availability. By dynamically optimizing the assignment of tasks, the control system can balance workloads, reduce congestion, and ensure efficient resource utilization like energy consumption (D'Antonio et al., 2019). AVS/RS control systems can integrate with order management systems and warehouse management systems (WMS) to further enhance their capabilities (Bruno and D'Antonio, 2018). This integration allows for seamless data exchange, enabling efficient inventory management, order fulfilment, and synchronization with other warehouse operations as well as quick detection of stock deviances. By connecting the AVS/RS control system with the broader warehouse management infrastructure, companies can achieve end-to-end visibility and control over their logistics processes.

1.2.2 Storage allocation strategies

The design of the JDE packaging material warehouse strategy can be categorized as an autonomous vehicle storage retrieval system (AVS/RS) problem. Roodbergen and Vis (2009) discuss important strategy choices, one of which is storage assignment. The five main strategies that can be used here are as follows: (1) dedicated storage assignment, (2) random storage assignment, (3) closest open location storage assignment, (4) full-turnover-based storage assignment, and (5) class-based storage assignment. Other strategies that are developed in literature concern complex algorithms like the artificial fish swarm algorithm (Fang and Tang, 2014) and the wolf pack algorithm (Fang and Tang, 2015). Other algorithms are created by Meng and Liu (2015) and Wang et al. (2020) and both concern goods allocation for business to consumer ecommerce warehouses.

When using dedicated storage assignment each item will only be assigned to a fixed location. This policy allows for certain items to be located at highly suitable places due to product characteristics. Examples could be heavy products at the bottom levels of shelves or SKU types that have high chance of malfunctions at easily accessible locations (for maintenance purposes). Negative effects of this policy are the high amount of storage capacity required because capacity for full inventory of each product has to be reserved, even when the product is out of stock. Random storage assignment on the other hand gives an SKU equal chance to be assigned to each empty storage rack. Closest open location storage assignment will place an SKU on the first place it encounters that has capacity. This policy typically leads to concentration of pallets around the entry point of the AVS/RS, and relatively more empty shelves further away from the entry point. Full-turnover storage policy concerns assigning goods based on their demand frequency (Yu and De Koster, 2009). This means that products that are ordered most often are assigned to locations that are most accessible. Finally, Roodbergen and Vis (2009) describe class-based storage. They describe this strategy as dividing the warehouse into a number of areas. Stored items are then assigned to one of those area's based on their demand frequency. Allocation of items inside the assigned areas happens according to random storage assignment.

1.2.3 Allocation and relocation strategies

Important research on the topic of allocation and relocation strategies was conducted by Marolt et al. (2022). This research evaluates three different strategies for allocation and relocation, namely random, depth-first and nearest neighbor relocation assignment. This means that the pallets that have to be moved in order to access the required pallet, will either be placed in a random free space, the nearest free space, or the free space with the most depth. However, this study was conducted for storage racks with depths up to 6 deep. That means that it has not identified behavior of these strategies for 10 deep racks, as is the case at JDE. Findings can thus not be generalized to deeper racks in the warehouse, but can be applied to the first 6 racks and give an give an indication of what may happen beyond that point.

Lehmann and Hußmann (2022) conducted a study where 4 different storage assignment strategies were used. Two of those strategies were based on random assignment, with one assigning randomly to a (free) storage lane, and the other to a free storage location. The option where pallets are assigned to the free storage location would slightly increase the probability that a pallet is assigned to a lane with relatively more free locations. The other strategies are based on filling variance. Minimal variance strategy chooses storage channels in a way that minimizes filling variance of all storage channels. Maximum variance strategy chooses the channel that maximizes filling variance of all storage channels. This study is based on an AS/RS system that uses a single storage retrieval machine that can access all channels, with channels being 3 storage spaces deep.

1.2.4 Integrated planning

A lot is to be gained in warehousing efficiency when more production planning and warehouse storage assignment are integrated Zhang et al. (2021). This study acknowledges the possible gains in efficiency when combining random storage assignment with production planning, but only with the use of IoT technology in the warehouse. Therefore, due to the presence of IoT technology in the JDE warehouse, random storage assignment integrated in production planning can be a feasible strategy.

1.2.5 Human-robot interaction

Bogue (2017) assesses the risks of human-robotic collaboration in an automated warehouse setting. Potential risks include financial costs, time loss or injury. Some problems that can cause these risks are unexpected robotic behavior due to a software update, poorly placed products causing robots to fail, humans moving too close to the robot, and software or hardware errors. Ways to mitigate problems include feedback, training, adjusting settings in robots, and providing continuous information about the robot's functionality by displaying this through some form of user interface. Because the human-robotic collaboration is a cornerstone of a well-functioning automated warehousing system, these hazards and their potential solutions as identified by Bogue (2017) are important to keep in mind when designing a warehousing strategy for an automated warehousing system such as JDE's packaging material warehouse.

1.3 Link to COSEM

This thesis project pertains to most key aspects of the COSEM program. The research concerns the design of processes that are instrumental to the success of the modern warehousing technologies used at JDE. The research is multidisciplinary by nature, combining human behavior and technology in a logistical environment. The designing of strategies and processes I such an environment, using system analysis is using the core concepts of COSEM. Multiple stakeholders are involved with central planning, plant management, production workers and warehouse workers all having different impacts and power. The societal goal that is pursued by this research is improving efficiency of labor and thereby enabling reducing production costs. Additionally, efficient warehousing can lead to a reduced waste of materials due to expiration and suboptimal use of power and therefore reduces environmental impact.

Chapter 2: Problem statement and design objectives

2.1 Problem statement

Jacobs Douwe Egberts has installed an automated warehouse including an autonomous guided vehicle. However, the lead time reduction that this system should bring has not yet been achieved. The control mechanisms of the automated warehouse, the autonomous guided vehicle and the processes that concern warehousing are not designed to fit the potential of this system. Lead time of packaging material can be reduced by achieving a higher degree of synergy between these systems. The importance of low lead times and the need for efficient storage and retrieval of pallets raises the question of what control strategies and procedural changes are required for improving performance of the automated warehouse and with that of the production facility as a whole. Current literature is generally limited to warehousing of end products and little is known about the application of end-product warehousing strategies to packaging materials for usage in production. Also, current literature does not take into account reshuffling to ensure better accessibility, but only relocation to access blocked pallets. Ensuring low lead times and good working conditions can increase economic, social and environmental efficiency in a meaningful way.

The objective of this study is to research what the root causes are for the suboptimal performance of the warehouse. Based on the analysis of the root causes a design will be made to improve the performance in terms of lead time. The design will focus on technological solutions, improved procedures, and control rules for shuffling and allocation in the automated warehouse. Changes in material planning or production planning processes are beyond the scope of this research.

2.2 Design objectives

The main design objective is to design a warehousing strategy and process for JDE packaging materials. To answer this question, five sub-objectives have been formulated:

1. Define the working of the system of warehousing and packaging in the KBU.
    a. Describe the JDE warehousing and production transformative processes.
    b. Describe the flows of packaging materials in the KBU.
    c. Describe the stakeholders that are involved in the packaging of coffee in the KBU.
2. Identify root-causes for labor waste and high lead time.
    a. Describe the issues that workers experience in and around PMW and AGV.
    b. Define the root-causes of the issues that are experienced by workers in and around PMW and AGV.
    c. Define the processes around PMW and AGV and determine where problems originate.
    d. Calculate statistical models for lead time and delays using regression.
3. Describe the design requirements for the control rules and process designs.
    a. Describe the principal functions.
    b. Describe the objectives.
    c. Describe the constraints.
4. Describe the design alternatives.
    a. Describe alternative means for each principal function.
    b. Establish design alternatives of logical combinations of means.

5. Evaluate the design alternatives.
    a. Estimate the effects each alternative has on the objectives.
    b. Select the best alternatives.
    c. List the communication that has to be send to the most important stakeholders.

Chapter 3: Methods

3.1 Research framework

The design of a new strategy for the JDE packing warehouse took a stepwise approach based on a five-stage prescriptive model adapted from the design process by Dym (2013) as depicted in figure 1. The process consisted of the following five phases: (1) problem definition, (2) root-cause analysis, (3) establishment of design requirements, (4) establishment of design alternatives and (5) design evaluation. These phases correspond to the five design sub-objectives. The strength of this approach lies in the feedback and iteration embedded in each step. The feedback occurs both internally and externally, for example using results of the problem definition phase to establish design requirements, which in turn will be used to design alternatives. The iterative nature lies in the fact that the further the design process progresses, the lower the abstraction level of the design will be, until the final design is achieved and communicated. This is visualized in the spiral depiction of the design process in figure 1.

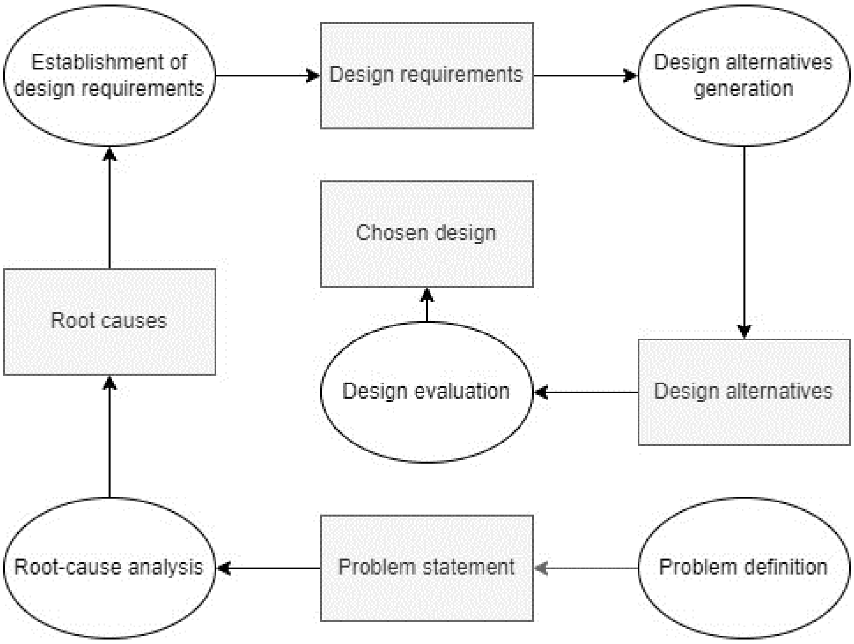


Figure 1. Five phase prescriptive model based on Dym (2013)

Note: ovals represent the five phases, and rectangles represent the inputs and outputs for the five phases.

3.2 Study approach

This study, pertaining to a design project, took a five-phase approach corresponding to the five sub-objectives and the five phases as visualized in the prescriptive model adapted from Dym (2013) in figure 1. Each phase builds on the results of the previous phase. The approach to each of these five phases is described below.

3.2.1 Phase 1

Phase 1 has defined the system using mixed methods approach, both using qualitative analysis to describe processes and organizational structure, and quantitative analysis to further define magnitude of different material flows.

3.2.2 Phase 2

In phase 1 a mixed methods approach was used to define the problem. Qualitative research explained what issues have occurred and where improvements could be made. Quantitative research revealed the occurrence of these issues and what impacts they had on the performance of the system, in order to gain insight into what impacts potential improvements might have.

3.2.3 Phase 3

In phase 2, the design space for the project was established. This phase indicated the functions, objectives and constraints that the design alternatives were to adhere to. These were based on the issues that were found in phase 1.

3.2.4 Phase 4

In phase 3, a qualitative approach was taken to explore the different design alternatives. Design engineering, brainstorming and literature research was used to identify the design alternatives. To do so, different control strategies for the automated warehouse and AGV were defined and processes for warehousing activities of different functions were described.

3.2.5 Phase 5

In phase 4, the alternatives that were established in phase 3 were evaluated with a combination of qualitative and quantitative analyses. These analyses gave insight into what issues can be solved and to what extent they can be solved. Where possible, these analyses also gave an indication of the lead time reduction that could be achieved in combination with the expected costs.

3.3 Methodology and analysis

3.3.1 Phase 1

Phase 1 lined out the scope and the definition of the system that has been analysed. To do so, several analysis techniques have been used. Firstly, to gain a good understanding of the value adding process at the KBU, a IDEF0 analysis was conducted. Idef0, or Integration Definition for Function Modeling, is a methodology employed in systems engineering and process improvement. It visually represents functions within a system using hierarchical diagrams, showing relationships and data flow with arrows. This method aids in comprehending complex processes. Idef0 shows what happens in the system, and not how it happens. Idef0 can be used both to understand the current process, and to describe the desired process (Manenti et al., 2019). In phase 1, the idef0 showed the current process and helped clarify the coherence between the different activities in the system. This aided in keeping a comprehensive overview of the overall system that the design is being tailored towards. Furthermore, the Idef0 indicated the scope of the project as to what processes and activities will be affected or changed, and what processes and activities will remain unchanged.

A flow diagram was used to describe the material flows in PMW. This shows the step-by-step decision making process that determines where a pallet is placed in PMW. This helps understand the algorithm that controls PMW and thus enables the design of improvements in that algorithm. Furthermore, the general locations that pallets flow through when moving through PMW are described to help visualize the system.

The roles of the stakeholders involved are first described and then categorized using a power-interest grid. This shows the level of power that each stakeholder holds, meaning how much influence they have, and their level of interest. This is done to gain a better understanding of which stakeholders matter most and how. This will identify stakeholders that are supposed to be monitored, kept informed, kept satisfied and managed closely. This will allow better understanding of what solutions are possible, and which will be more difficult to implement due to stakeholder conflicts.

3.3.2 Phase 2

In Phase 2, a comprehensive process of problem definition and analysis took place to establish a clear understanding of the system requirements essential for developing design alternatives. The multifaceted approach of phase 1 created a strong foundation for subsequent design considerations and problem-solving strategies. It encompassed the following key activities:

1. Utilized semi-structured interviews to gain valuable insights into existing issues.
2. Conducted observations to assess practical processes and identify potential problem areas.
3. Utilized descriptive statistics to validate and verify identified issues.
4. Employed a Ishikawa diagram to delve deeper into the underlying causes of the issues.
5. Applied the Functional Resonance Analysis Method to gain a comprehensive understanding of the processes and the factors contributing to variability in process quality.
6. Statistically model determinants of processing time and waiting time.

Semi-structured interviews were conducted with 2 warehouse operators, 2 production planners, an employee from the system integrator (i.e., Viscon), and three production employees in order to identify strategies that already have been implemented, detailed workings of the system, principal functions, objectives and constraints. These interviews were conducted using a topic list, with questions on the use of the system, perceived problems and suggested improvements. Interviews were transcribed verbatim and analyzed thematically by identifying informative quotes, categorizing these by type of response (i.e., pertaining to process descriptions, causes of problems or suggested solutions) and assigning themes to them based on their content. More knowledge about the situation at JDE was acquired through observations. Observations were made in the production facilities between April 2023 and August 20203 and aimed to gain an understanding of possible malfunctions in the system. Additionally, warehouse operators were observed by shadowing them for two full work days on 13th and 14th of march 2023. Field notes were collected and analyzed for all observations. Both the interviews and the observations also explored the workings of the interrelations between stakeholders in the system. Descriptive statistics were used to analyze system data obtained from the Viscon (software and hardware provider for automated warehouse) servers in order to validate and quantify the interview and observation findings.

The problem analysis was expanded upon with a root-cause analysis using an Ishikawa diagram. This provided insight into the workings and common practices as well as bottlenecks and (potential) problems, and included a causal diagram to gain insight in networked problems.

To gain understanding of the processes and the qualitative variability of these processes, a Functional Resonance Analysis Method (FRAM) was conducted. The FRAM is used to describe and decompose the processes in and around PMW in a meaningful way. FRAM is a method that describes 'work as done' rather than 'work as imagined'. In other words, FRAM allows the processes to be described as they are done, rather than how they are supposed to be done (Hollnagel, 2017). This means that the model described the processes as they are actually done, as was described by the employees in interviews and as observed in day-to-day operations. This means that the focus did not lie on identifying problems and describing the cause, but on describing all functions and the variability therein (Salehi et al., 2021) in order to clarify the effects of different combinations of unexpected outcomes. This effect wherein two functions can either amplify or dampen each other's positive or negative effects can be identified particularly well using the FRAM. When the resonances and variability in the system become clear it is much easier to identify where risks lie and what their sources could be. This allows for the effective design of strategies that can reduce the causation of such variability, for example implementing a strategy that utilizes technology to reduce variability, or establishment of feedback mechanisms. This can greatly increase the resilience of socio-technical systems which is very useful for the system of PMW at the KBU.

FRAM is especially useful for this study since it is helpful in gaining understanding in interactions and dependencies between different activities in the system. Other methods (like swim lane) tend to focus more on visualizing the flow of work and the responsibilities each department has. Since the partial automation makes it unclear what effects each activity has on other activities, it is useful to analyze these interactions using FRAM. FRAM can exactly show what activities impact other activities, and enabled by the different forms of input, can show how those activities impact each other. Specifically gaining insight in the 'how' impacts flow will eventually make sure that solutions become emergent.

The four steps to conducting a FRAM according to Hollnagel (2017) were applied in this study. The first step is to identify and describe all important system functions and characterize each of these functions using six basic aspects. Functions are typically what people have to do to perform a task or achieve a goal. A function can also be described at an organizational level, for example the KBU that produces coffee, or something that is done by a technical system such as a transport robot that moves a pallet. The basic aspects are input, output, prerequisite, resource, control, and time. Functions transform inputs into outputs. Inputs act as the trigger for a function to start and outputs are the results of the function's process. Prerequisites are what needs to be established before a function can commence. Resources are what is needed for the transformation process, but these are not transformed themselves. Resources can therefore be things like energy or people's competence. Controls supervise and steer functions such as plans or procedures. Lastly, time can influence a function in numerous s ways, it can be seen as a resource when it is used, but also as a control or even as a precondition. To establish the FRAM, all functions have to be connected to represent what the source of each aspect is, and where each aspect goes.

The second step that to be taken for designing the FRAM was a characterization of the variability of the functions. The variability is often in the output of (certain) functions, and this variability can cause differentiation of performance upstream in the system. Output can therefore be of varying quality when the function is repeated. FRAM helps to visualize this variability and shows where the variability can cause problems further upstream in the model.

The third step is looking for functional resonance. Functional resonance is the combination of different outputs that resonate to create a positive or, more often, negative result. This means that there are functions upstream of other functions, that together can create (un)desirable effects. In the case of JDE, an example could be a function that can create a material order, with a material number that is not correct, creating variability. Another function upstream might be a check of this number, and when this check also goes wrong, the outcome of the combination of these two functions is an undesirable event, namely the ordering of the wrong material.

The fourth and last step for the FRAM was to identify ways to monitor the development of resonance either to dampen variability that may lead to unwanted outcomes or to amplify variability that may lead to wanted outcomes.

Finally, determinants of processing time and waiting time were modelled using regression. First, a linear regression was used to model the associations between processing time, calculated by subtracting the time the order was started from the time the order was finished, and determinants, including lane distance, floor distance and number of unblocking actions. Linear regression is used for this analysis since it is expected that the relation, if present, will be linear (Doreswamy, 2011). Second, a logistic regression model was used to determine the associations between average waiting time before an order starts, calculated by finding the difference between the time the order was placed and the time picking stared, and determinants, including time of the day and weekday. All determinants were selected *a priori* based on literature and the problem analysis. Logistic regression analysis is suitable for this part of the model since a likelihood for delay is being analyzed here, rather than a deterministic model for exact lead time. Delay was specified as lead time that exceeds 10 minutes, since the vast majority of materials are delivered within this timeframe and is therefore a good indicator that something other than the regular determinants of lead time caused a major delay. For both models, first univariate and then multivariate regression was performed; calculating the odds ratios and 95% confidence intervals. Statistical significance was set at a $p<0.05$. For all analyses, STATA (v17, College Station, TX, USA) statistical software was used.

3.3.3 Phase 3

In phase 3 the design requirements were established. These were categorized as principal functions, objectives and constraints as prescribed by Dym (2013). The functions were predominantly based on the FRAM, and especially the functions in the FRAM that either cause or suffer from a lot of variability and could therefore benefit from improvements that would reduce these effects. The objectives were based on the problem statement and the results of phase 1&2. The primary objective was hence increased efficiency, which was measured in lead time and labor need. Where needed, these objectives were further analyzed using an objectives tree. An objectives tree allows for intangible goals, such as efficient warehousing, to be analyzed until it is split into goals that can be expressed in a clear unit (such as euros, hours, seconds).

3.3.4 Phase 4

In phase 4 the design alternatives were generated using engineering design (Dym, 2013). The individual functions were each researched, through brainstorming and literature review, to establish alternative means to achieve the function. These were then placed into a morphological chart to identify the design space (Dym, 2013). Several different logical combinations of means for the different functions then formed the design alternatives.

3.3.5 Phase 5

In phase 5, the design alternatives were evaluated based on their performance in on the objectives that were determined in phase 3, by using results from phase 1&2. Quantitative performance was measured through the results of the statistical analyses, where the linear model was able to evaluate performance on processing time, and a logistic model estimated odds that extreme lead times occur. The qualitative performance was measured by conducting a prospective FRAM. The prospective FRAM conducts the FRAM analysis again, but under the hypothetical new situation when the designs are implemented. This way, the alternatives were tested for variability. The design that scores best on the objectives is selected and for this design the key communication message is compiled, based on the power interest-grid from phase 1 that determines how the involved stakeholders should be informed, and what change is required.

Chapter 4: Phase 1: System analysis

This chapter will provide the outline on which the rest of this thesis can be build. It will provide a detailed description of the working of the warehousing process as well as the packaging process at the KBU (=Koffiebranderij Utrecht). A good understanding of how the system works is instrumental to being able to understand and solve problems in that system in the later phases.

4.1 System description

The automated warehouse at the KBU is used to store a variety of packing materials for vacuum and Senseo coffee products. These include all packing materials that are required to turn the roast and ground coffee into finished products ready for shipping to the retailer or wholesaler. That means that the materials are partly logistical packaging, such as boxes and cardboard dividers for pallet storage, but also include the foil that forms the outer wrapper of the products and the foils and filters that form the Senseo pad or the vacuum packaging. Each product produced uses a combination of these materials, of which some materials are used in multiple products such as some boxes for Senseo, but foils contain product specific information and are therefore usually unique to one product. This amounts to a total portfolio of around 200 materials that are stored in the packaging material warehouse (PMW).

The warehousing system at the KBU consists of a combination of technologies. These include conveyor lanes, storage lanes, satellites, lifts, sensors and a control system which autonomously performs all warehousing tasks that take place between input and output. This system is used to store and retrieve all packing materials required to produce the vacuum and Senseo coffee varieties that JDE carries. The factory is divided in 2 parts, one producing vacuum and the other producing Senseo. The part where Senseo is produced uses an autonomous guided vehicle (named Kitt) to transport materials from the warehouse to the production lines.

There are several important considerations to take into account when designing potential control strategies for automated warehousing. These include the requirement of human activity within the system, consisting of the manual unloading of pallets from trucks into the warehouse, remedying malfunctions in the automated systems, and returning pallets into the warehouse with a QR code providing updated data on the pallet content. Additionally, there exists a set of rules that determines the allocation of goods entering the warehouse, based on the zoning layout of the warehouse.

The warehouse at the factory in Utrecht stores pallets in deep racks. These racks contain pallets of varying sizes that can be stored up to 10 pallets deep in some places. This means that the space is utilized in a highly efficient way. However, the storage and retrieval of pallets, especially when the warehouse is at near capacity, is a growing problem JDE faces in their factory's packaging material warehouse. The storage and especially retrieval of pallets in a storage system with 10 deep racks is especially complicated when the system is at near capacity. This is due to the fact that pallets can be located anywhere in the warehouse, and when retrieved, it can require up to 9 pallets to be relocated as they block the pathway. The relocating of these 'blocking' pallets also has an effect, because they are often relocated to locations that will then block the retrieval of other pallets. Therefore, it is crucial to make sure that the pallets required in the near future are not located in the rear of storage racks, but rather at the more accessible front locations. To ensure that this is the case, the pallets will have to be allocated to suitable locations when entered into the system and reshuffling of pallets needs to be strategized to ensure a more favorable configuration.

The packaging department in this system functions as a customer of the packaging material warehouse. It orders products and the warehouse has to fulfil these orders as efficiently as possible. This means that demand comes from production and supply comes from the packaging material warehouse (PMW). There are some mechanisms in place within this system that also occur in normal supply/demand market systems. Supply is relatively set; the warehouse has capacity and when this capacity is full supply stops. This means that only one ‘customer’ (i.e., production operator) can be served at a time. When there is more demand than supply, shortages can occur. Thus when multiple operators order materials, they are effectively competing with one another for the capacity of the PMW.

Something that is not yet being considered in the current warehouse control strategy of JDE is production planning. Although planning is made a week in advance, there is no strategy that takes into account what pallets will be requested by production at certain times. This is challenging given the fact that the plan often changes throughout the week. This means that some pallets might be stored in easily accessible locations, without the need of easy access, and other pallets that will be requested sooner might be stored in inaccessible locations in the warehouse, thus needlessly increasing lead time.

Table 1 portrays the JDE packmat case in key figures. The data used was collected in the period from 14-9-2-2022 to 6-5-2023, amounting to 33 weeks. In summary, it gives a good insight in the scale of operations in and around the packing materials warehouse at JDE. In table 1, outfeed and infeed are not equal. It is important to note that infeed and outfeed are not equal, since some actions like combining batches (i.e., feeding out 2 pallets, merging the contents and feeding in the combined pallet) do not appear in the category outfeed for production, but will result in new infeed, additionally this may indicate that the dataset used has some missing values. Appendix 1 shows the same data as presented in VLC (interface of packmat warhouse) before reconfiguring.

Table 1: JDE packmat key figures for infeed and outfeed of pallets

	Number of pallets*	**Number of pallets per week***
Pallet infeeds	17552	399
Pallet outfeeds for production	15832	360
Pallet outfeeds Senseo	10267	233
Pallet outfeeds Vacuum	996	23
Pallet outfeeds combi**	4404	100
Other warehouse pallet movements	7567	172

*Packmat warehouse has 1000 pallet places in total

**Materials in this category are used by both Senseo and Vacuum

4.2 Idef0 analysis of JDE coffee roastery

To describe the processes at the KBU in detail, an IDEF0 model was used. The analysis covers all processes at the KBU, but focuses primarily on those related to the packing materials warehouse. The whole process is visualized in the following Idef0 model in figures 2 & 3.

When taking into account the overall KBU, the process is as follows. Inputs are green coffee and packing materials. The main mechanisms that drive the process are PMW (warehouse), warehouse operators, production operators and production planners. Other mechanisms were kept out of scope to keep overview, including the roastery, washing facility, “masterblenders” and grounders. The control of the process comes from the central plan, which determines what products will be produced in the KBU, and the warehousing control rules that are currently present. The outputs of the factory are the finished goods, namely the Senseo and Vacuum coffee products.

The process at the KBU starts with the intake of green coffee. After washing, this coffee is mixed in relative proportions of different types of beans, to form a blend that corresponds to the intended flavor and quality the product requires. This coffee blend is then roasted to create the exact intended flavor. After roasting, the coffee is ground, the level of grinding is determined based on the brewing process. The final step is packaging. The roasted and ground coffee is transported to production lines of either Senseo or Vacuum and then packed. The Vacuum coffee first gets a vacuum foil, second, it gets a paper packaging around the foil, and finally a toplabel is attached. These are then packed in bundle foils and finally in shrink foil. The Senseo coffee is packed in a top and bottom filter paper, placed in a foil bag and placed in boxes. Both vacuum and Senso have several different variants of sizes, branding and content.

When zooming in, the process can be divided into 7 mains steps. Coffee that comes in is first washed, after this the quality is checked and only the coffee that meets the criteria is selected. From the selection a blend is made, by combining different types of coffee beans together. This blend is then roasted, and after that, ground. This roast and ground coffee then goes to the packing process, which is the focus of this research.

The process of packing is where the roast and ground coffee that is created in the earlier steps is transformed into finished goods for the consumer. Here, the coffee is either packed into multi-serve vacuum products, or into single-serve products of the Senseo type. These packing processes require different types of materials, such as filters, foils, boxes and labels. The materials are supplied to the warehouse with trucks at the dock. The warehouse operator enters these pallets, provided with a QR code, into the warehouse at the dock. The materials are then stored in the warehouse according to the warehousing strategy. This strategy determines where a pallet is placed when entered into the warehouse, according to the different allocation strategies (explained below), and what pallets are retrieved when a material order is placed, and there is a choice of multiple pallets that carry the required material.

Figure 2: Idef0 A0

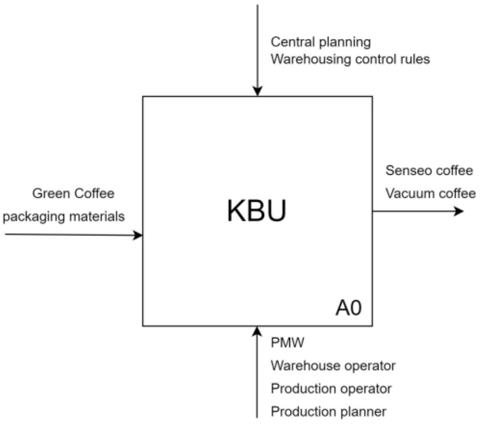
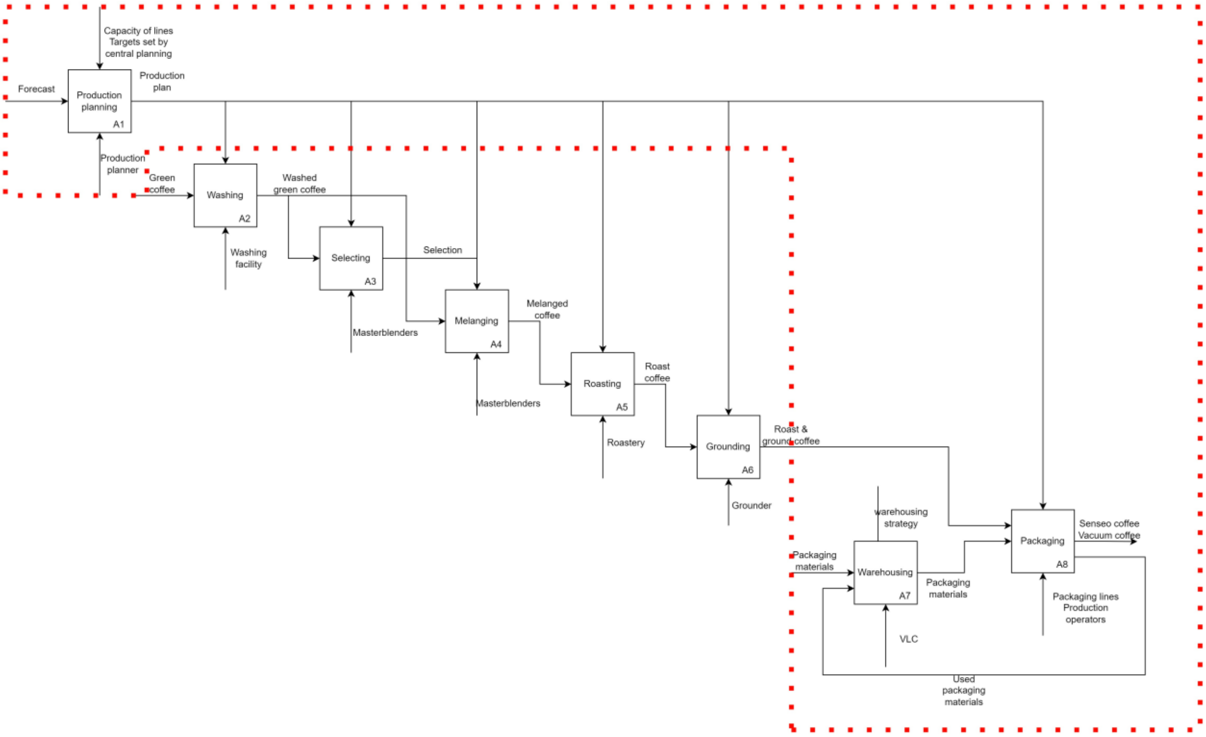


Figure 3: Idef0 level A1



Note: the red dotted line visualizes the project scoping

4.3 Material flows in KBU

When the production needs certain materials, the production operator manually orders the required materials. These materials are then retrieved from storage and moved to the production lines, either by manual transport or using an autonomous guided vehicle (AGV). The Senseo lines and vacuum lines are in distinct parts of the production facility. The Senseo lines can be supplied either by manual transport, or by the AGV. Table 2 indicates the number of outfeeds conducted through AGV transport and manual transport in the period from January 1, 2023 to July 20, 2023.

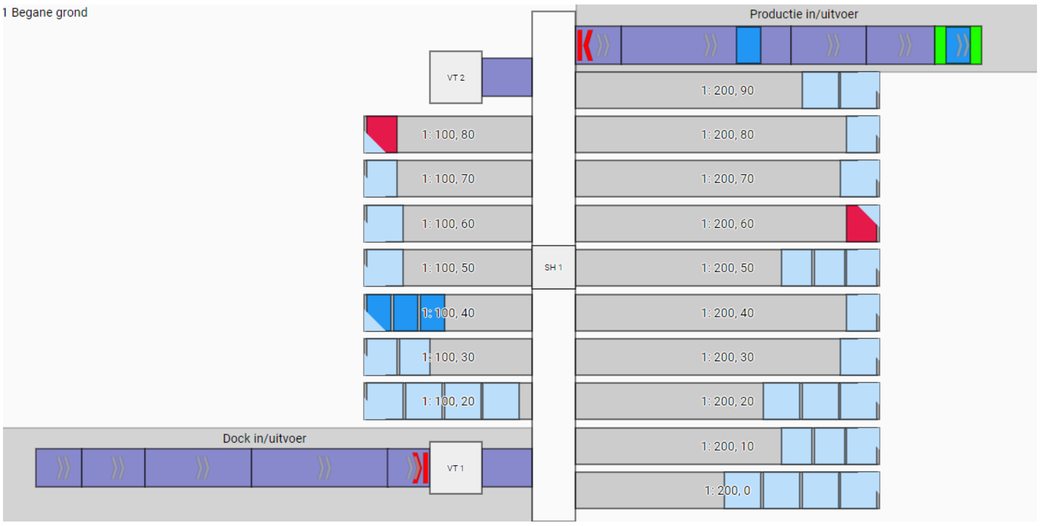
Table 2: Senseo outfeeds between January 1rst and July 20th 2023

	Number of pallets	Percent
AGV	2908	45
Manual	3626	55

The vacuum production does not make use of the AGV yet. The AGV was implemented in 2022 and the beginning of 2023 was considered the “ramp up” phase. AGV was intended to be implemented for Vacuum as well by the end of 2023. The implementation for vacuum has not yet happened yet. Parts of the vacuum employees are opposed to this implementation, and implementation in the Senseo process has not been optimal so far which will be discussed further in chapter 9. Vacuum has access to a buffer area that it uses to store packing materials in advance of production. When the materials arrive at the production line, the production operator uses the materials to produce the required products. When finished, remaining packing materials will be returned to the warehouse or the buffer area. The warehouse is only available to take in packing materials within the timeframe from 12:30 to 14:00, to prevent congestion. Therefore, any materials that have to be returned, are placed in a buffer area next to the warehouse. From here, in order to re-enter materials into the warehouse, the warehouse coordinator has to perform several tasks, namely: measuring the amount of packing materials that remain, printing a new label for the pallet based on the measured amounts, tie up any loose rolls, cover with foil and then input back into the warehouse.

The warehouse consists of storage lanes, transport lanes and lifts. The pallets that enter, either returned at the production in/outfeed point or at the dock, are allocated to a storage lane. To transport it there, the pallet has to go through a transport lane, use the lift to get to the intended floor (if not already on the right floor), and then go to the storage lane via another transport lane. When a retrieval order comes, the system uses the same transport method to transport the pallet to the output point where it can be picked up by either the AGV or the production operator. Figure 4 contains the layout and usage of the ground floor of PLC 16:30 on the August 7, 2023.

Figure 4: Top view of ground floor of PLC



Materials enter the factory through the dock that is connected to the warehouse, and are fed into the warehouse by the warehouse coordinator at the dock. This involves placing pallets from the truck onto the entry point, and subsequently scanning the barcode that comes attached to each pallet. VLC (warehousing software & hardware provided by Viscon) then takes in that pallet and links the information via the barcode to the pallet. After taking in a pallet, VLC determines where to place the pallet. In the current situation, there are a few rules based on which pallets are allocated a storage lane. To summarize, each material has one of three allocation strategies. These are either (1) exclusive, (2) mixed or (3) low-floor. The storage lanes correspond to one of these three strategies. Exclusive lanes can only contain one material type and will therefore never have to unblock pallets. Mixed lanes can have a combination of materials and will thus have to unblock pallets. Low floor materials are stored on heavy pallets that are more prone to malfunction, and are therefore only stored on the first floor to make potential maintenance easier. Each of these materials have their own rules when it comes to allocation and relocation. The allocation of materials is visualized in figure 5. VLC follows these rules when it comes to allocation of pallets in the warehouse. Additionally, the warehouse will always allocate pallets to the lane that is closest to the entry point.

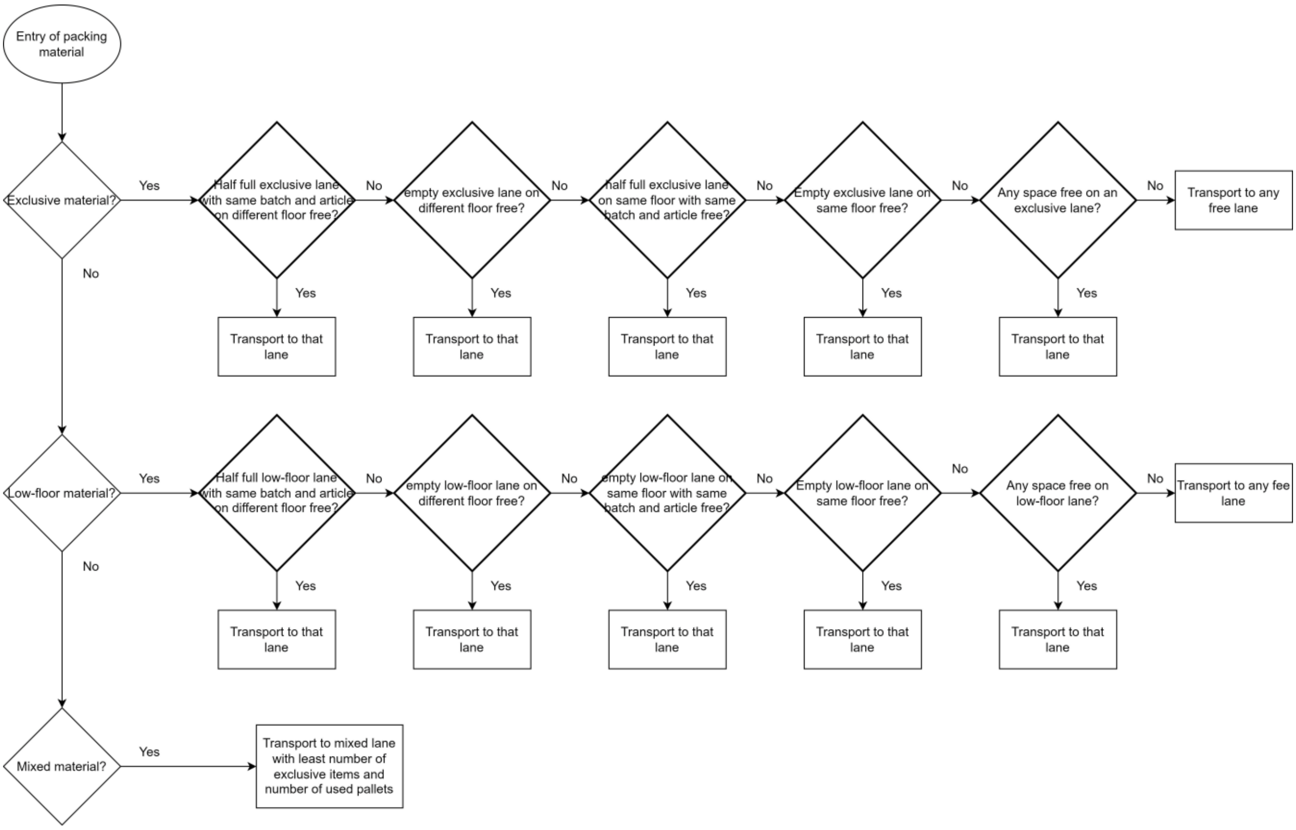


Figure 5: Process flow diagram of material allocation

Unblocking of pallets happens according to similar rules. However, exclusive lanes are not used to store unblocking pallets, since that would only cause new blocking of the exclusive pallets. Figure 6 visualizes the process flow for unblocking pallets.

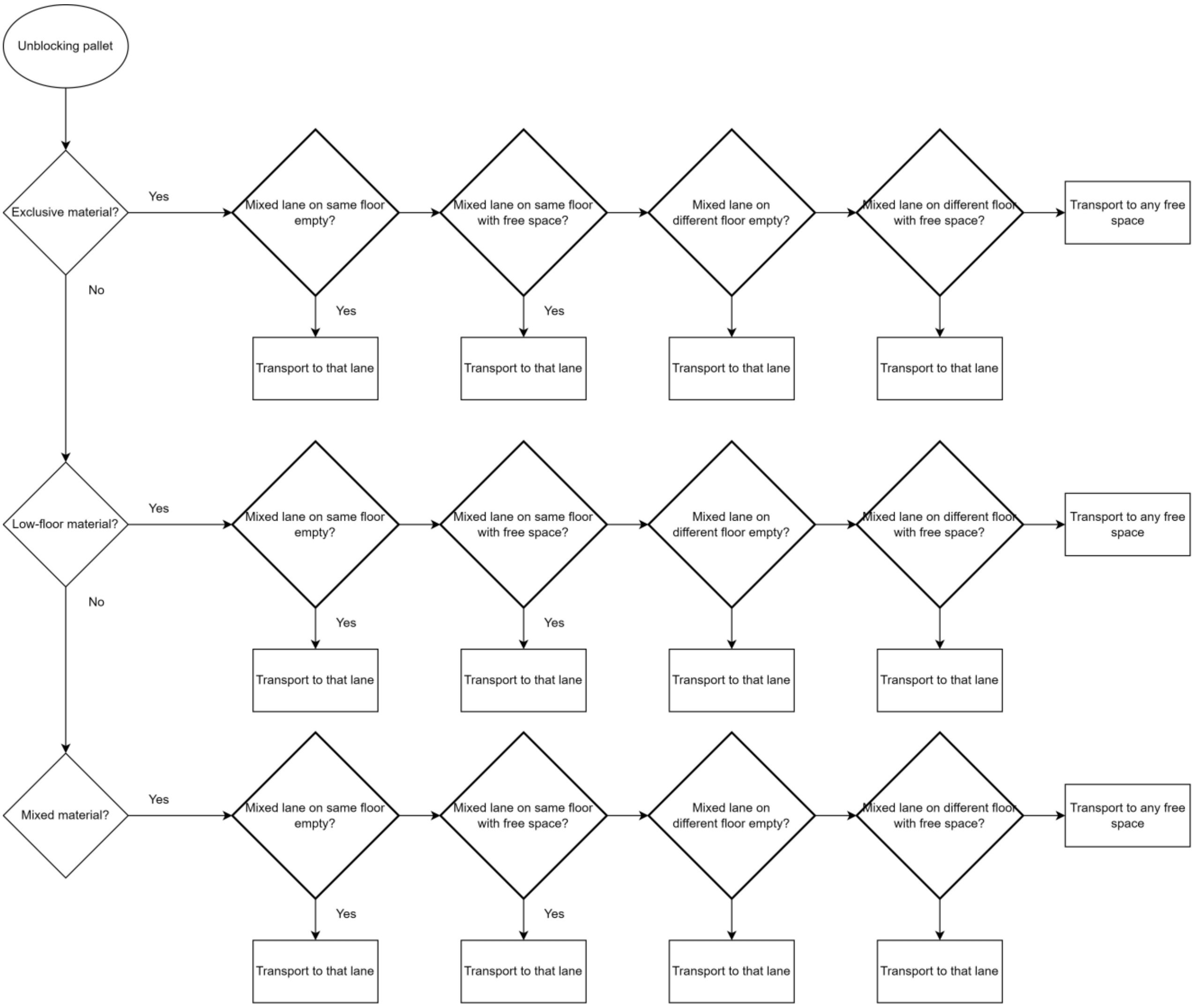


Figure 6: Process flow diagram unblocking of pallets

To transport the pallet, the system uses conveyors, satellites and lifts. From the dock entry, a conveyor leads into one of two lifts. The lift transports the pallet to one of seven floors. On each floor, there is a short conveyor that places the pallet into the central lane where transport is done by a satellite that can access the storage lanes (racks), across the storage racks transport is done by conveyors again. When a pallet is requested by production, the satellite moves it to the lift which takes the pallet to the ground floor (unless it was already stored on the ground floor). From there, another satellite transports the pallet to the conveyor leading to the input/output point at the production side.

Pallets that are in the output point are moved either by the AGV named Kitt, or by manual transport. Pallets that are bound to the Vacuum production hallway are moved manually, and pallets transported to the Senseo hallway are moved either by Kitt or manually (depending on the choice of the operator). PLC places the pallet on the input/output point autonomously, but from there it is dependent on either Kitt or the operator to pick up the pallet. As long as a pallet is on the input/output point, no other pallets can be fed out by PLC. In case a Vacuum pallet is in the way for Kitt, Kitt can move it to a buffer area to be able to obtain the pallet Kitt needs.

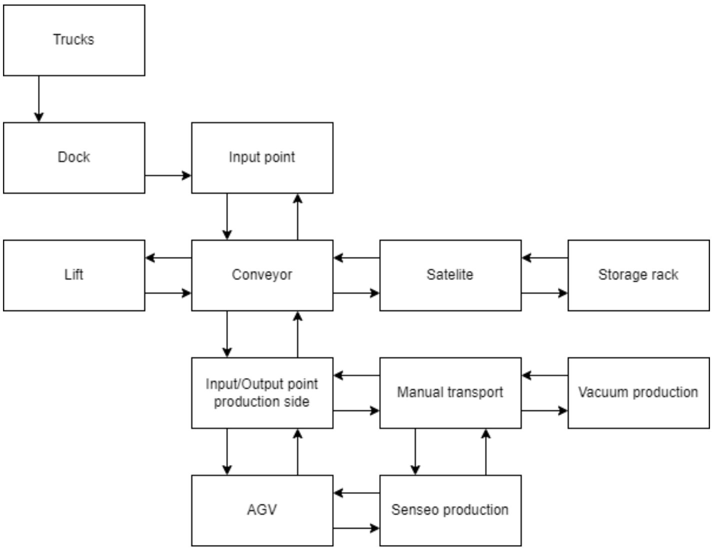
Vacuum pallets are usually ordered by a material worker of the Vacuum team, and this person orders materials to fill up the buffer. The buffer zone is located near the Vacuum production lines and can store sufficient materials to let these lines run for the medium long term. This means that there are barely any delays due to material shortages on the Vacuum lines. The size of buffers in the Senseo hallway is much smaller and only has space for a few pallets per production line. Each line has 2 places for 'planos' (unfolded boxes), one position for top filter, one for bottom filter, one for foils and one switch position. This means that there is one place where a pallet can be placed in the overlap time when one pallet is almost empty. The switch position can then be used to place an extra pallet of material, and once the pallet runs out the operator can immediately switch to a new one. This means that only one type of material can be ordered at any time, and only after the switch is made, a second pallet can be ordered. Due to this mechanism, the Senseo lines can suffer from material shortages relatively quickly when pallets from packmat warehouse are delayed.

Any pallets that are not fully used up and are not required for production for some time, based on the operator or material workers choice, are moved away from the production hallway to the buffer zone next to the packmat warehouse. On a set moment of the day, the packmat warehouse is blocked for output, giving the warehouse coordinator the chance to return all items in this buffer zone into the warehouse.

When a pallet is returned from production to the warehouse the process is largely the same. The main difference is that the warehouse coordinator has to measure the contents of the pallet precisely and make a new label with barcode that has the updated information about the contents of the pallet. The smaller rolls of material are tied up, which is important to prevent malfunctions, the pallet is covered and then put onto the entry point properly (i.e., straight and within the rails), and then entered into PMW by scanning the barcode.

The flows that are discussed above are visualized in figure 7. Note here that the conveyors and lifts used are not all the same, there are conveyors on all floors and on multiple locations, and lifts on both sides of the central lane of the warehouse.

Figure 7: Material flows KBU



4.4 Stakeholder overview

In the JDE packaging process, different stakeholders can be identified. In this section an overview of the identified stakeholders is provided and analyzed in terms of their most important powers and interests based on interview and observational findings. This will help gain insight in the different motives at play in the system and indicate the relationships between these stakeholders.

Production operators are an important group of stakeholders. They are responsible for the packaging process and make use of the warehouse to gain access to the stored materials that they then use for the packaging process. This group can be divided into Senseo operators and Vacuum operators. Each are clearly distinct groups with their own group culture, even though some individual operators work in both groups. Each group consists of operators, A-operators and shift leaders. The operators are often long-term employees with a lot of technical knowledge of the system. They want to perform their own tasks, but, according to …, some do not want to do extra work, and are reluctant to accommodate change. They have some influence in the form of the impact they have when ordering materials. They have the freedom to choose when to place orders, thus increasing or decreasing demands at certain points in time. Their main interest lies in the need for a quick and smooth supply of materials so that they can properly carry out their tasks. Furthermore, they want to maintain a manageable workload.

Warehouse operators are responsible for the warehousing of packaging materials. The team consist of two people, a coordinator and a general employee. They unload trucks, check the pallets for quality, and are responsible for the infeed of these pallets. They are also responsible for counting materials, checking the contents of pallets and updating simple information in the IT systems. Infeed of material pallets is done by the warehousers every day between half past 1 and 3. To do this, they measure the contents and enter it into the system to generate a new QR code, after which they feed the pallet into the warehouse. During the infeed hours, the warehouse is blocked for outfeeds. The warehouser can override this blockage for any urgent material orders. The warehouse operators have a specific interest in smoothly running operations, and therefore few returned pallets, which causes a lot of work. Furthermore, they need to count materials, and therefore need to be able to enter the warehouse, and have materials sorted by type to make it easier to count. Their power lies in the fact that they have first line responsibility over the warehouse. This means that they can overrule blockades, they can shuffle materials in the warehouse manually and have a lot of impact when they have a direct line to the material planner.

The material planner is responsible for the availability of packing materials, and orders new materials based on the production planning and monitors the stock levels of all materials. Therefore, the material planners interest lies in good insight into current stock levels in the warehouse and expected material requirements and good storage accessibility for the materials. The material planner can decide when and what to order and therefore has a big impact on stock levels in the warehouse. Furthermore, the material planner has the final say in blockades of materials, is responsible for the final count of materials and can make decisions autonomously, therefore this is the actor with the most power.

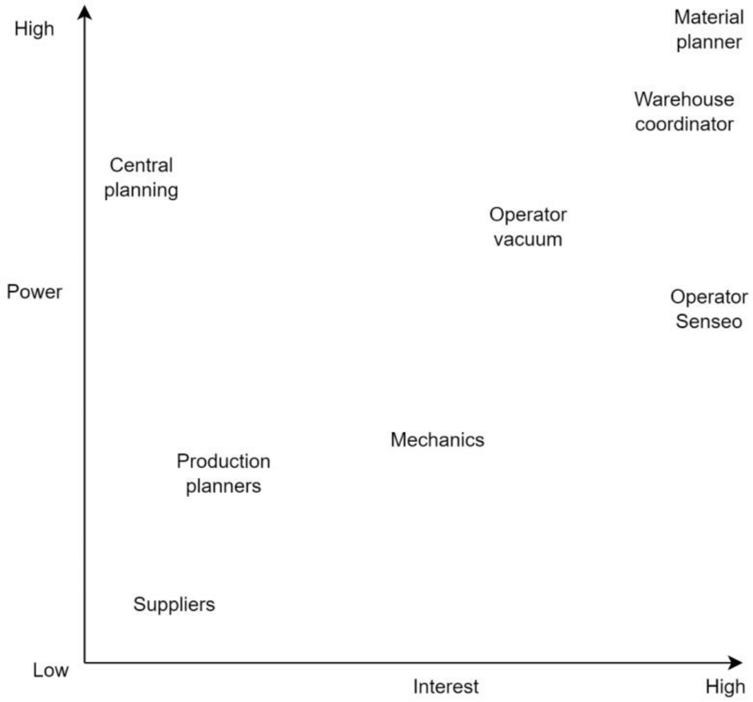
The production planners are responsible for creating the weekly production plan, one for Senseo, one for Vacuum. To do this, they take into account the requirements that are stated by central planning, which are provided weekly. The capacity of the production facility is dependent on several factors. Firstly, there is a limited number of production lines. Secondly, each line has to be manned by a production operator, who are often in limited supply. Aa a result, production lines cannot all run for the full three shifts. Finally, the inputs are dependent on the roasting and grinding facilities that have to create specific blends for each product, although some different products still use the same blend and roast. The production planner thus tries to create a broad portfolio of different products and package sizes, but also tries to limit the number of switches on the lines to reduce the work for operators and mechanics. For production planners interest is not very high, they have nothing to do with day to day operation of PMW and surrounding processes and their main interest is that the materials that are needed for their plan are delivered in time, so that the operators can execute the plan without delays. They have some power in the system however, since the production plan they design each week determines what materials are needed when.

Central planning sends a weekly report based on stock levels of finished products and sales forecasts. The report contains the products that need to be produced by the factory in Utrecht for that week. Central planning has the objective to never go out of stock on products and therefore has interest in a good flow of finished products which is indirectly dependent on efficient warehousing, however they have no interest in the way the factory is run, as long as the product is there at the end of the process. Central planning can request the KBU to make the decision to allow overtime or weekend work. Doing so, greatly increasing both costs and capacity. The final decision on this however lies with management of the KBU, and therefore there is some power with central planning, but no final say. Central planning has more power when it comes to planning changes. When they change the plan, this has big impact on warehousing and material needs of the KBU, therefore their overall power is fairly high.

Mechanics are responsible for general maintenance and fixing malfunctions in the warehouse, as well as on the production lines. The mechanics can personally prioritize the tasks they have. They have an interest for not having too many malfunctions and especially not at once, which would require them to prioritize even more. By prioritizing, mechanics can have great impact on the functioning of the system, fixing malfunctions quickly or not, as well as creating durable solutions to malfunctions or choosing quick fixes.

For each of the stakeholders, figure 7 visualizes the aforementioned amount of power and interest. Power in this figure constitutes the impact that the stakeholder can have on the functioning of the warehouse. Interest concerns the preferences they have in the way in which the warehouse is operated. For instance, central planning has a lot of interest in good performance of the warehouse and packaging as a whole, but is not affected much by the process design, and therefore is categorized as low interest. It is very useful to know what stakeholders have high interest according to this definition, since it gives insight into what stakeholders will have to be convinced and managed closely when implementing a new warehousing strategy design.

Figure 8: Power-interest grid



4.5 Conclusion

The warehousing and packaging operation has been clarified enabling the further exploration of the issues that are present in this system. The scope of this thesis has been established to be production planning, warehousing and packaging. Analyzing the material flows has provided meaningful insight in the current allocation rules that PMW uses, which will assist in better understanding issues surrounding allocation. The stakeholder analysis has shown that the material planner and warehouse coordinator have very high power and interest, whereas central planning also has high power but less interest. This will be used to establish the communication that has to be provided to each of the stakeholders when a final design is chosen.

Chapter 5: Phase 2: Root-cause analysis

This chapter aims to find issues that occur in the warehousing and packaging system in and around PMW and AGV. By conducting interviews a general understanding is formed about what issues are experienced by workers. Where possible, these issues have been supported with data to make clear what the size of the problem is (i.e. is it anecdotal or a persistent problem). The causes of the identified issues are determined and visualized using a Ishikawa diagram to gain deeper insight in the causes of the issues, and therewith the changes required to fix those issues. Using functional resonance analysis method (FRAM) the processes that experience issues will be visualized, and the root causes can be traced back systematically to the processes that caused the issues. Finally the regression analyses will assist in confirming effects that distance and unblocking have on lead time and quantify these effects, as well as assisting in confirming any of the effects that have come forth from the interviews.

5.1 Issues

Identifying the issues impacting lead time and labor waste presents a varied landscape across different departments within the organization. Notably, employees tend to expeditiously draw conclusions and highlight the prevailing issues. However, they have regrettably failed to take requisite measures to proactively avert or rectify these issues. Moreover, certain issues were cited without precise specifications, others turned out to be one off events. Therefore, it is imperative to assess each reported issue on relevance by analysis based on occurrence in interviews, supplementary data and drawing insights from observations made on the work floor. The interviews have been coded according to quotes that were summarized, given a type and attributed a theme. The detailed coding can be found in appendix 2.

Section 5.1 aims to dissect the identified issues, delineating their significance and magnitude of their impact on lead time and labor waste. Table 3 presents the interviews conducted, the role of the interviewee and whether they work at the office, in the factory or externally. The results have been sorted per theme on which issues are reported by interviewees, so that each of these issues can later be further investigated to find root causes of the issues.

Table 3: Interview overview

Interview number	Role	Internal/external	Key findings
1	Product owner VLC	External	Exact description of current allocation and shuffling rules. For Viscon it is useful when solutions are applicable to other clients as well.
2	Shift leader Senseo	Factory -Senseo	Process descriptions of Senseo packaging process. General opinion of AGV is low.
3	A-operator vacuum	Factory - vacuum	Issues caused by Senseo, process descriptions of vacuum packaging process.

4	Operator vacuum/occasionally Senseo	Factory - vacuum	Identified a lot of resentment towards Senseo, blames them for most issues. Reluctant to solutions that require change from them. Also gave insight in personal preferences about methods.
5	Production planner Senseo	Office	Detailed process description of production planning process for Senseo, effects of forecast changes and occurrence of forecast changes.
6	Production planner vacuum and former warehouse coordinator	Office / former factory	Detailed process description of production planning process for vacuum. Overview of historic workings of the warehouse and explanation of already taken measures to prevent issues.
7	Warehouse coordinator	Factory	Detailed description of warehousing activities, examples of common malfunctions, description of infeed and outfeed process.

5.1.1 Issues surrounding ordering of materials

Operators of the Senseo production lines have to manually order materials they need for their current and upcoming productions. To do this, they have to enter a material number and can choose whether the AGV has to pick up the materials, or they pick up the materials at the input/output point themselves. It was made clear by multiple interviewees that this process often causes problems. Pallets remaining on the output point without being picked up, or pallets being picked up when the AGV was supposed to pick them up show that the procedure is not always followed. These situations were mentioned by vacuum operators having observed this among the operators of the other section, and were acknowledged by a Senseo team leader (interview 2, 3 & 4; see table 3). The same observations were also made during the shadowing of warehouse operators (field notes, appendix 8). Firstly, the entry of material codes can go wrong when a wrong material code is ordered. How often this happens is not clear, and this problem should not occur when the operator is working conscientiously. However, with shift work, including night shifts, it is likely that operators' attention levels differ and fluctuate (Vlasak et al., 2022). Observations on the work floor, have made clear that this is a recurring problem. Observations have shown that multiple pallets of unused materials were in the buffer zone to be returned to the warehouse, and the warehouse coordinator confirmed that these were materials that were ordered erroneously. As a response to these observations, repeated checkups on other moments spread out over several months showed similar situations thus confirming the regularity of these problems.

Secondly, a problem that is mentioned by employees from all departments is the fact that materials are often ordered multiple times (interviews 2, 3, 4, 6 & 7). This problem occurs when the operator doesn't receive materials quickly enough. The operator does not have sufficient insight in the status of his material orders, and therefore chooses to order the material again. A shift leader of Senseo mentioned this practice and illustrated this by describing scenes of twenty pallets of packing material at production lines, where only one was required (“But then just 20 pallets come out and you think… right”; interview 2). Other interviewees confirmed with similar quotes that this is a common occurrence. Ordering superfluously creates a lot of activity in the warehouse causing delays for other orders as well as creating work returning these pallets to the warehouse, which again would cause a lot of activity. Besides the sheer number of movements required by the warehouse to extract and re-enter all these pallets, this also rearranges pallets in the warehouse to a large extent as a result of all the (unplanned) movements. The returned pallets are materials that are evidently not needed for production in the near future, and will naturally be placed in front positions in the racks. Therefore, these pallets that are likely not needed for production block pallets that might be required by production in the near future.

5.1.2 Issues surrounding concentration of activity

As mentioned above, lead times for materials can sometimes be very long. At certain times throughout the day, the system is very busy, with material deliveries from trucks, materials from the production floor that have to be returned, and the orders of production operators. There are no sequencing rules or priority options for ordering materials as mentioned in interview 1. This means that the warehouse operates under a first come first serve principle.

As a result of the lacking prioritization of activities, lead times can be drastically increased during the most active hours in the warehouse (commonly from 7:00 to 12:00). These hours are most active and most prone to lead time increase because in the mornings, all material deliveries come in at the dock and the packaging material warehouse (PMW) will be busy storing materials all morning. Two other forms of activities further contribute to activity overflow in the mornings as described below. Figure 9 provides the supporting data for this concentration of activity.

Firstly, between 12:30 and 14:00 the warehouse coordinator returns any materials on the production floor into the warehouse. Since this has to happen in the same place as where materials come out, material orders are blocked for operators in these hours. This means that in the hours leading up to this time window, the operators order all the materials they need to work through this time window. This leads to a concentration of material orders in the morning, when the PMW is also busy storing the newly delivered materials.

Secondly, the vacuum production floor has space for buffers. This means that they have enough space to store materials for a longer time. Once every shift, a material worker orders materials to fill up depleted buffers (interview 3 & 4). This also happens in the mornings, creating further overflow of activity.

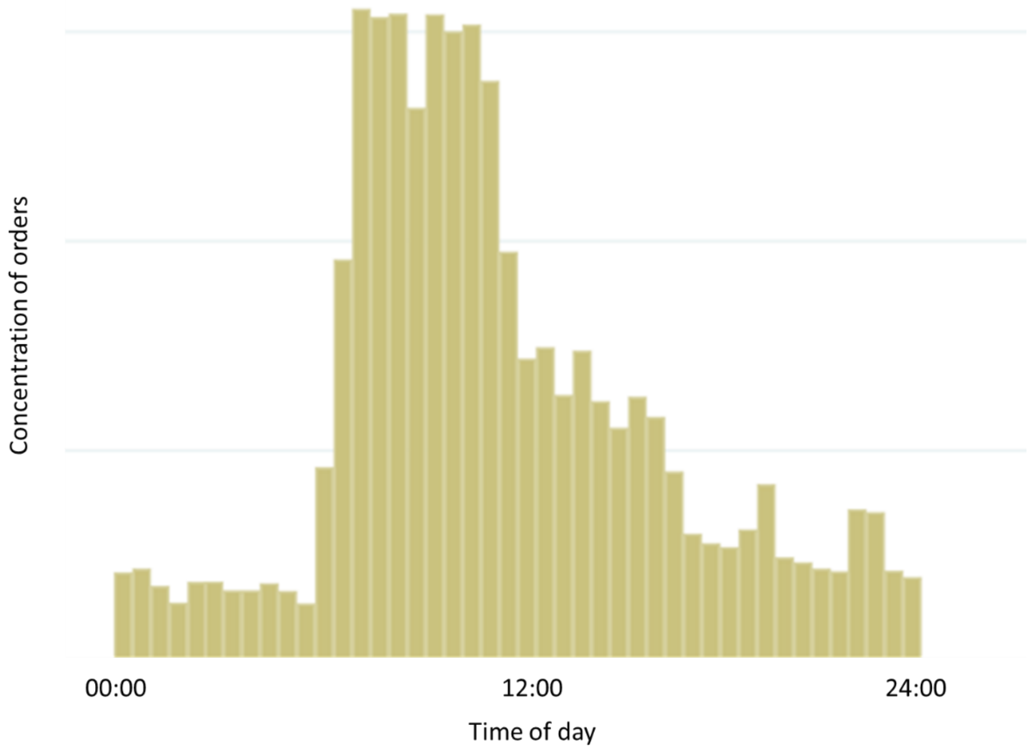


Figure 9: PMW activity across the day

Additionally, on Mondays, materials are ordered that are required for the weekly planning, and are not present in the buffer zone; as described in interview 3 and 4: “on Monday we know the planning for the whole week, so we check which materials are in the buffer zone and we order what is missing”.

Mondays are also a moment in the week where a lot of material switches take place. It was mentioned in interview 2 that on “Sunday night the new shift starts with new coffee varieties, so all materials have to be swapped out”. Many of the production lines start producing a new product on Monday and therefore require new materials. To further illustrate, table 4 shows the average time between order generation and completion, as well as total frequency of orders on each weekday.

Table 4: Frequency and lead time per weekday

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Frequency	4257	4475	3292	3914	2942
Average lead time	00:06	00:04	00:04	00:02	00:09

Senseo orders materials fairly constantly across the day (figure 10). With the exception of some small peaks after the infeed timeslot (approximately 15:30) and at the start of the morning shift (6:00-7:00). This is a logical conclusion from the fact that Senseo production does not have a large buffer area, and throughput of some materials, like boxes, is very quick. This means that each production line requires a new pallet of boxes roughly every 2-3 hours, resulting in a relatively steady average flow of materials across all Senseo production lines as seen in figure 10.

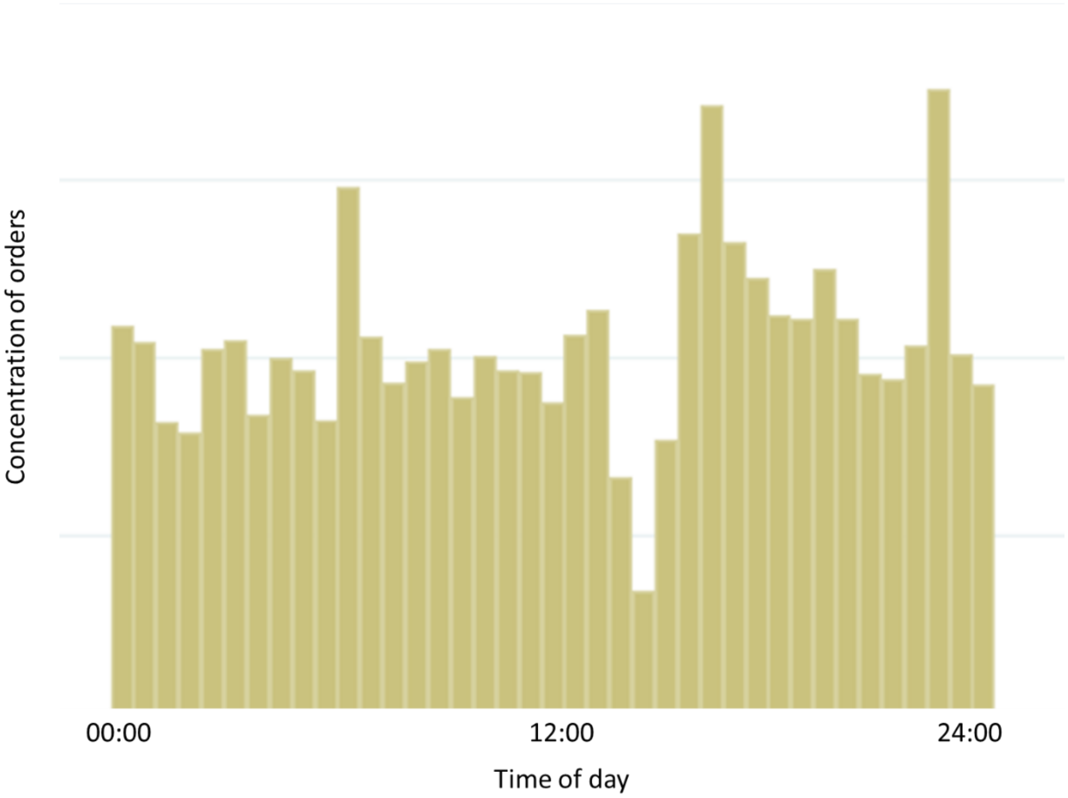


Figure 10: Senseo orders across the day

Vacuum on the other hand has the freedom to order materials whenever they see fit. They have enough buffer to store materials for the whole day, or even longer. This makes it especially inopportune that Vacuum seems to order materials precisely at the time of the day when the system is most busy (figure 11 and figure 9). It is important to note here that Vacuum does not run night shifts regularly (only on exception). When comparing the numbers, this means that about 25% of orders in the particularly busy hours between 6:00 and 12:00 are Vacuum materials, whereas in the hours where the warehouse is not busy there are almost no Vacuum orders. In addition, some materials are ordered both by Senseo and Vacuum, and therefore their data is difficult to interpret. To interpret these pallets that carry universal materials, and therefore cannot easily be attributed to one of the production departments, the same graph was created. The graph for these universal materials (appendix 5) looks like a combination of figures 9 and 10, and therefore it can be assumed that the effects seen in materials that are dedicated to either Senseo and Vacuum can be extrapolated to the combination materials ordered by both Senseo and Vacuum. This is important to understand when making assumptions about what departments have what impacts on overall concentration of orders.

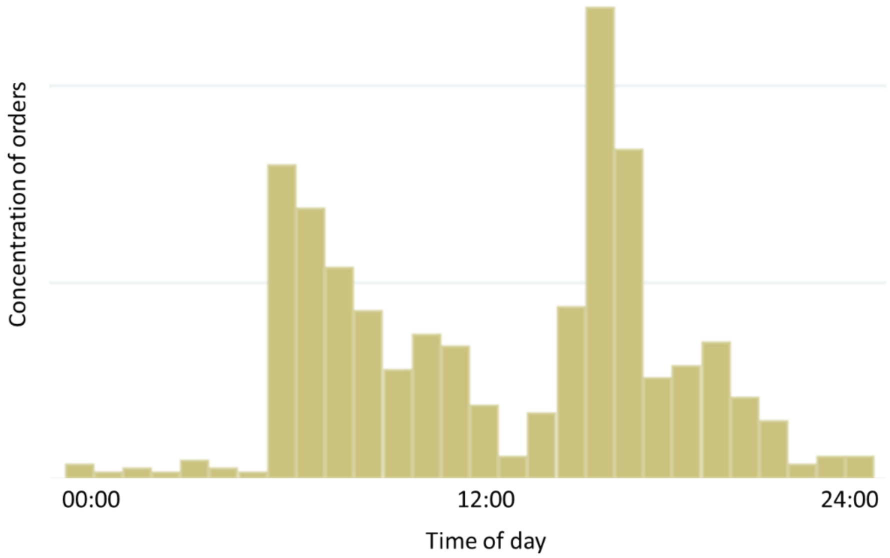


Figure 11: Vacuum orders across the day

5.1.3 Issues surrounding allocation

Allocation into the warehouse happens based on several rules, as described in figure 6. However, according to the warehouse coordinator, allocation could be a lot more organized in order to create more coherence in the warehouse (interview 7). In the current state, only boxes and bottom filters are stored in dedicated lanes. This creates a well-structured overview of the warehouse. If there would not just be dedicated lanes, but dedicated floors, it would make the whole warehouse more organized. The warehouse coordinator moreover reported that “this is useful when you have to count materials, this way you would know where to find all items at once, and not have to look in different floors” (interview 7). However, observations have shown that malfunctions can occur in places that take a whole floor out-of-order for multiple hours. Therefore, it is not advisable to store all material of a certain type in one floor, this way when one floor is in malfunction, the material can be extracted from other locations; as similarly claimed in interview 1 by the VLC product owner.

5.1.4 Issues surrounding shuffling

Shuffling plays an important role in efficient warehousing, but in the current state still causes more problems than it solves. The warehouse coordinator indicates that they are manually moving and sorting a lot of pallets in the warehouse (interview 7), meaning that this is not done automatically by VLC. However, there are rules present in the warehouse that would trigger the same or similar shuffling actions according to the VLC product owner in interview 1. This means that the warehouse coordinator is manually moving pallets around that would possibly be moved automatically if they would wait for the shuffling to commence. Furthermore, shuffling causes delays for material output, since VLC will first finish its shuffling activity, and only then respond to material orders (interview 6 & 7). This means that shuffling has to be planned at ideal moments, as to not interfere too much with regular warehouse activity.

It is not known to operators or the warehouse coordinator when the warehouse will start shuffling (interview 2, 3, 4 & 7). Therefore, the operators are sometimes surprised by delays, and when they ask for clarification on the cause of those delays the answer is that the system was shuffling. In interview 2 it was mentioned by the Senseo shift leader that "I need this kind of pallet now and it takes very long until it can finally roll out again, I don't know 20 minutes to half an hour is pretty common; and if we ask questions, we're told yeah that's when it's shuffling". This would mean that shuffling is not concentrated in the non-busy hours, causing delays for regular material orders. However, this is not true since PMW always prioritizes material orders above shuffling activity as claimed by the VLC product owner in interview 1.

Furthermore, it is good to note that energy consumption of the system increases during shuffling. The warehousing operator noted that he has changed the control so that the warehouse would conduct shuffling actions during the night, and got confronted by a facility manager about increased energy consumption during those hours (interview 6). This means that shuffling actions are not without monetary and sustainability consequences since it will consume significant amounts of power.

5.1.5 Issues surrounding input

Input occurs on two occasions. Firstly, pallets from material deliveries are entered at the dock. Secondly pallets that are left over from production are entered at the input/output point on the production side of the warehouse (interview 6 & 7). Pallets that are put into the system have to be double checked for damages, loose materials or wrapping plastics to prevent malfunctions (interview 6 & 7). However, the warehouse coordinator only does this when he steps out of his forklift to scan the QR code of pallets (interview 7). Some pallets have the QR code attached to the side of the pallet facing the coordinator in the forklift, so that he does not need to leave the forklift to scan it. This creates an easier process for him, but allows for damaged and poorly wrapped pallets to be entered into the warehouse without inspection or fixes, causing frequent malfunctions according to multiple interviews (interview 2, 3, 4, 6 & 7). There is a scanner at the input point, however observations show that this scanner does not detect all poorly wrapped pallets. This scanner only is made to observe whether the pallet falls within the boundaries, so it detects anything sticking out, but cannot detect poorly wrapped materials that can shift during transport.

5.1.6 Issues surrounding malfunctions

According to operators and warehouse coordinators, malfunctions are a common occurrence both within the warehouse, and concerning the AGV (interview 2, 3, 4, 5, 6 & 7). Some of these have been described above, and are caused by damaged pallets or loose materials. When such pallets are entered into the warehouse, it can happen that halfway in the warehouse the pallet gets stuck. This means a mechanic has to go into the warehouse to the location of that pallets, fix the damage of shifted materials, and then get out of the warehouse to find out if the cause the malfunction is fixed by rebooting the system (interview 7). To prevent having to walk up and down the warehouse to check if the problem is fixed, two mechanics often work on malfunctions. One will go inside to fix the cause, the other stays at the interface to check if the malfunction is solved, keeping contact using a phone. During this process the whole warehouse has to be shut down for safety purposes in the lock out tag out try out principle (i.e., LOTOTO).

When a malfunction in the warehouse occurs, the warehouse coordinator has to be notified, who in turn escalates to the material planner. The material planner can then decide whether to shut down to enable maintenance, continue operations or find another solution that they see fit at that moment. According to the warehouse coordinator, when they proactively chase this process, malfunctions can still take up to 1,5 hours to fix (interview 7).

Observations have shown that mechanical problems also occur. Typical problems include untightened chains that run out of their tracks as a result of heavy pallets. This problem can easily be prevented by tightening the chain, however the solution that is chosen, is often simply reattaching the chain, causing the problem to keep reoccurring. This means that there is a culture of fixing problems ‘the easy way’ and not ‘the right way’. This can partly be attributed to a lack of experienced mechanics and general knowledge of the system in combination of limited time, according to management.

In addition, the AGV often malfunctions, and is therefore unpopular among employees across both Senseo and Vacuum (interview 2, 3, 4). AGV is used only for Senseo, but when it causes malfunctions in the warehouse outfeed, Vacuum also suffers delays. When looking at the data (table 2), the AGV is used for only about 46% of Senseo outfeed orders. This is a clear indicator that the AGV is not popular among operators, who evidently often choose to pick up pallets manually. Table 5 shows the number of AGV assisted outfeeds of Senseo materials since 1-1-2023, this date is chosen since it can be presumed that the AGV has had a startup period, thus making the data collected before this date less accurate to represent the real situation.

Table 5: Users

	Frequency	Percent
Warehouse coordinator	47	0.83
Admin	7	0.12
AGV	2596	45.64
Other	3038	53.41
Total	5688	100

Lastly, a Senseo shift leader has also indicated that there are days when the AGV is more prone to malfunction and when this happens during a night shift, it means that there are not many mechanics around to fix it, and operators lack the knowledge and training to fix these problems themselves. In this situation, the Shift leader instructs operators to direct all orders away from the AGV to manual pickup, thus causing a lot more labor-intensive work (interview 2). The situation concerning the decreasing popularity of the AGV becomes very clear when comparing usage over time. Usage of AGV has greatly reduced since its original introduction at the start of 2023, and recent months. The drop in usage of the AGV since April corresponds to the tenure of the AGV product owner, who was responsible for overall AGV performance until the end of March. Table 6 & 7 indicate the number of outfeeds conducted through AGV transport, and manual transport in the period from January 1, 2023 to April 2, 2023, and from April 1, 2023 to July 20, 2023, respectively.

Table 6: Senseo outfeeds between January 1, 2023 and April 1, 2023

	Number of pallets	Percent

AGV	1823	56
Manual	1414	44

Table 7: Senseo outfeeds between April 1, 2023 and July 20, 2023

	Number of pallets	**Percent**
AGV	1085	33
Manual	2212	67

5.1.7 Issues surrounding planning changes

Planning changes can occur due to different circumstances. The most important cause is a forecast change (interview 5 & 6). In that case, central planning will change the requirements for the KBU, and in turn the production planner will try to comply with central planning. According to the production planner, production planning is conducted while keeping in mind that individual production batches should not be too small, with a minimum of 2 tons (interview 5). Furthermore, the size of the packaging should not switch too much, since changing the line to a different size of packaging takes a lot of time and resentment from employees (interview 5). These are fairly strict requirements for the production plan, which makes it all the more difficult to create a new plan when forecasts are changed last minute.

The production plan is made in the week leading up to the week where production is run. On Tuesday, the planners will finish their preliminary production plan. Based on this plan the material planner will order the materials needed for the next week. On Thursday however, central planning finalizes their plan, and when this differs from the draft it means that the planners have to adjust their plans to accommodate the new requirements (interview 5 & 6). Effectively, this means that the production plan is only finalized after the planners have made adjustments to their plans based on final demand forecast by central planning on Thursday (often end of day when there are big changes). The timeline corresponding to production planning is visualized in figure 12.

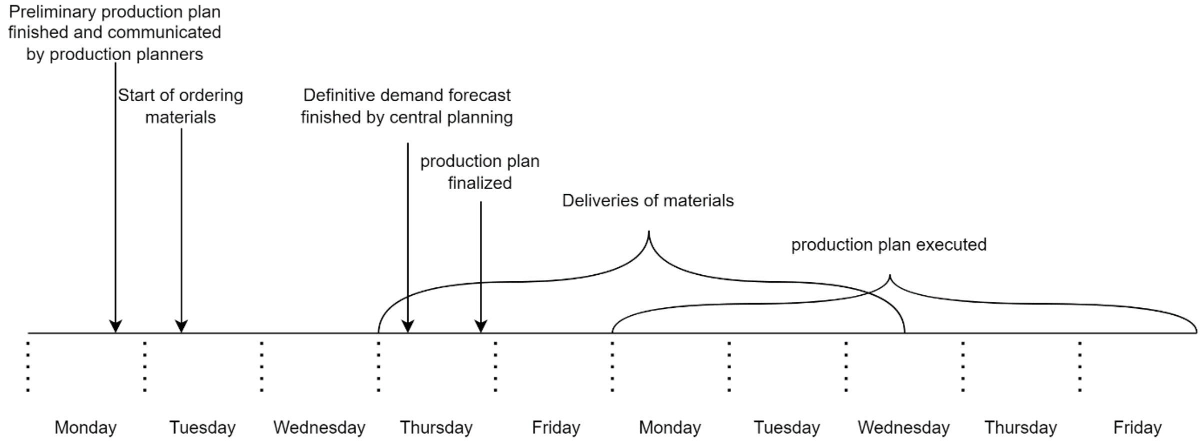


Figure 12: Timeline production planning

5.1.8 Issues surrounding IT

IT causes some problems in the system. As mentioned above, Senseo operators claim that the lack of insight in the status of both the warehouse and AGV is a problem for them (interview 2). Vacuum operators blame Senseo operators for not responding to malfunctions or issues adequately and swiftly (interview 3 & 4). The lack of insight in the status of the warehouse and AGV reduces the ability of Senseo operators to quickly respond to malfunctions and make good choices between manual or AGV orders (interview 2). However, the current VLC software already offers this information (interview 1), meaning that either this information is incomplete, inaccurate or the operators do not have the proper knowledge or training to interpret the information.

Additionally, the status of malfunctions is only available online. This means that mechanics fixing malfunctions can only see whether their fix worked by leaving the warehouse as PMW blocks WI-FI signal, and can't be activated with mechanics inside due to LOTOTO. This requires a lot of time due to the elaborate and highly necessary LOTOTO safety measures for getting in and out of the warehouse. The fact that there is currently no possibility to both inspect PMW and fix it within the warehouse is a cause of longer maintenance downtimes for the warehouse, due to the necessary safety measures.

5.2 Root cause analysis

Based on the identified issues, a root cause analysis was conducted. This means that the main causes behind the issues were identified and analyzed. To gain a full insight in the causes of issues and the interdependencies and causalities between different aspects of the system an Ishikawa diagram was constructed. The Ishikawa diagram is a valuable tool for mapping root causes by visually representing the underlying causes of the issues encountered in the JDE packaging an warehousing process. Ishikawa diagrams can be used when there is one specific problem, in this case the high lead time for materials, and several main fields of causes (Luca et al., 2017). The Ishikawa diagram provides a comprehensive overview of the thematic problems identified, schematically illustrating the relation between the identified main fields of causes and the high lead time. This structured representation facilitates effective problem analysis and identifies what potential solutions may be feasible. The Ishikawa diagram is depicted in figure 13. However, it is important to note that the Ishikawa diagram may fall short in capturing the intricate relationships and complex dependencies among different causes. To mitigate this, thematic color coding was applied to the most important cross thematic causalities. The main fields of causes and cross-thematic causalities will be discussed below.

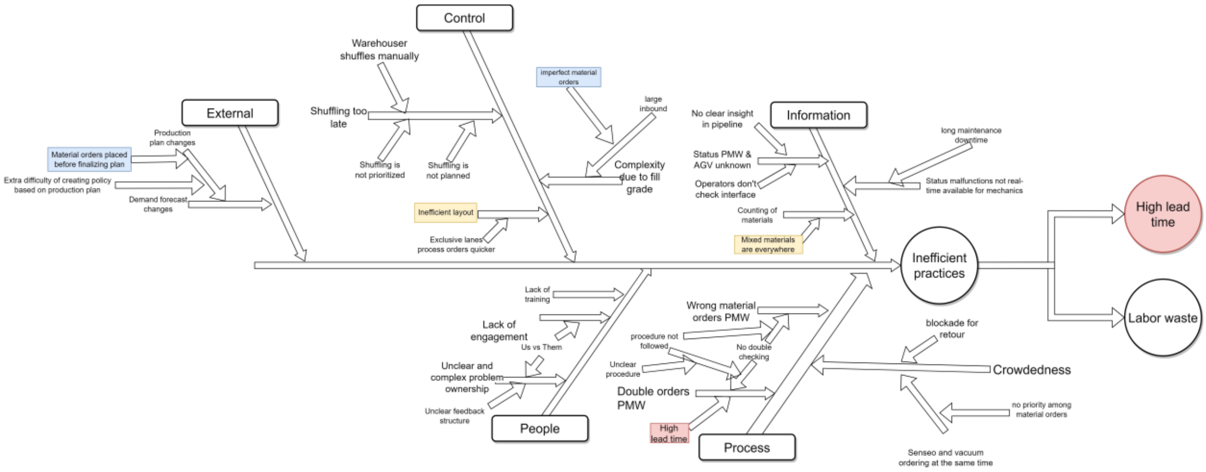


Figure 13: Ishikawa diagram

Note: colors indicate cross-thematic causation

5.2.1 Process

The ordering process for materials that is conducted by operators allows for variability in quality. This means that there are checks that should be followed, but the process allows for these checks to be bypassed and for mistakes to be found too late. Firstly, operators have to order materials by entering the material code, and typing errors, when they go unnoticed, can cause wrong materials to be ordered and transported to the production line for no purpose. Secondly, operators can order materials, when they have already placed an order for those materials, causing double deliveries. This is also due to the fact that the process allows for ordering materials freely with no check as to whether this material is really required. Thirdly, analysis has shown that there are big surges in demands at certain moments of the day, and the process does not plan material orders, prioritize or otherwise spread activity. This means that during the times at which activity is highest, lead time increases drastically.

5.2.2 Control

The issues that are caused by control mechanisms primarily center around the automated functions in and around the warehouse itself. PMW is divided into 3 zones, each of which has specific rules when it comes to allocation of pallets. This layout is not optimal, and has been determined in an iterative trial and error way. The zones that are classified as ‘exclusive’ can feed out pallets much quicker since there are no unblocking actions. However, when more zones are appointed to be exclusive, a less diverse combination of materials can be stored in the warehouse. For example, a single mixed lane can store up to 10 different materials, whereas 10 different materials would have to be stored in 10 separate exclusive lanes. The lack of insight into what materials are most important, means that a lot of potential lead time reduction is lost.

Secondly, shuffling of materials causes uncertainty amongst workers. Interviews have shown that some are under the presumption that shuffling blocks their material orders (interview 2) while this is not true (interview 1). The warehouse operator manually moves around pallets through the interface, whereas this specifically is something that is supposed to happen automatically. This causes the warehouse operator to spend valuable time doing a task sub-optimally, where the control system is supposed to do this in an optimally structured way without costing any additional labor.

In addition, layout and shuffling happen based on generic rules, even though it is known what materials will be used in the following week, and what pallets won’t be used. This means that each week pallets go into valuable positions in the warehouse, i.e. in front of mixed lanes or exclusive lanes, but may not even be used frequently in that week. Other pallets that will be used more intensively in a week can be put in the back row only to be moved forward once the material orders come through, possibly causing higher processing time at a time when PMW is already very busy.

5.2.3 Information

Information, or rather the lack thereof causes issues across the system. These can be categorized as follows. Firstly, information about current status of both PMW and the AGV in terms of occupancy, malfunctions and with that overall accessibility of these resources is not always entirely clear for operators, especially in the Senseo section. Vacuum lines have a line of vision to PMW, so they can see the output point and the interface from their workstations, whereas Senseo is located in a different hallway without such visual accessibility. The fact that operators do not have full insight into the status of PMW and the AGV can have the effect that orders are placed when the system is actually down.

Secondly, information flows to mechanics are not optimal. This aspect has two sides. Firstly, there is a relatively complex escalation ladder that is followed in case of malfunctions that need assistance of a mechanic. This falls largely under the process theme; however, it does concern information that is not readily available to mechanics, hence its categorization here. Thirdly, the fact that information is not available causes downtime of the system due to maintenance tasks to increase, as well as increase the man hours required to fix malfunctions.

Finally, counting of materials has to be conducted regularly, since the system is not capable of keeping track of inventory levels perfectly. This means that periodically, the inventory of each material has to be physically counted and checked against the material that is available 'on paper'. This takes up a lot of time, due to the fact that materials that fall in the 'mixed' category can be located anywhere in the warehouse, and therefore the coordinator lacks oversight of what materials might be found where.

5.2.4 People

A lot of issues that are discussed in this section emerge from interviews with operators and production employees. These employees themselves acknowledge their own behavior, as well as blame each other for several issues that occur in the delivery system. The causes that have human behavior as their root cause will be discussed here.

Interestingly, according to management, some of the issues that have been identified during interviews are being caused by behavior of the same employees that mentioned them. The most prominent examples will be discussed here. It is indicated that the AGV often has malfunctions and thereby causes delays. However, the AGV is highly dependent of its proper use and the state of its environment, meaning there should be no obstructions. This means that these man-made disruptions can quickly cause breakdowns. An example of this is an operator who removes pallets from the input/output point that are supposed to be picked up by the AGV. This means the AGV will not be able to find the pallet it was sent to pick up, and will thus fail in its task. Other forms of obstructions could be pallets that are not properly stored. Additionally, it is the operators that place double orders, causing delays in the delivery of materials, causing operators to double order.

The AGV malfunctions directly cause increased lead time. The malfunctions themselves can have different causes. These include operators moving pallets that are meant for pickup by the AGV, causing the AGV to be unable to retrieve those pallets. Additionally, paths may be blocked, or mechanical issues can arise causing malfunctions in the AGV. This means that the ordered pallets are delayed, which increases lead time and can also trigger operators to re-order materials, meaning those materials will be ordered double. Malfunctions in the warehouse itself can similarly be mechanical in nature, caused by either wear or by human behavior.

5.2.5 External

The irregularity of demand forecast causes several problems. Firstly, as discussed, materials are ordered based on the preliminary production plan, but this plan may be subject to change, causing materials to be ordered and delivered that will not be required that week, thus needlessly increasing stock levels and fill grade of the warehouse. This is caused by production plans changing, and material orders being placed before the final plan is available. In addition, the changing production plan is something that causes strain on potential solution design, since the plan is not set it will be more difficult to organize material flows strictly, since requirements of production may shift.

5.3 Functional resonance analysis

This section will discuss the process of warehousing and packaging at the KBU using Functional Resonance Analysis Method (FRAM). The focus in this analysis lies on three subsystems that experience issues, and where it would thus be useful to gain a better understanding of what activities cause these issues. Furthermore, it is valuable to see where functional resonance occurs, so that solutions might emerge that would otherwise remain hidden. The three subsystems are (1) the entry of pallets at the dock, (2) checking for and remedying malfunctions and finally (3) the ordering, using and returning materials for production. The retrospective FRAM is depicted in figure 17. This analysis is ‘retrospective’ since the system is already in use and the activities are being analyzed as they already happen. This allows for the analysis of the work ‘as done’ rather than only ‘as imagined’. Later, in the design evaluation a ‘prospective’ FRAM will be employed to analyze the proposed designs.

The nature of the described system of material storage and retrieval at the KBU is one where processes do not happen ‘as imagined’ consistently. This is due to malfunctions that force employees to improvise (interview 2) or time pressure that lets employees choose ‘quick’ work methods rather than the methods that are preferable (observations, interview 7) and other reasons. Examples are operators manually picking up pallets when the AGV is in malfunction, warehouse operator manually shuffling pallets to free up space when the automated system has not done this in time (according to him), or mechanics choosing quick fixes over durable solutions for mechanical issues.

5.3.1 FRAM activities

This section will describe the subsystems that have been analyzed using FRAM. As described in 3.3.2 FRAM describes 5 types of inputs, in the figures described by a C(control), T(time), I(input), P(prerequisite), R(resource) and O(output). Each activity typically transforms an input into an output under the influence of time, control, prerequisites and/or resources. Some activities exhibit variability, meaning that the quality of the output is not constant each time the activity is executed. Figure 14 depicts the subsystem ‘material intake’, figures 14 to 17 depict the subsystems. In the center of the analysis, PMW is depicted as a black box. This is since PMW does not have human activities inside it, but is for all these subsystems both the start and finish. Appendix 6 contains the full overview of the FRAM analysis and appendix 7 contains the detailed description of each activity including descriptions of all connections between the activities.

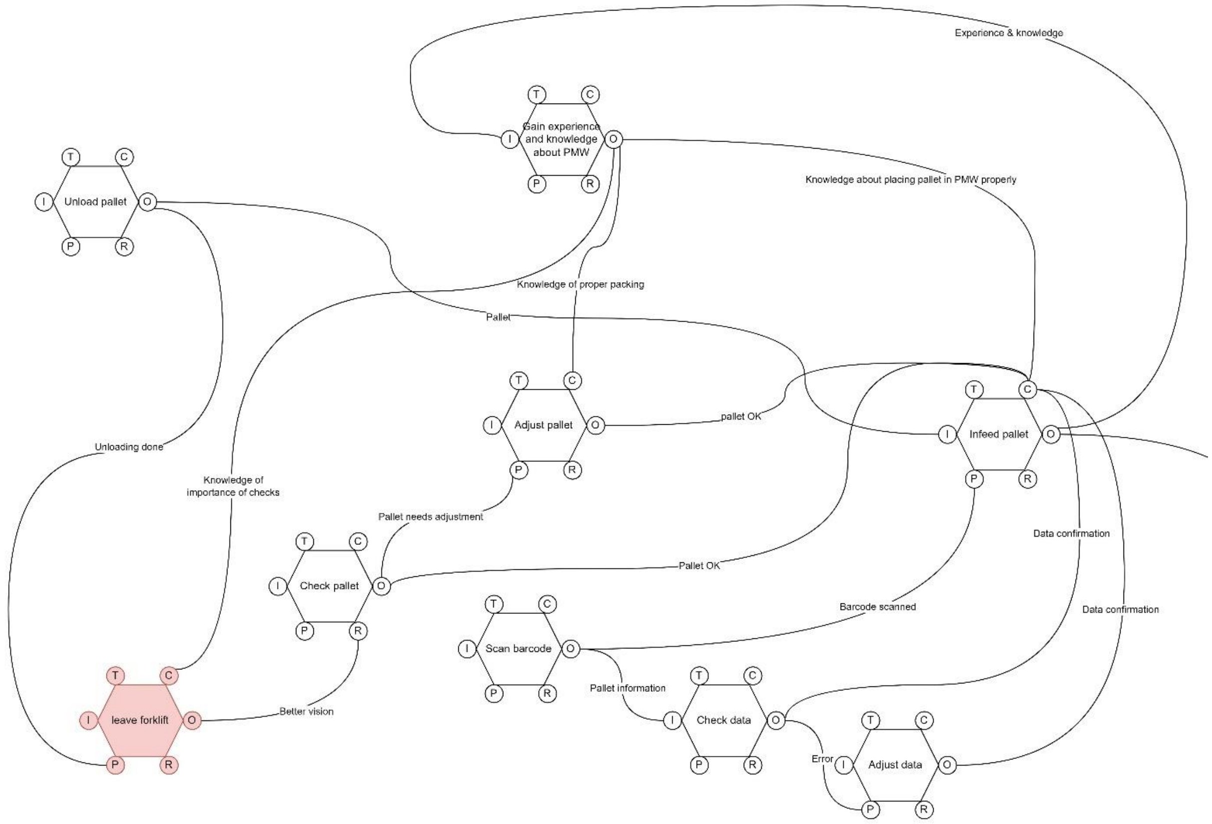


Figure 14: FRAM subsystem material intake

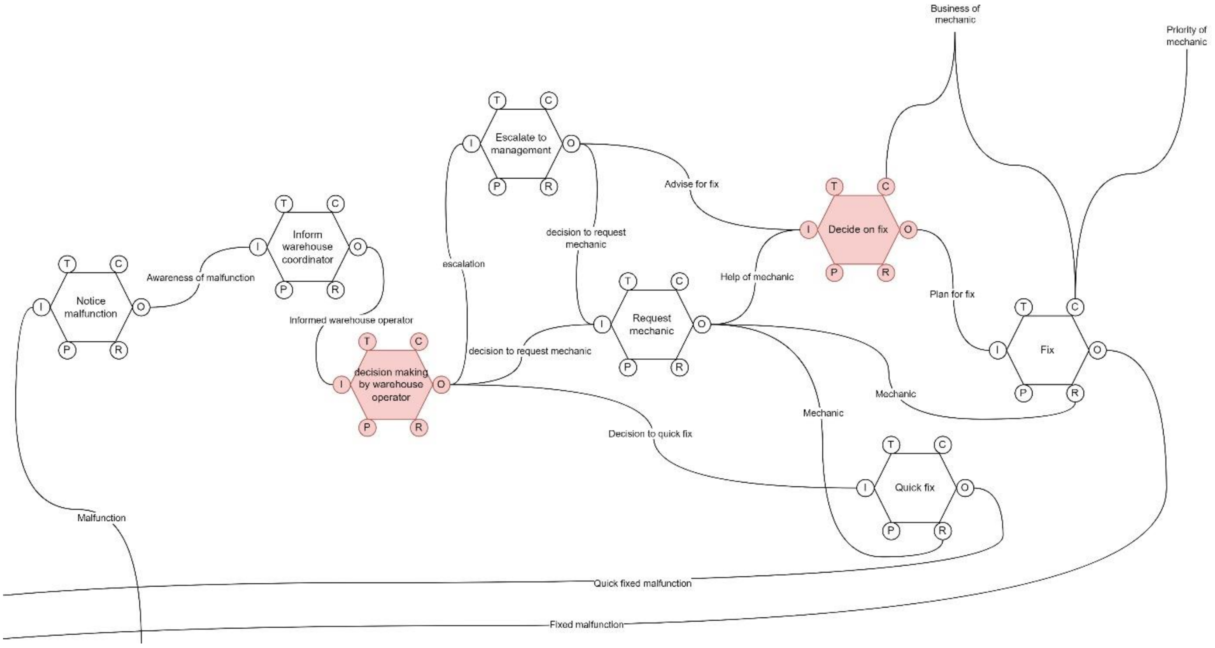


Figure 15: FRAM subsystem malfunction adressing

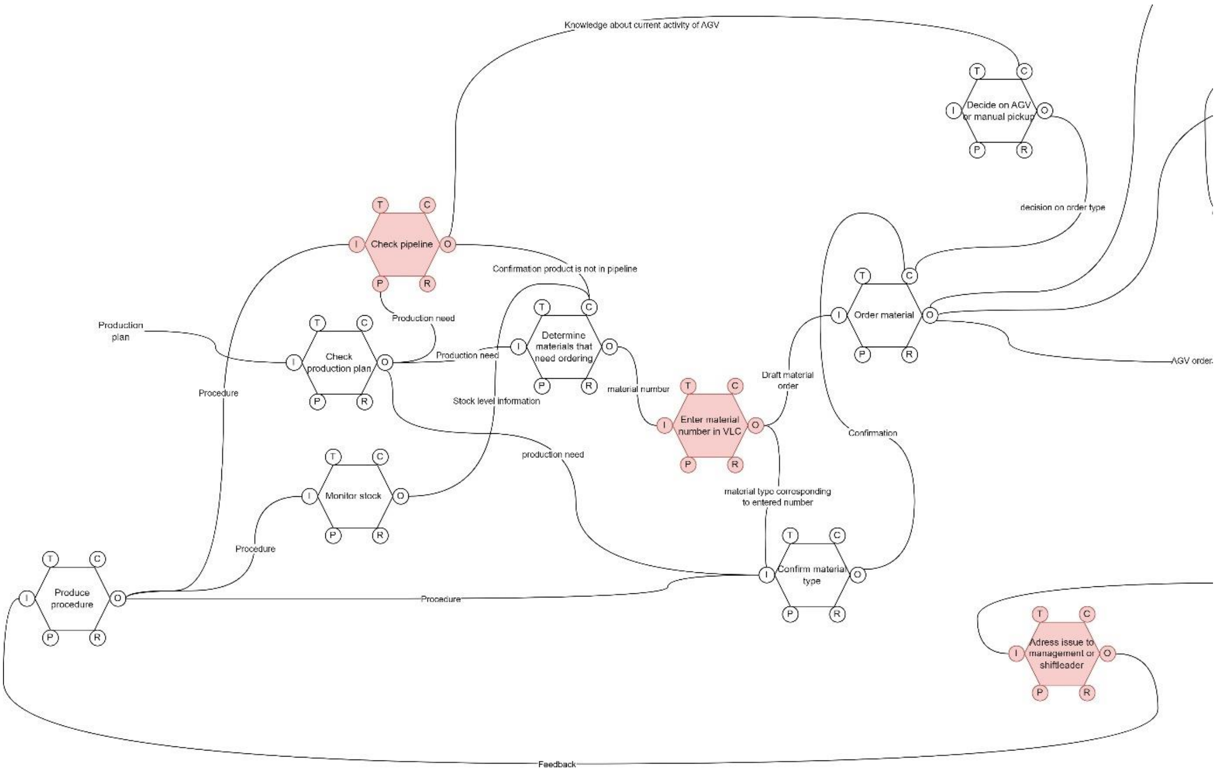


Figure 16: FRAM subsystem material ordering

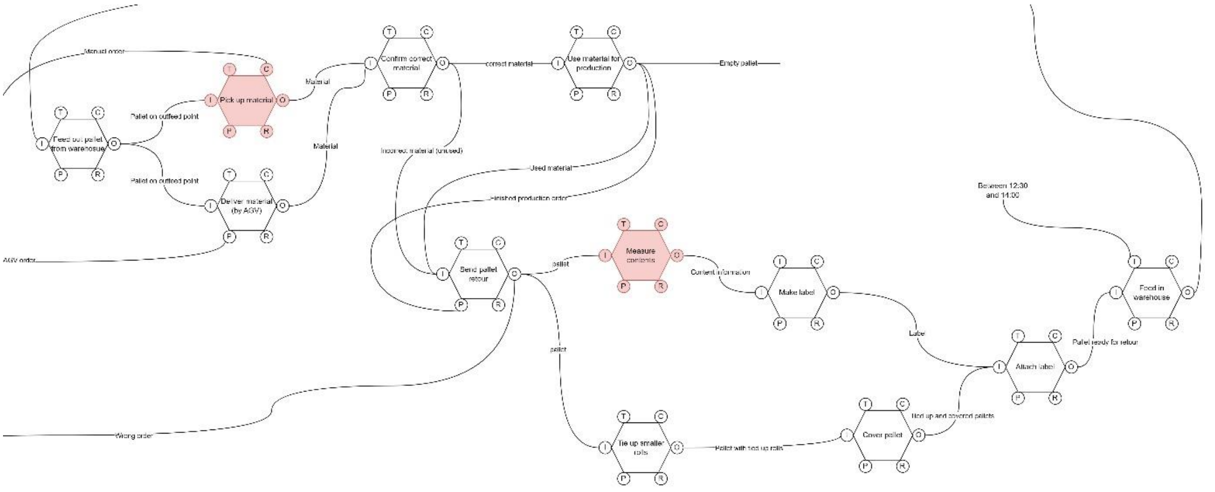


Figure 17: FRAM subsytem material returns

5.3.2 Variability

Each of the three subsystems have processes where variability can occur. The processes that experience high levels of variability are visualized in figure 17 in red. The variability will be addressed in the same order that the processes were described. The first place where variability occurs is in the subsystem where pallets are unloaded and placed into the warehouse. Here the FRAM shows that the warehouse operator leaves the forklift to perform the checks. In practice this does not always happen. That means that the visual checks carried out by the warehouse operator differ, and sometimes is of limited (because they check from their forklift). The FRAM shows that the operator learns from experience, and therefore knows how important the quality of the check is, which was acknowledged in interview 7 and during observation. However, this does not prompt them to always perform this check meticulously.

Variability also occurs when ordering materials. As mentioned, theoretically a feedback loop exists when wrong orders are placed and the warehouse operator should report this to the responsible party. However, as mentioned in interview 7, and observed in day-to-day operations this rarely happens. Issues that occur are usually not addressed by the warehouse operator, and therefore this function has significant internal variability. Sometimes the operator will report this, sometimes they will mention it but not insist on action, and often they will just let it pass. This can be attributed to routine, as the issues occur nearly daily, and therefore the warehouse operator does not feel like their actions have impact which means they largely ceased them.

Variability also occurs in checking the 'pipeline'. This is due to the fact that this is not a readily available feature in the VLC interface. That means that operators have to remember themselves what they ordered and communicate with shifts before and after them what they ordered. This causes a lot of variability in this function internally. It also means that knowledge about current malfunctions of AGV is not always clear and it might not be clear what products are underway to the operators' workstation.

When entering the material number, variability exist in the quality of outcome. This is due to the simple fact that typing errors can be made, which causes the wrong material to pop up.

Picking up of materials has a different kind of variability. Here it is not so much the question how the process is performed, but whether it is performed at all. Data (table 6 & 7) shows that materials are fairly often picked up manually, when the pallet was meant for the AGV. This means that the process can fire, without the input conditions being fulfilled.

Measuring materials suffers from variability in the quality of output. It often occurs that the measurements that are reported in the system do not correspond with the true contents of the pallet. The measuring happens by placing a ruler across the middle of a roll, and then confirming the contents using a conversion table. This allows for errors and therefore outputs are not always of the same quality.

When confronted with a malfunction, the decision-making process by the warehouse operator shows some variability. This comes in several forms. On the one hand the decision made might be of poor quality, on the other hand the decision can be put off meaning no action is taken at all. The decision can be of poor quality, since a DIY quick fix might be used, whereas this does not solve the problem. All together this means that this function has a lot of variability.

Variability can again occur when the mechanic decides on how to fix the problem. Due to factors such as time pressure and his own assessment of priority, he might choose other methods of fixing the problem than was desired by the material planner.

5.3.3 Functional resonance

Due to the variability identified above, functional resonance occurs in the whole system. Some processes have singular negative effects, other functional variabilities amplify each other's negative effects. The processes that cause the resonance, and the effects this has further on in the system will be discussed in this section.

The variability of checks of pallets at the dock has effects in other parts of the system. It means that a portion of poorly wrapped pallets remains undetected, and will be fed into the warehouse without adjustment. This can cause disruptions in the system when materials come loose and jam the conveyor in PMW. Effects of this are the start of the malfunction subsystem, and delay of material deliveries, both of which take place within the black box.

In ordering materials there is a lot of resonance. A combination of the effects of poor 'pipeline' checks, and the limited feedback that forms proper procedures has impact on multiple functions. As mentioned above, the warehouse operator does not consequently address issues to the proper people, meaning that feedback does not flow. The establishment of procedures therefore is based on false assumptions that work goes as imagined, also when mistakes have been made. The procedure that follows from this function is therefore not adequate, and this has implications on the functions: monitor stock, confirm material type and check 'pipeline'. All of these are vital functions, and the resonance of them has severe negative effects. Not monitoring stock properly makes it impossible for operators to order materials properly, especially at the start of their shift when they start ordering the materials they need. This is a known cause of many cases of double ordering. Confirming material type is also important, although it's not clear how often this causes problems, since it only becomes a problem when entering the material type in VLC is not done properly. When the wrong number is entered, and the check is not performed, the wrong material will be ordered. Checking the 'pipeline' is very important for multiple functions. First of all, materials in the pipeline should be counted towards the stock, and can have the same effects of double ordering. Secondly it is important in decision making for manual or AGV pickup. Without knowledge of activity of both PMW and the AGV it is not possible to make good decisions. When materials are ordered through the AGV when there is a lot of business in the system, it will cause crowdedness and delay. When the AGV is in malfunction and gets a material order anyway, the material will remain in the pipeline until the malfunction is fixed, further increasing the effects when the pipeline is not checked properly. However, when manual pickups are chosen when the AGV is available, valuable manhours are spent picking up materials, a task that could have been performed automatically by the AGV, which would have been cheaper and often also quicker.

The variability in the measure contents function causes problems in the system when poorly measured pallets are used for production. The material planner bases material orders on perceived inventory, however, when measurements are incorrect the inventory data will not correspond to the actual inventory. This can cause material orders for production to be too low when actual inventory is much smaller than data suggests. However, when data suggests that inventory is much lower than the actual inventory, it can also cause materials to be ordered that are not actually needed, causing fill grade of PMW to increase needlessly and uses up working capital for unused materials.

The functional resonance that flows from the variability in the malfunctions subsystem is easy to reason, but more difficult to assess. It is logical that quick fixes are less durable, and therefore will be a cause for new malfunctions quicker. In addition, malfunctions that are not addressed promptly, will remain an issue for a longer period causing further strains on efficiency. Malfunctions can occur in both PMW and the AGV: AGV malfunctions will increase lead time (due to the resonance explained above) and force workers to manually pickup materials. Malfunctions in PMW can have different characteristics. Some will take a single lane out of order, while others can break down the whole system. Due to these differences, the (negative) effects can also differ hugely.

5.4.4 Conclusion

The analysis of chapter 5.3 has shown the key activities that exhibit variability and the functions that suffer from the functional resonance. These are also the activities that are in need of redesign, since the (negative) functional resonance is what causes high lead time and labor waste. Concretely it means that either the variability must be stopped, or the functional resonance mitigated. The functions that need to be redesigned or are in need of mitigating measures for the functional resonance that flows from them are therefore: checking pallets, ordering materials, material returns and malfunction addressing.

5.5 Regression analysis

Lead times for materials in warehouse operations often exhibit significant durations. The lead time, encompassing the interval between order generation and the commencement of picking, as well as the time required for the picking process itself, plays a crucial role in operational efficiency. The former encompasses the waiting time required for VLC to initiate picking, caused by concurrent activities or malfunctions. The latter involves moving blocking pallets, pallet transportation to the input/output point, and, when necessary, AGV conveyance.

In order to obtain a quantitative understanding of the various factors influencing the lead time for packaging materials, a regression analysis is employed in this study. The analysis comprises two distinct models, one logistic and one linear, each serving a specific purpose. The logistic model aims to assess the time difference between order generation and the initiation of picking. This phase encompasses unpredictable elements, such as delays caused by malfunctions or queues. The linear model focuses on determining the time difference between the start and completion of the picking process. This latter phase is characterized by more deterministic factors, including the time required for unblocking actions, movement speed through lanes and lifts.

5.5.1 Logistic regression

To predict significant disparities between order generation and order initiation, a logistic regression model was utilized. The dependent variable in this model is the time difference between order generation and order initiation. The independent variables encompass the day of the week, the time of day or time category, and AGV (Automated Guided Vehicle) usage. Furthermore, this model exclusively incorporates orders pertaining to outfeeds.

Table 8: Logistic regression model

	Odds ratio	**Standard error**	**P**
Material type			
BG	Ref.	Ref.	Ref.
BX	0.28	0.06	<0.001
CV	-	-	-
FP	0.11	0.06	<0.001
Film	-	-	-

Safety	-	-	-
SHF	0.43	0.43	0.399
Storage (PAL)	2.90	3.36	0.356
Storage top labels	0.08	0.09	0.023
Stretch foil	2.80	1.70	0.091
SWB	0.68	0.40	0.521
TL	20.62	17.67	<0.001
WRI	0.39	0.18	0.041
WRO	-	-	-
Floor			
1	Ref.	Ref.	Ref.
2	0.44	0.23	0.166
3	0.33	0.18	0.038
4	0.37	0.20	0.061
5	0.35	0.19	0.053
6	0.20	0.11	0.005
7	0.45	0.23	0.126
Part of day			
10:00-14:00	Ref.	Ref.	Ref.
14:00-18:00	1.32	0.36	0.309
18:00-24:00	1.05	0.29	0.873
24:00-06:00	0.17	0.09	0.001
06:00-10:00	1.03	0.30	0.915

Note: “-“ = omitted due to low number of observations; ref. = reference group

Table 8 shows that the logistic regression model has indicated several significant determinants of lead time including two particularly informative determinants. First, the odds of extreme lead time are overall lower for all floors when compared to ground floor (1); and the odds are significantly lower among floors 3 to 6. This can be accredited to the fact that the ground floor stores mainly big pallets that are more prone to malfunction. Second, the odds of extreme lead time are significantly lower in the night hours (24:00-06:00) compared to the hours 10:00-18:00. It is likely that this has to do with the hugely reduced concentration of activity in those hours.

5.5.2 Linear model

The model employed to estimate the processing time of orders utilizes a multiple regression approach. In this model, the dependent variable is the difference between the time the order is initiated and the time it is completed. The independent variables consist of the distance traveled in lanes, the vertical distance covered across different floors, and the number of unblocking actions performed. This model provides valuable insights into the potential time savings that can be achieved by shuffling pallets expected to be ordered on a given day closer to the exit point.

Table 9: Linear regression model

Difference started-finished	**Coefficient**	**Std. error**	**P**
Floor difference	-.8376	9.28	0.928
Unblocking tally	44.444	12.34	0.000
Lane difference	-.5688	.65	0.384
Constant	137.33	39.54	0.001

The linear regression model in table 9 shows that unblocking actions have significant impact on processing time. This implies that each extra unblocking action causes processing time to increase by 44 seconds. However, there is no significant association between the difference in floors or lanes and the processing time. This means that the distance traveled does not contribute significantly to the processing time. Therefore, it is not logical to assume that moving pallets closer to the input/output point will reduce lead times in the system meaningfully, which is important to keep in mind when designing solutions.

5.5.3 Conclusion

Regression has helped give insight in priorities when it comes to reducing lead time. Using regression as an extension of the interviews and observations provides a more complete image of the working of the warehousing system, since any effects that are obscured by the automated processes can be seen by looking at the data using regression. Results suggest that distance is not as important in this system as literature has suggested. However, unblocking actions have huge impact on lead time and the final design should therefore focus on minimizing unblocking actions, which differs from the statements in interviews about distance and floor numbers being important. The lack of linear relation between floor numbers can be explained by the heavy pallets on the ground floor, as was stated in interviews 1, 6 and 7. Logistic regression suggests that extreme lead times are more likely in the busy hours, and less so in the night hours when activity is minimal. When designing allocation and shuffling strategies these are very important to keep in mind. Allocation should be tailored to minimizing unblocking actions. When determining the time when shuffling takes place, it is important that this is not in busy hours so that it does not contribute to extreme business and with that extreme lead times.

Chapter 6: Phase 3: design requirements

The system analysis has identified the key workings of the system as it is right now. In addition, the root cause analysis points to the aspects of the system that cause issues and are due for (re)design. This section will provide an overview of functions that are currently not present, or should be carried out in an improved manner. This will be the basis for the design alternatives. The design should accommodate the principal functions of the warehousing system, acknowledge the constraints and achieve the objectives.

9.1 Principal functions

Functions are 'those things a designed device or system is supposed to do' (Dym, 2013). The principal functions of the warehousing system at KBU are determined in this section. Based on the problem analysis, a selection has been made of those functions that are in need of redesign. The list is kept as concise as possible, and only the functions that are relevant for redesign are considered. These are largely the functions of the FRAM analysis that either cause a lot of variability, or suffer from functional resonance. Other functions that are described have come up through the system analysis and pertain to the automated parts of PMW and AGV. Allocation and shuffling are important since the root cause analysis showed that it is undesirable to have the warehouse operator do this manually.

6.1.1 Material intake

The intake of materials is in need of redesign. The problem analysis and FRAM show that intake of materials in its current form allows poorly wrapped pallets go into the warehouse where they can cause disruptions. Therefore, the first function that has to be designed is the intake of materials. This concerns the process where materials are transported from the truck, into the warehouse as well as the administration of these activities.

6.1.2 Allocation

The second function that has to be designed is the allocation of pallets in the warehouse. For this, the warehousing system needs a set of rules that determines what pallets are stored where. This has already been partially designed and implemented. The warehouse is divided into exclusive, mixed and low floor zones. The mixed zone contains different materials, whereas exclusive zones contain only one material per lane. To improve on this current situation, the design will have to specify whether or not more materials will have to be stored in exclusive lanes, and what the specification of each lane would be. For instance, low floor zones only contain a specific type of pallet, which has different dimensions and weighs more than regular pallets. These are therefore slightly more prone to malfunction, so for reasons of accessibility for maintenance these are always located on the ground floor.

6.1.3 Material ordering

The FRAM shows that the way in which materials are ordered causes a lot of problems, and therefore should be redesigned. The purpose of this function is to allow the operators to efficiently order materials in a way that allows them to get the components they need for executing their production plan, to the right production lines. Currently, ordering of materials works, but can cause unforeseen delays and can cause superfluous activity in both the PMW and AGV, as well as give both production and warehouse operators unnecessary work. The redesign should focus on reducing the frequency pallets are ordered without being used, thus decreasing lead time for those materials that are needed for production.

6.1.4 Shuffling

In the current situation several shuffling ‘strategies’ are in place. These have been described in chapter 5. However, the root cause analysis has shown several problems that occur with the shuffling itself, as well as problems that may be mitigated by improving the shuffling process. These include the time when shuffling commences, whether or not the production plan is taken into account and how, and whether shuffling should or should not be prioritized over regular material orders.

6.1.5 Material returns

Pallets of materials that have been ordered by production operators are not always used up completely. These pallets that still contain material have to be returned into PMW to make place on the production floor for other materials, and become available for ordering when needed for a different production later. To enable this, it has to be clear how much material has remained on the pallet. Currently, the warehouse operator measures this by placing a ruler that has indicators for amounts of material on each roll left on the pallet and adding up the amounts. This allows for a lot of human errors which are not systematically checked. Furthermore, the pallets that are returned are regularly not ordered according to procedure, and are therefore returned into the PMW unused. There is no clear feedback mechanism where the effects of this are returned to the responsible operator. Finally, when returning materials, it is not possible to order materials since there is no 2-way traffic in the conveyors. It is useful to see how and if this can be improved.

6.1.6 Malfunction addressing

Malfunctions occur on multiple points in the system, including the AGV and in all parts of PMW (i.e., loading dock, in storage lanes, entry point, conveyors or anywhere else). Malfunctions can incapacitate parts of, or the entire system. Therefore, it is useful to redesign the way in which malfunctions are monitored, communicated, escalated and fixed. Efficiency can be increased by informing people affected by malfunctions to mitigate impact and making sure malfunctions are dealt with adequately and swiftly.

6.2 Objectives

The objective of this design is to improve efficiency by reducing lead time for materials and reducing human labor required. The designs will therefore be tested on effects on these 2 factors. To further indicate what the detailed objectives are, an objectives tree has been constructed in figure 18. The objectives that are constructed in this analysis are based on the original problem statement that was presented in chapter 2.

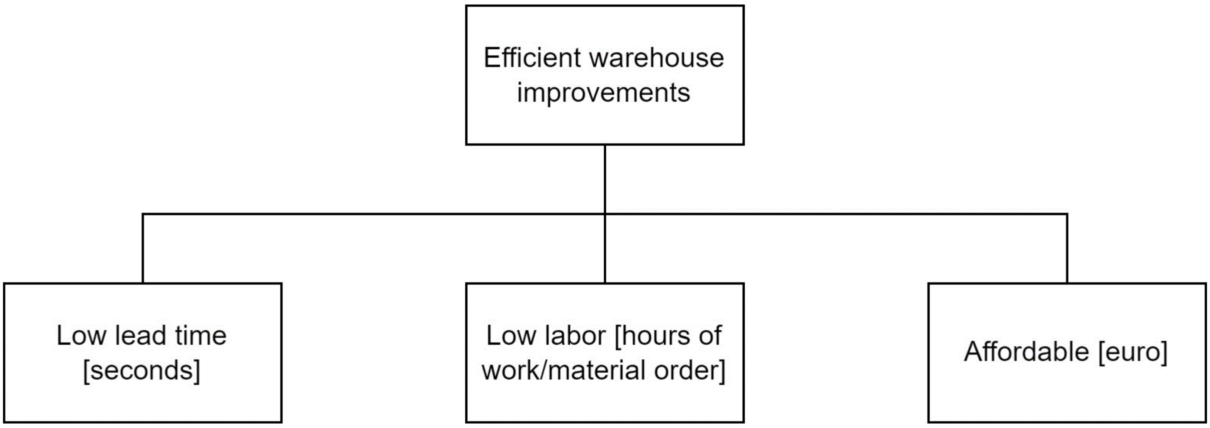


Figure 18: Objectives tree

6.3 Constraints

The constraints are the limitations that the final design needs to take into account. The way materials are ordered from suppliers should remain unchanged because this specifically concerns the flow of materials of suppliers into the factory. This is falls out of the scope of the current project and also has been specifically requested by the client.

Chapter 7: Phase 4: Design alternatives

Chapter 7 will build on the understanding of the system that was established in earlier chapters to define alternatives that meet the design requirements that were formulated in chapter 6. To do this, for each of the principal functions the alternatives are described. These are then merged into a morphological chart which will be used to define logical combinations of alternatives.

7.1 Description of alternatives per function

This section will describe the alternatives that are available for each principal function. These are based on brainstorming, have been suggested in interviews or are suggested by management.

7.1.1 Material intake

The function of material intake can be improved on in several ways. In its current form, the basic function works properly, namely, the pallets are fed into the warehouse quickly, however, interviews and the FRAM do show how problems can occur here. On the one hand, these problems are centered around the workload of the warehouse operator, and on the other hand, they center around the quality of the checkup of inbound materials.

The most direct way to mitigate the problem of the inaccurate checkups of inbound materials is to automate this process. This would mean that an additional machine is installed in the dock area that scans the pallets for any parts that are hanging over de edges of said pallets. This would take away the human factor in the checkups, and remove the need for the warehouse operator to thoroughly check the pallets before entering them. However, these options would require significant investment for the purchase of such a machine.

A far more easy and readily available solution would be to remove the barcode from the truck and place it somewhere that forces the warehouse operator to leave the forklift to confirm the material entry. This would still keep the human factor in the checkups intact, but would greatly improve the accuracy as the main cause of the inaccurate checks was identified as the warehouse operator not checking all sides of the pallets.

Another way to spur on the warehouse operator to do the checks properly would be to find a feedback mechanism that individually address shortcomings and recognizes highly qualitative performance. This could be done through a tally of the number of malfunctions in PMW that could have been prevented at the intake. This would however be difficult to implement, since the warehouse operator would likely have to give himself feedback this way. Therefore, this would only work if someone else was responsible for the PMW malfunctions.

7.1.2 Allocation

The current allocation rules in PMW are already fairly complex. However, tweaking the current process slightly can have significant impact on the system as a whole. The current system of mixed, exclusive and low-floor area's is logical. However, the exact distinction of what materials belong in what category can be optimized. There are multiple ways to do this, these have been discussed in the literature review, and adjusted to fit the JDE case.

A logical start is to make a ranking of the packaging materials in the KBU based on number of outfeeds per material number. This would determine what materials go into what allocation strategy. The ranking would have to periodically renewed to determine whether it is still relevant, or that some materials might need to be assigned to a different strategy. By doing this the a ‘class-based allocation’ strategy as presented by Roodbergen and Vis (2009) will be implemented. However, since the regression analysis showed that reducing distance is not beneficial to lead time, this class based approach will be used to determine what materials will go into exclusive lanes (described as dedicated storage by Roodbergen and Vis).

A second option would be to use a more dynamic approach. Here each week an similar analysis would be conducted. However, this analysis would be based on the production plan and the materials that are required for that plan according to PRS (production planning software). This would mean that each week, the materials that are used most often in that specific week will be identified as high ranking. It is important to note that the efficacy of this alternative completely depends on the stability of the plan. When the plan is changed after the strategy for that week is determined, the whole point of the ranking analysis will be forfeit.

7.1.3 Material ordering

Material ordering by production operators is perhaps the most troublesome function in the JDE packaging material system. Several avenues of improvement can be taken to mitigate the problems identified in the FRAM and root-cause analysis in different ways. Steps have already been taken to mitigate the wrong ordering. This included a maximum number of orders per hour; however, the problem still prevails and this is not a targeted measure, but a general one. This also affects the ability of operators to adjust, since they cannot order many materials at once anymore.

Alternatively, the material ordering process can be further automated. Currently, operators have to order materials by entering material numbers that they find in their production plans. However, by making the two systems communicate better, the materials can be preloaded into the ordering system, the ordering itself can be automated, and improvements can be made in the information that is provided by the system to operators.

The first option is to make a tab in the interface for each production operator, showing what materials are on their way to their workstation, to prevent them from ordering materials that have already been ordered. This would require a software update for VLC to show each operator what materials have been ordered.

Another option is to automatically establish material orders that are required for production. This would be somewhat more difficult since it would require the system to gain insight into what materials are present at the production location. PRS (planning software) has knowledge of what materials are required for each production, but simply ordering those materials automatically would not be helpful since materials that are already present would also be ordered. Although automatic ordering of materials would aid in further streamlining the processes, it would take away much of the flexibility of the factory. This option thus has 2 varieties, either the order is placed automatically, or a system is introduced that presents premade order suggestions. A premade order would then only have to be approved by operators.

This could also include a warning when orders are placed manually, that contain materials that, according to the production plan, are not required for that production line.

A fix for the double ordering could be a restriction on the number of orders in the pipeline. This would prevent operators from ordering while material is under way. However, it would also mean that it is no longer possible to order multiple materials at once when production of one product is done and another product has to be produced. To mitigate this, the restriction on the number of orders in the pipeline could be supplemented with the installation of a system that only blocks multiple pallets of the same material type in the pipeline. It is also important to note that this pipeline check is not restrictive in nature, but is simply to warn the operator before confirming the order. This could be done in the form of a pop-up in the software that alarms the operator that the material being ordered is already under way.

A restrictive alternative would be to block the orders, instead of providing only a pop-up warning. Due to the importance of the double-ordering design sub-alternative, these alternatives have been added to the morphological chart in table 10 separately from the material ordering design alternative.

A quick win that can be implemented regardless of other choices is to prevent vacuum operators from ordering in the very busy hours. This would amount to blocking all vacuum VLC accounts in the hours between 10:00 and 12:30. This would partially reduce the strain on the system in those hours and will not affect vacuum production efficiency directly.

7.1.4 Shuffling

The function shuffling has to be approached in several ways; in terms of what pallets have to be moved where and why, but also when this has to happen. Several moments that would be well suited for shuffling have been identified. The main parameters to consider are concentration of material orders, the likelihood of malfunctions and the availability of mechanics.

The first option that arises is Friday afternoon. Figure 9 shows that PMW gets significantly less busy around half past 3, and Friday is also the day that production ends for the week. This means that at a certain point in the afternoon, material orders will stop completely, but mechanics will still be available to service in case of malfunction. This would require shuffling to be reduced to a weekly event.

A second option would be to let the warehouse do the shuffling during the returns time slot. The time that the warehouse uses for returns is only a few minutes per pallet, and much of that is used for the measuring and printing of labels. Therefore, there is plenty of time left for the warehouse to do any needed shuffling in that timeframe.

Finally shuffling can be done in weekends. This, however, would mean that the warehouse would be very active without mechanics present to address potential malfunctions. Nonetheless this would provide a 48-hour window for shuffling, which is more than enough for any type or extent of shuffling to be done, and means that theoretically, the whole layout of the warehouse can be changed each week.

7.1.5 Material returns

The material returns form another function that works properly but not optimally in its current form. The FRAM has shown that there is a mismatch here between the function as imagined (by management) and the work as done (according to interviews and observations). This mainly lies in the fact that pallets are returned into the PMW by the warehouse operator without giving feedback to the people responsible for the returns of unnecessary (i.e., wrongly ordered) materials. There are several options to improve this process.

Firstly, the material returns contain a lot of unused pallets. Currently these are returned into the warehouse without any repercussions. An alternative would be to use the material number to identify the operator who placed the order for the material, and have this be recorded for individual scoring of operators. This would mean that the warehouse operator has to identify unused pallets, and make a note of this upon re-entry in the system. A software update would then be needed to install the check that identifies who ordered the pallet that was noted as unused upon re-entry.

Another option is to fully automate this feedback process. The pallets that are returned will be labeled and therefore the system should be able to see that pallets that have been ordered are being returned to the warehouse with identical contents. This should be recorded and the last VLC account to order that specific pallet has to be connected to this event. This will allow for individual feedback to be dealt and will provide clear long-term statistics as to who is responsible for poor performance of the team, and will incentivize all employees to work carefully, knowing that errors can be traced back personally, instead of only lead to generalized poorer team or factory performance.

A third option that would extend upon the second, is to have the AGV do all material returns. This would still require the warehouse operator to measure and tie up the used pallets, but could automatically perform the checks on unused pallets and keep score of those operators that perform poorly. Furthermore, this would increase time that the warehouse operator has for other activities, like counting of materials.

7.1.6 Malfunction addressing

Malfunctions in both PMW and the AGV need to be addressed adequately and to do so a clear protocol needs to be established. Several forms are available, these include technical and organizational solutions.

Andon is a visual system that signals malfunctions in real time using lights or other forms of alarm. This helps with communication of problems and quickly escalates issues to the problem owner. These are already installed on each production line, and could easily be implemented in PMW and on the AGV. The AGV already has light signaling, but this may be extended upon with digital alarms in VLC, informing all those affected of the malfunction.

A more restrictive measure would be to block orders in the affected areas altogether. Although this would prevent the piling up of material orders, it does take away some adjustment capacity for workers.

A last option can be described as status quo. The system that is described in FRAM is in no way the system that is imagined by management. The system was intended to have line leads of each production team be responsible for AGV and PMW. They are supposed to observe malfunctions and escalate these to mechanics, where in reality this is done by the warehouse operator. Re-iterating what the intended way to work is according to management by instating these line leads would create time for the warehouse operator to conduct their normal work and would ensure that there is always someone present who is responsible (note: the warehouse operators do not work in shifts).

7.2 Morphological chart

The morphological chart summarizes the means that are available for each function. This will allow the creation of different design alternatives. Table 10 contains the morphological chart for all the alternatives that were discussed above.

Table 10: Morphological chart

Function	Means 1	Means 2	Means 3	Means 4
Material intake	Automated scanner	Remove sticker	Warehouse operator feedback mechanism	
Allocation	Ranking	Periodically dynamic ranking	Weekly ranking based on production plan	
Material ordering	Automated through PRS	Suggestions through PRS + warnings	Status quo	Block vacuum in busy hours
Preventing double orders	Pipeline status tab	Automatic pipeline check warning	Restrictive automated pipeline check	
Shuffling	Friday afternoon	Returns time slot	Weekends	
Material returns	Warehouse operator returns and provides feedback	Automated feedback	AGV automated returns and feedback	
Malfunction system	Andon	Block VLC in case of malfunction	Reestablish work as imagined	

7.3 Design alternatives

The design alternatives will be established by using different approaches. The first approach will be one with a focus on organizational solutions, and minimal required investment. The second approach will be a design that focuses on technological improvements to reduce variability in the system. The third approach will construct a design that requires a lot of change, and will try to utilize the production plan more in order to improve efficiency. All three will be presented using the morphological chart and provided with a short description of the chosen alternatives and the thought behind each choice.

7.3.1 Design 1: Low investment

The first design will focus on organizational improvements that will mitigate the issues that were identified without the need for large investments or conceding flexibility in planning. Table 11 visualizes the design alternative that has been named: “Low-investment”. This design will likely not have large-scale improvements in efficiency as a result, but also will not require large organizational change and expensive investments.

Table 11: Low-investment

Function	Means 1	Means 2	Means 3	Means 4
Material intake	Automated scanner	Remove sticker	Warehouse operator feedback mechanism	
Allocation	Ranking	Periodically dynamic ranking	Weekly ranking based on production plan	
Material ordering	Automated through PRS	Suggestions through PRS + warnings	Status quo	Block vacuum in busy hours
Preventing double orders	Pipeline status tab	Automatic pipeline check warning	Restrictive automated pipeline check	
Shuffling	Friday afternoon	Returns time slot	Weekends	
Material returns	Warehouse operator returns and provides feedback	Automated feedback	AGV automated returns and feedback	
Malfunction system	Andon	Block VLC in case of malfunction	Reestablish work as imagined	

The proposed design would make use of the current system of material intake, with the addition of an individual feedback mechanism that would help solve the problem of poorly wrapped pallets being allowed into the warehouse. Allocation would happen based on a simple ABC analysis but will not update itself periodically and also will not use the production plan as basis. This would mean that production planning can keep happening as it happens now, since there would be no additional impact of late-stage changes in the plan. Material ordering would happen the same way it happens now, but only with the addition that the operators will gain the ability to check what materials are underway to their location before placing orders. This would help solve some of the problems with wrong ordering, but certainly not all. Shuffling will be planned daily in the returns time slot, so that it does not disturb regular material ordering. Returns would also happen the same way they happen now, but with the addition that the warehouse operator will provide feedback to responsible shift leaders when pallets are returned unused. The warehouse operator will no longer be responsible for malfunctions in PMW and AGV, and these will be addressed solely by shift leaders that are in charge at that moment.

7.3.2 Design 2: Technological solutions

The second option is to focus on investing in technological solutions to further automate processes in and around PMW thus increasing efficiency. In table 12, the morphological chart is again provided, this time marked with the design alternative that has been named “Technological solutions”. This design will focus on using technological solutions to improve efficiency, but will therefore also require financial investment.

Table 12: Technological solutions

Function	Means 1	Means 2	Means 3	Means 4
Material intake	Automated scanner	Remove sticker	Warehouse operator feedback mechanism	
Allocation	Ranking	Periodically dynamic ranking	Weekly ranking based on production plan	
Material ordering	Automated through PRS	Suggestions through PRS + warnings	Status quo	Block vacuum in busy hours
Preventing double orders	Pipeline status tab	Automatic pipeline check warning	Restrictive automated pipeline check	
Shuffling	Friday afternoon	Returns time slot	Weekends	
Material returns	Warehouse operator returns and provides feedback	Automated feedback	AGV automated returns and feedback	
Malfunction system	Andon	Block VLC in case of malfunction	Reestablish work as imagined	

This design makes use of technological solutions where possible thus eliminating most of the variability that is caused by human errors in the current system. The checking of materials at the dock will happen using a new scanner. This will check the pallet thoroughly for any plastics or other parts that are out of bounds of the pallet, thus preventing malfunctions from occurring once the pallet is already in the warehouse. Allocation will happen according to an ABC analysis, which will be periodically performed and automatically adjusted in the settings for VLC. This would require new software to be developed. Furthermore, PRS (planning software) and VLC (warehousing interface) need to be integrated. This will enable the automated generation of material orders for production operators. By using the production plan and the corresponding bill of materials from PRS, VLC can establish a suggested material order which only has to be approved by the production operator. This will fully prevent the operator from ordering wrong materials. Moreover, VLC will have built in warnings when materials are manually ordered that do not correspond to the production plan, or materials that are already in the pipeline. This will greatly reduce the number of wrong pallets being ordered thus greatly reducing the amount of work that the warehouse operator has to do when returning those pallets as well as reduce the activity in PMW for the retrieval and storage of those pallets. Pallets that are still ordered wrongly, will be returned and an automated feedback system will be used to record what operators are responsible for these orders. This will enable feedback based on personal performance rather than team performance. Shuffling in this case will happen according to the existing rules, but will happen at a set moment every day during the returns time slot. Finally, malfunctions in PMW and Kitt will be addressed using the Andon system that is already in use for the production lines. This will include signal lights, and a digital warning in VLC warning the operators that are affected by the malfunctions for consequential delays.

7.3.3 Design 3: Production planning integration

The most far-reaching design alternative will be the use of the production planning for the week as a basis for most processes and strategies. In table 13, the morphological chart is again provided, this time marked with the design alternative that has been named "Production planning integration". This design will be able to provide gains in efficiency, but will also impact the flexibility of the production facility as a whole.

Table 13: Production planning integration

Function	Means 1	Means 2	Means 3	Means 4
Material intake	Automated scanner	Remove sticker	Warehouse operator feedback mechanism	
Allocation	ABC	Periodically dynamic ABC	Weekly ABC based on production plan	
Material ordering	Automated through PRS	Suggestions through PRS + warnings	Status quo	Block vacuum in busy hours
Preventing double orders	Pipeline status tab	Automatic pipeline check warning	Restrictive automated pipeline check	
Shuffling	Friday afternoon	Returns time slot	Weekends	
Material returns	Warehouse operator returns and provides feedback	Automated feedback	AGV automated returns and feedback	
Malfunction system	Andon	Block VLC in case of malfunction	Reestablish work as imagined	

At the material intake, little can be gained from using the production plan. Here the same method will be used as in design 2, an automated scanner. Allocation can happen based on a weekly established ABC formula. This one not based on average number of orders of materials, but based on the expected orders per material for the next week according to the production plan. This will very precisely estimate the number of orders per material thus maximizing the number of orders that can be fulfilled through exclusive lanes each week. Material orders can be fully automated based on the production plan. This will require the introduction of a warehouse management system that also keeps track of pallets that are on the floor near each production line, but then it will be able to fully automatically order materials, thus removing the probability of human error in ordering. The ordering of materials manually will generally not be necessary anymore, but in case manual ordering is required, the system will block the ordering of any materials that are already on the floor or underway. Shuffling will happen on a weekly basis, due to the allocation strategy. The best moment for this is Friday afternoons, since that is when the production plan is final and PMW is least busy and has the lowest fill grade, making it easier to move the pallets that are left to their new locations. The AGV will be fully automated to return pallets as well, making the work of the warehouse operator here redundant, freeing him up for other tasks.

Chapter 8: Phase 5: Design evaluation

This chapter evaluates the design alternatives regarding their performance on the objectives that were established in chapter 9. The evaluation was done by conducting a prospective FRAM for each design. This means that the functions are described as they would perform after implementation. This will allow for identification of variability that will either be solved or remain as it is now when compared to the retrospective FRAM that was developed in chapter 7. To indicate the prospected difference between the current situation and the envisaged situation, the expected difference in variability is colored in orange and green. Orange indicates that variability will partly be reduced, green means it will be fixed completely. Moreover, any gains in lead time were analyzed using the models that were established in chapter 8. Finally, the properties of each design were described where possible using the data from PMW.

8.1 Design 1

The "Low-investment" design that focuses on low investment solutions can solve some of the issues that were identified in the FRAM. Figure 19 depicts the work as imagined after implementation of design 1.

As figure 19 indicates, not all functions that cause variability and negative functional resonance are fixed. However, given the limited investment and change required, this design yields reasonable results. The intake of materials will be slightly improved, since a reliable feedback mechanism to the warehouse operator will ensure him being keen on preventing poorly wrapped pallets from entering the warehouse. However, the proposed system will still allow poorly wrapped pallets to go through, so the problem will not be fully addressed.

In this design, malfunctions will be addressed by the shift leader (again) as it was intended originally. This will decrease the variability in the decision making based on malfunctions. First of all, there is always a shift leader present which means that the malfunctions can now always be addressed immediately. Problem ownership will be very clearly in the hands of that shift leader, which means that they will be the only one responsible for fixing it. Any problems that are ongoing can be transferred to new shift leaders meaning that there is more general awareness about malfunctions. This would require some additional training, given that shift leaders have been known to leave malfunctions instead of addressing them (interview 3).

Checking materials in the pipeline will be made easier for operators when ordering materials. The proposed system will however still require operators to be proactively checking before ordering, something they have proven to not always do carefully. Still this improvement can prevent part of the wrong orders by informing operators better.

Material returns will be conducted by the warehouse operator in the same way as is currently happening. Feedback should be provided by the warehouse operator, however, in the current situation this is also supposed to happen but does not. Therefore, it is not likely that the variability in the function 'address issue to management or shift leader' will reduce much.

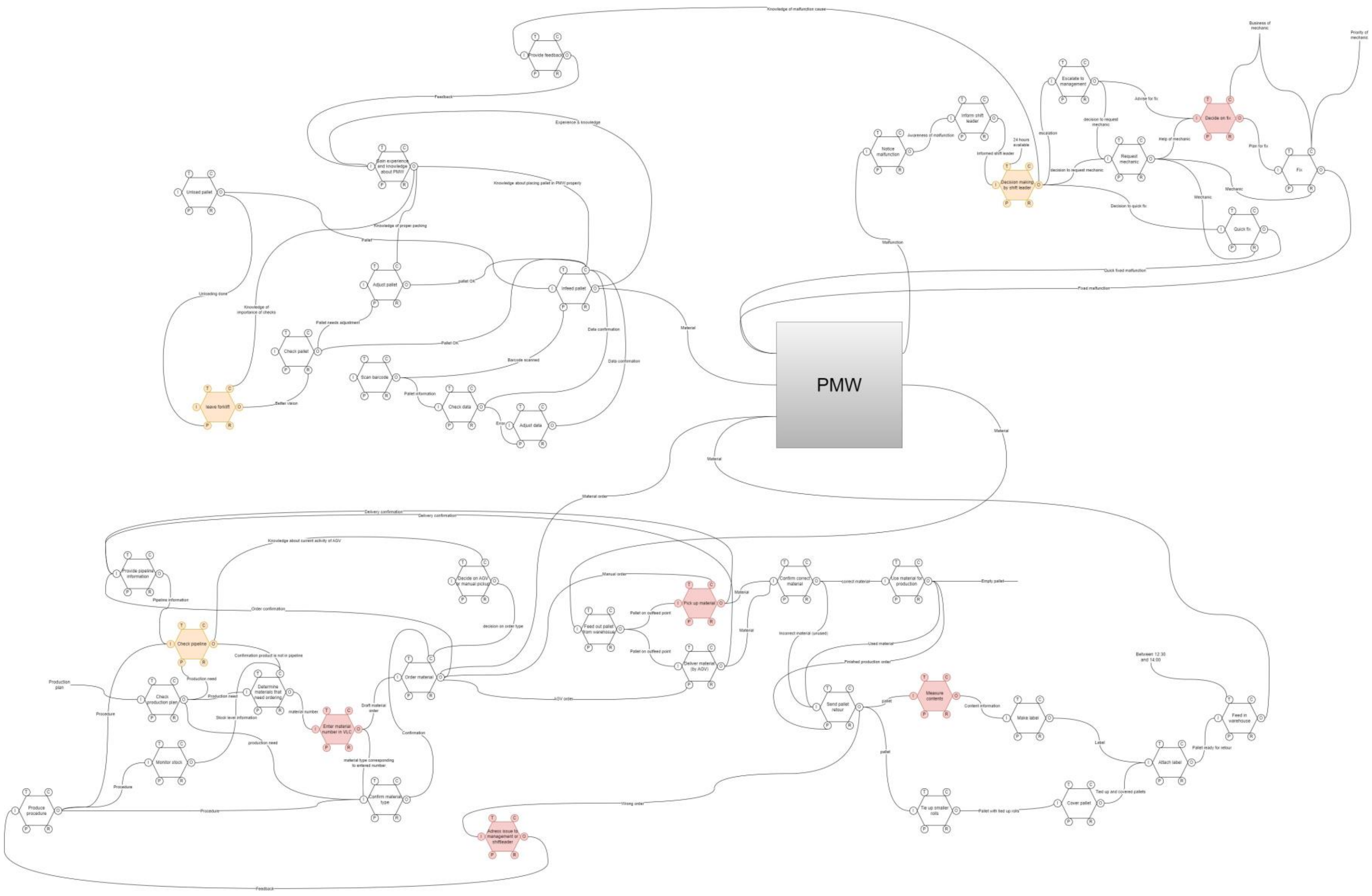


Figure 19: Prospective FRAM based on design 1

Allocation based on a ranking analysis can bring some improvement in efficiency. Analysis has shown that currently, several items are allocated through an exclusive strategy that has a limited number of movements per week. Whereas others are allocated using mixed entry, which are actually in the top 20 fast movers. Adjusting this can significantly and permanently reduce the number of unblocking actions that are required and are currently causing a lot of extra lead time. Appendix 3 shows a list of materials, their current allocation rules and the number of movements in and out of PMW over a seven-week period as well as a proposed division of allocation strategies. The list of materials and their numbers of movements clearly shows that there is a lot to be gained by using an updated selection of exclusive and mixed strategies, since many pallets are allocated to exclusive lanes and remain almost untouched, whereas some move through mixed lanes and are moving often. Note that low-floor entries will not be changed, due to the risk of malfunctions in these pallets, as identified by mechanics.

Table 14 shows the envisaged results when exclusive allocation would happen based on the ranking of the number of movements per material type, rather than the current allocation rules. It would mean that over the seven-week period that is analyzed here, 292 additional movements (6.2% of total movements) would happen based on exclusive allocation. This omits the need for making more lanes in the warehouse ‘exclusive lanes’, as having more exclusive lanes would reduce capacity. Since mixed retrievals cause approximately 2.99 unblocking movements, and an unblocking movement costs 44 seconds in lead time according to the linear model, it means that these 6.2% of total movements will reduce lead time by an average of 132 seconds. To generalize, this would mean that the average lead time would be reduced by 132*0.062= 8.2 seconds.

Table 14: Movements per allocation strategy

Strategy	Current #	Current %	Envisaged #	Envisaged %
Exclusive	2830	60.4	3122	66.6
Low Floor	456	9.7	456	9.7
Mixed	1402	29.9	1110	23.7
Total	4688			

8.2 Design 2

The “Technological solutions” design does a better job at reducing variability and in particular reducing negative functional resonance. Material intake happens the same way as in design 1, but with the addition of a scanner that can prevent more loose pallets from getting through. This translates to FRAM (figure 20) as causing no reduction in variability, but it does reduce functional resonance in the ‘check pallet’ function (hence this function was colored green). It means that even though no additional effect on the function ‘leave forklift’ was achieved, the effects were mitigated by making the check no longer heavily reliant on this function.

Malfunctions will be addressed the same way as in design 1. Yet will additionally use an ANDON system. This system will allow for the use of signaling lights, both physically on the affected machines and digitally in VLC to warn operators that certain parts of the system are out of order. This will also automatically escalate to mechanics, since they also see the ANDON notification. The complexity of the escalation ladder will therefore become redundant, and it will be very clear what has to happen and who is responsible in case of malfunction. ANDON alerts about either PMW or Kitt will moreover be expanded upon by also alerting workers about malfunctions through VLC alerts. This will signal to operators whether certain parts of either PMW or Kitt are unavailable. This should block orders from being placed on parts of the system that are out of order, which will prevent an accumulation of orders that will re-appear once systems are back online. This will also stimulate operators to use other parts of the system.

PRS will provide the production plan to VLC. This will allow for two major improvements that will reduce the variability in the FRAM. Firstly, orders can be generated automatically based on the production plan. This will reduce the possibility of typing errors in material orders. Secondly, when products are ordered that are not in the production plan, VLC can give a warning to the operator. Operators will still be able to order materials autonomously, so it cannot be guaranteed that double orders won't happen anymore. The automatically generated orders can keep track of pipeline materials however. Therefore, the variability of checking pipeline will reduce significantly, but not completely.

The automated feedback will ensure that there is more accountability in the system for the operators that are responsible for wrong orders. Especially with the improvements described concerning order generation and checks, operators should be well equipped to make few mistakes. Those who still do can be easily identified in the new design.

When comparing periodically dynamic allocation to the static allocation strategy described in design 1, the difference will be none. However, it is likely that after several months material portfolio's will shift (for example, two fast moving products have changed in May 2023). This would gradually reduce the efficiency of the static strategy. Hence the determination of what materials are exclusive has to happen periodically (i.e., the periodically dynamic allocation), which will cause a big need for shuffling all materials whose strategy changes, but also ensures more durable efficiency.

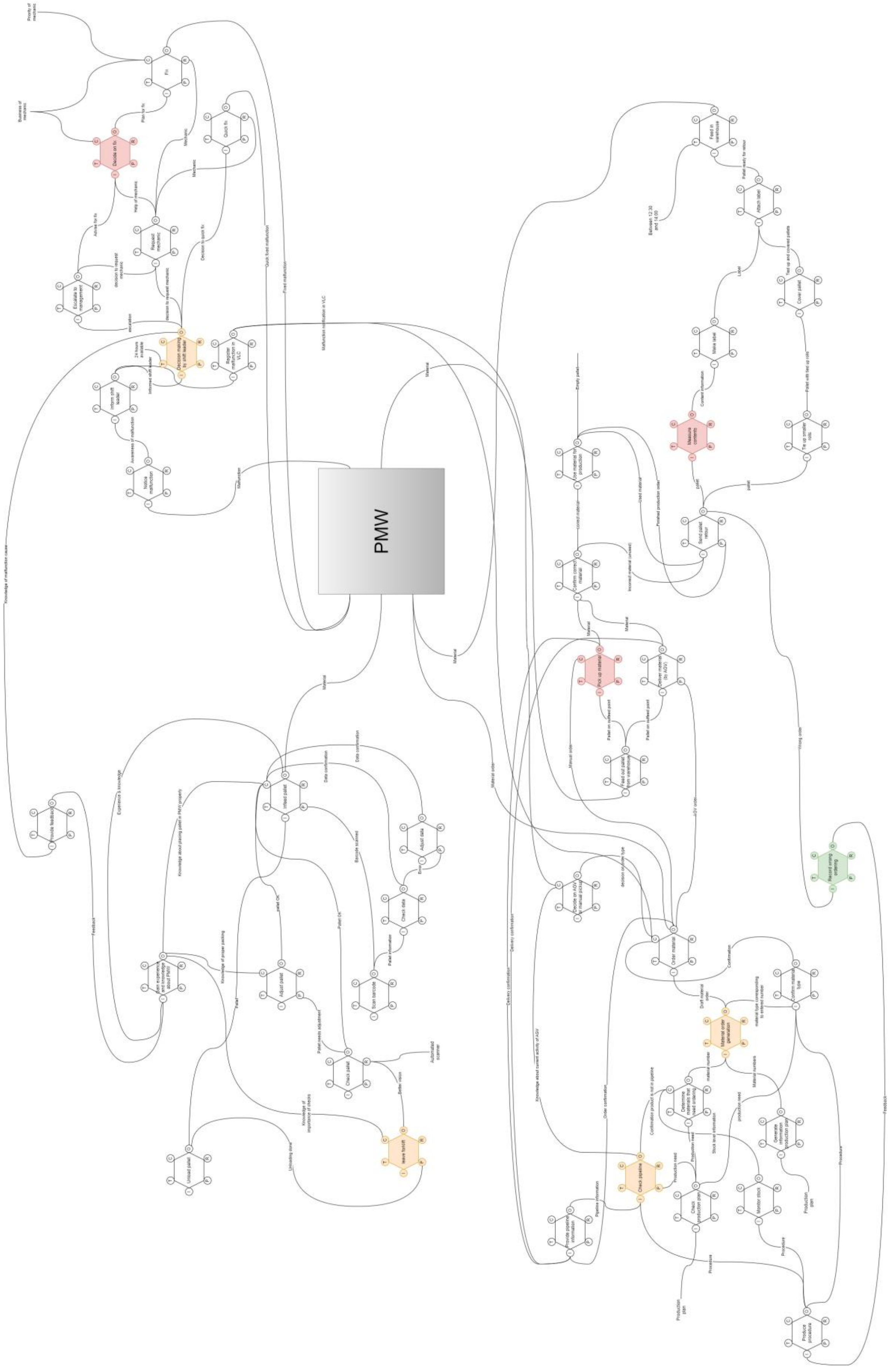


Figure 20: Prospective FRAM based on design 2

8.3 Design 3

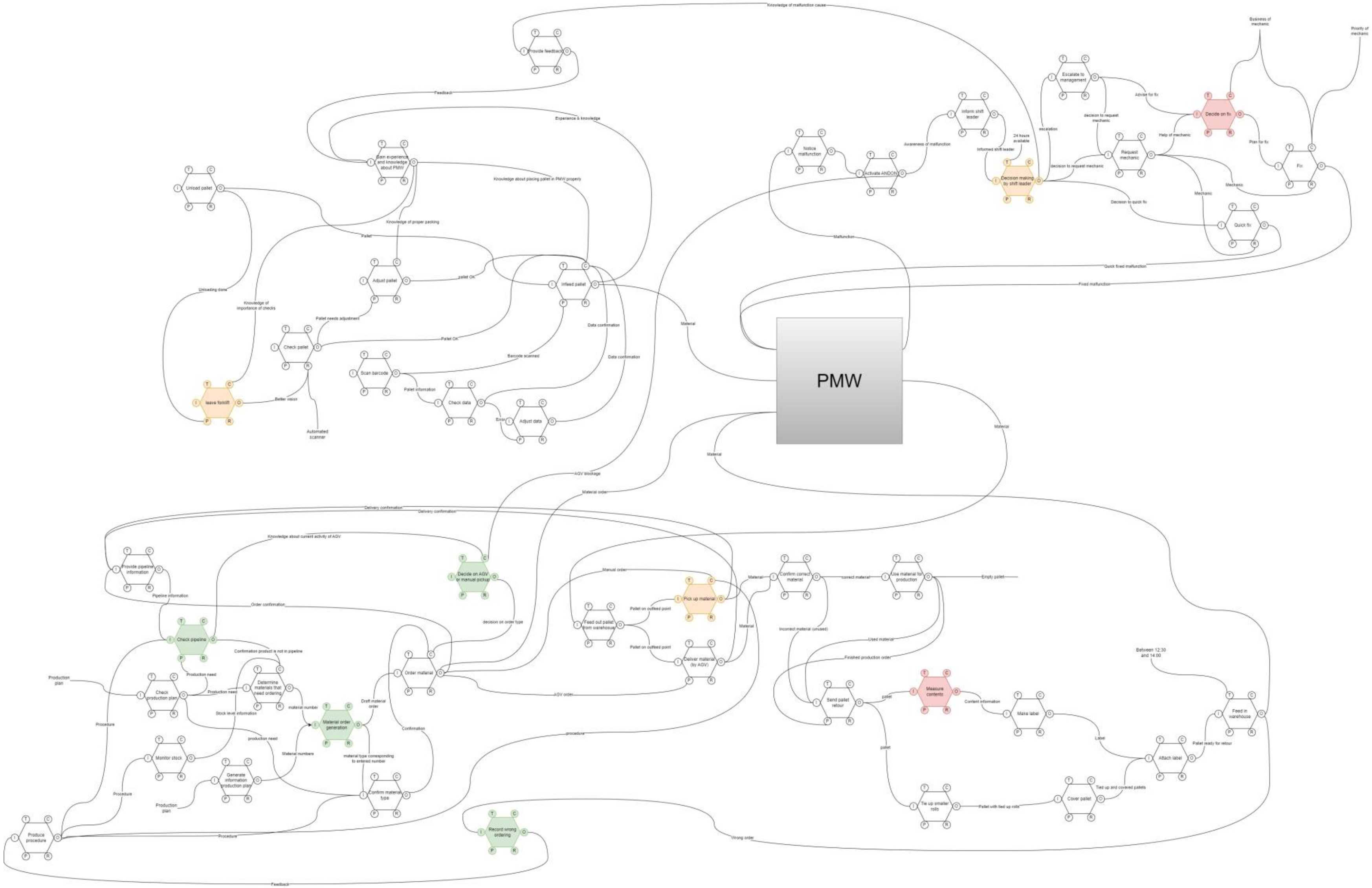
The final design, “Production planning integration”, will prove most complex to implement, but also yields the largest wins in terms of reduction of functional resonance. Implementation of this design requires the production plan to be set in stone a week in advance, and does not allow for last minute changes.

The differences between this design and design 2 lies in the more restrictive nature of means. This results in nearly all variability to have been removed in the FRAM (figure 21). As a start, malfunctions will be communicated by the shift leader through VLC to signal to operators whether certain parts of either PMW or Kitt are unavailable. This should block orders from being placed on parts of the system that are out of order. This will prevent an accumulation of orders that will re-appear once systems are back online, and will also stimulate operators to use parts of the system. This would mean that it becomes impossible to order materials as long as malfunctions are active. This will completely rule out the possibility of accumulating orders during malfunctions.

Material orders can be fully automated based on live status of material stock on the production line and the production plan. Good implementation of this solution will completely erase all ‘wrong orders’ and will ensure that no more returns have to be made needlessly.

Regular material returns will be executed by the AGV in this case, which will greatly reduce the labor required for this function. In addition, this will allow for shuffling to be planned around the moments of material returns, since the system will be able to plan returns and shuffling movements automatically, and will not be dependent on the moment when the warehouse operator decides to perform the returns.

Figure 21: Prospective FRAM based on design 3



The potential gains from creating allocation rules based on the production plan is fully dependent on the production plan of that week. In general, production plans that have high use of certain materials can gain a lot by dynamically changing the allocation rules, since that will result in higher percentages of material orders being fulfilled through exclusive lanes. When the production plan is very 'wide' and has a broad portfolio, the effects will dampen. An example is given in table 14, where, as an example, week 23 of 2023 was analyzed. Interestingly, the margin here is smaller than that of a broader sample, meaning that in week 23 the current allocation strategy fit the actual orders exceptionally well.

Table 15: Movements per allocation strategy week 23

	Current strategy		**Proposed strategy**	
	Occurrence	**Percentage**	**Occurrence**	**Percentage**
Exclusive	343	61.5	357	64.0
Low floor	52	9.3	52	9.3
Mixed	163	29.2	149	26.7
Total	558		558	

8.4 Overview

The alternative designs discussed in this chapter each yield different levels of results in terms of efficiency. However, the costs of each design also vary, both on an investment level and in terms of difficulty to implement the solutions. Figure 22 visualizes the amount of investment required, and the difficulty of implementing the solution in the organization. This means that solutions that have both low investment costs and require little change, are so called 'quick wins'. Solutions that are more difficult to implement require a solid plan for implementation and the solutions that require expensive investments have to yield good returns. Solutions that are both expensive and difficult to implement have to yield large returns to be worthwhile.

In practical terms, this means that design 1 is already worthwhile, even with only limited gains in lead time reduction and efficiency. Design 2 would require some more efficiency improvements and design 3 is only to be considered when the expected results are very large and the organization is willing to change a lot in its current functions. However, the prospected results from design 3 are the only that truly fulfill the objectives, removing nearly all functional resonance and ensuring minimum lead time. Therefore design 3 is selected.

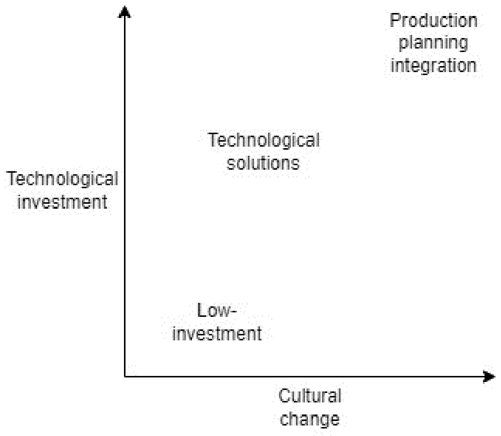


Figure 22: Costs per design

8.5 Communication

This section will discuss the most important design considerations for the chosen design. As discussed in section 4.4 the people with most impact on the system, and therefore who are most key to be well informed about these changes are operators of both vacuum and Senseo, the material planner, the warehouse operators and central planning. For each of these the most important message will be described here.

8.5.1 Vacuum operators

For Vacuum operators not much changes, the only real change is that there is no longer any need for a dedicated material man to restock the buffers every day, this can be done automatically. The orders still have to be send and due to new restrictive settings in VLC this will be done in non-busy hours to ease pressure on the system in the most busy hours. In practice this means that the vacuum operators lose some power in the new situation.

8.5.2 Senseo operators

For Senseo operators a lot changes in their daily activities. Due to the proposed improvements, material ordering is nearly fully automated for them. It is important for them to know that when they do order something, any wrong orders will be registered leading to impact on their individual performance. Furthermore their reduced responsibilities in material ordering will allow them to operate more production lines at once.

8.5.3 Warehouse operators

Warehouse operators are responsible for day-to-day running of PMW and need to understand the proposed changes well. The changes can only be successful when they do not manually shuffle pallets anymore, since the allocation rules will not be effective when this happens. Furthermore they have to stop intervening in malfunctions of the AGV so that is remains clear who is responsible for this (shift leaders of Senseo operators).

8.5.4 Material planner

The material planner does not have to change much in her daily activities. However, it is important to note that she has final responsibility for PMW and so has to check and monitor whether the proposed design is well implemented. This will mainly pertain to checking whether the warehouse operators do what is necessary of them, and do not fall back into old habits. It is known that they tend to manually change much in PMW, but for the efficiency of the new strategy it is key that they do not and therefore it is important that someone is responsible for enforcement.

8.5.5 Central planning

Central planning is instrumental to the success of the proposed changes. The changes are largely build around a stable production plan, so they have to be very punctual in providing the weekly plan at the moments described in figure 12. It has to be made clear to central planning that these improvements can greatly increase efficiency of the KBU and will therefore benefit the company as a whole. Changing the plan will negatively impact efficiency and is therefore highly undesirable, and this is the message that has to be communicated to central planning.

Chapter 9: discussion, reflection and conclusion

This chapter discusses the results of this design project. The results are discussed critically and compared to literature. The shortcomings are discussed and the opportunities for future research are described. Finally, the results of this thesis will culminate to an answer to the research questions in the final conclusion.

9.1 Discussion

This project aimed to design a warehousing strategy and processes in order to improve the efficiency in the KBU. This study provides a unique take through its qualitative approach. Current literature on AVS/RS bases its findings on large scale data driven studies, and thereby often overlooks the crucial component of the human factor in warehousing. For instance, Manzini et al. (2016) established a detailed model to determine travel-time and distance in AVS/RS systems and Yetkin Ekren (2021) optimized for cycle time and energy consumption. The current study has similarly identified various modes of lead time reduction, as largely supported by data, but has additionally found root causes identified by the stakeholders themselves. The interaction between humans and technology in the warehouse has proven to be the cause of frequent and extreme lead time increases, meaning that these are as important as determining models to improve travel time and distance. This holistic approach has allowed to impact multiple factors in the system, human labor requirements by reducing needless actions, better information provision for stakeholders and lead time reduction by planning the use of the system better.

Interestingly, this study has attempted to determine the relationship between travel distance and lead time and did not find a significant relation. This means that the effect of travel distance is so marginal in this case that it cannot be measured, even though many studies evaluate class-based storage strategies, placing the fastest movers in zones closest to the output point to minimize travel distance (Ekren et al., 2015). Likely, this is due to the relatively small scale of the JDE PMW, and a larger impact of human factors that were the main focus of this study. An interesting avenue for future research is to better evaluate what the critical size is for a zonal approach to be effective.

Also, a few of the key solutions presented in this study have also been found in previous studies (Bogue, 2017). This includes continuous information about the robot’s functionality in an interface, and feedback and collaboration between mechanics and workers to identify problems. Thus, strengthening the likelihood that the proposed solutions will in fact have an impact and may even be generalizable to similar warehouses.

This study is aimed at mitigating a wide range of smaller problems and issues that interfere with the overall performance of JDE PMW After implementing solutions for the identified issues, it will become possible to look at optimizing the system that emerges. In its current form this would be difficult, since lead time and efficiency are influenced by all the smaller problems. Examples of these include poorly addressed malfunctions, causing malfunctions to happen for weeks on end heavily influencing data. An example of which was a poorly tighned conveyor chain, causing malfunctions when heavy pallets used this conveyor. Simulation or optimization studies might have suggested not storing heavy pallets in this location, where the simple solution is to simply tighten the chain. The large prevalence of small problems like these make it more difficult to conclude where the system has to be optimized in terms of, for example, determining the exact number of exclusive materials that can be in the portfolio, where exclusive lanes and where mixed lanes should be located and why. A simulation or optimization study could provide answers to these questions and will become possible after the human factor in the system has been reduced.

The example of the loose chains could serve as a broader message to the academic community, that data and mathematical optimization does not always lead to optimal results. When model studies do not provide the answers scholars are looking for, this study forms an example of it being worthwhile to take human behavior into account in a more qualitative way.

9.2 Reflection

The current study did encompass a few limitations that have to be addressed. Firstly, this study has made use of data provided by VLC, the software connected to PMW. Large amounts of data were missing, and it remains unknown whether this has caused a bias in the conclusions of this study based on these limited data. For future research, it is important that there is a more reliable data collection than VLC has provided thus far. Secondly, this study utilized FRAM to identify the functions that required redesign. FRAM is a tool that allows for work as done to be identified, rather than work as imagined (Hollnagel, 2017). However, in using FRAM for the evaluation of the hypothetical designs, only a work as imagined approach could be taken. This does not undermine the use of FRAM as a method in this study, yet it does imply the need for an additional future step. Namely, after implementation of the strategy and process design, a future study should design a FRAM again to analyze the work as done. Furthermore, FRAM identified functions that caused functional resonance due to variability. This study has made recommendations to reduce the variability or mitigate the functional resonance. It is not clear whether after implementation other areas will start resonating due to unforeseen variability or effects of the new processes and strategies. Thereby reiterating the benefit of conducting the FRAM again after implementation of the strategy and process design.

FRAM has proven very useful as a tool to analyze human factor in automation. The clear distinction between controls, which are steering, and prerequisites, which are restrictive, has allowed for the distinction between measures that partially reduce human interference, and measures that will completely remove these. This has been a crucial factor that differentiates FRAM from many other process analysis tools.

Conducting a combination of interviews and Ishikawa that fed into FRAM has proven very useful. The soft analysis from simply describing issues and their causes as perceived by workers has helped gain a broad understanding of the system, which in turn allowed for the deeper understanding of the processes behind these issues and causes by conduction FRAM. Using regression to further support these findings may not have been the most obvious choice, but it has been very useful in gaining a better understanding of what goes on inside PMW and the AGV. Since these are robots and automated systems it is not possible to interview them, and regression analysis has elegantly made up for this and formed the missing piece in the puzzle.

The methods employed in this thesis have provided meaningful insight into the causes and potential solutions of issues in automated warehousing in the KBU. However, the methods employed have been mostly descriptive. Evaluation of design alternatives was therefore also mostly descriptive. However, because the problem analysis was very extensive this has made up for the lack of predictiveness in the evaluation. It does mean that future research could include a more predictive method like simulation to gain a more detailed understanding of impacts design alternatives will have on the system.

9.3 Conclusion

This study has provided a deep understanding of the issues and potential solutions for shortcomings in and around the automated warehouse for packaging materials at the Jacobs Douwe Egberts factory in Utrecht. The aim of the study was to design a warehousing strategy and process improvement for the JDE packaging materials that would improve efficiency in terms of lead time of materials and labor use. Conclusions are presented per research sub-objective below.

9.3.1 Define the working of the system of warehousing and packaging in the KBU.

The system was analyzed using several techniques which led to novel insights in the working of the system,. An important conclusion that follows from the stakeholder analysis is that central planning holds much power over the system, but is not interested in how the system actually operates, only in in results. This actor was therefore labeled ‘keep satisfied’.

9.3.2 Identify root-causes for labor-waste and high lead time

The semi-structured interviews led to a deeper understanding of the areas where issues occurred. The most important ones were crowdedness in PMW, ordering materials, production planning changes and malfunctions. The Ishikawa diagram shows that these can be put into five main themes of causes: process, information, people, control and external causes. To further investigate the causes, a FRAM analysis was conducted showing that the functions where variability originates and cause functional resonance are material ordering, material returns, material intake and addressing of malfunctions. Finally, two statistical analyses were conducted. Linear regression analysis showed that each unblocking movement caused approximately 44 seconds of additional lead time. Logistic regression analysis suggested that the odds of extreme lead times were generally significantly higher for pallets at the ground floor and for orders during the daytime due to the overall concentration of activity during daytime hours.

9.3.3 Describe the design requirements for the control rules and process designs.

The requirements that were established were based on the results of phase 1. The issues and their causes led to a set of principal functions in need of redesign. These functions are allocation, shuffling, material intake, material ordering with the subfunction of preventing double orders, material returns and the addressing of malfunctions. Each of these functions also impacts others which is why it is so important to establish a full design, instead of designing for these functions separately. The objectives for the redesign were to reduce labor, reduce lead time for packaging materials, and to have affordable improvements . The only constraint identified was to keep material orders externally the same. This was therefore considered out of scope of this study.

9.3.4 Describe the design alternatives.

Three main alternative routes have been described that JDE can take to improve its efficiency. The first design focused on quick wins; it is easy to implement and has low costs. Nearly no investments will have to be made to implement it. This design consisted largely of processes that are not present in the current system, but management thinks or imagines that these processes exist. This accounts primarily to workers giving each other feedback, which in reality does not happen. This is due to the fact that work as imagined is not the same as work as done, and design 1 suggests actually implementing the work as imagined. This means that malfunctions are the sole responsibility of shift leaders, who in turn must provide feedback to the warehouse operator for poorly wrapped pallets. Allocation to exclusive lanes should happen according to movements per week. The warehouse operator should conduct material returns but will provide feedback consistently to operators who order wrong materials. Material ordering will happen as it is done now, but operators will be provided with better information systems to prevent double ordering.

The second alternative would change the system more thoroughly and adds several technological improvements to reduce the probability of human error. Firstly, a scanner would be installed that detects poorly wrapped pallets before entering the warehouse. Furthermore, the production plan would be used to improve the processes, but not direct these. This results in mechanisms providing warnings to operators who are ordering materials that do not correspond to the production plan, but will not automate ordering completely thus leaving room to operate outside of the plan. ANDON will be used to further improve the addressing of malfunctions in the system by extending the ANDON alerts into VLC to warn operators when certain parts of the system are out of order. Allocation and shuffling would be done the same way as in the first design, with the addition that the analysis of what materials move most will be conducted periodically, preventing the system from becoming outdated. Finally, returns will be automatically registered by VLC when the pallet is unused, and VLC will keep track of which operator ordered these 'wrong pallets'. This will allow for better individual feedback.

The third design focused on the production plan and bases all operations on the production plan. This means that material orders will be automatically generated and placed, and ordering of other materials will be blocked. Malfunctions will be reported through VLC and will completely block ordering through those elements of the system that are affected. Allocation rules will be reevaluated weekly, based on the production plan and the bill of materials for that plan. This will lead to perfect predictions of the most used materials each week, thus maximizing the efficiency. Due to the need of weekly shuffling according to the new allocation rules, the whole of Friday afternoon will be reserved for shuffling. Thus, preparing the warehouse for the upcoming week at one of the least busy moments of the week in terms of both fill grade and activity. Returns will be automated and performed by the AGV as well.

9.3.5 Evaluate the design alternatives.

The main trade-offs that were identified lie in the flexibility and broadness of the portfolio of the JDE factory in Utrecht on the one hand, and possibilities to improve efficiency on the other hand. Design 1 can provide gains in efficiency but will not eliminate all variability in the system. However, it is very easy to implement and will require very little investment. Design 2 will be able to remove most of the variability, but only in the weeks where the production plan is not changed at the last minute. When such changes are made, the gains in terms of reduction of functional resonance will drastically reduce. It will however still be possible to change the plan in this design, albeit this is not recommended. Design 3 will eliminate nearly all variability in the functions that cause functional resonance according to the FRAM. However, this solution will require an investment and disables the possibility of changing the production plan. To accommodate this design, much change will be required by both central planning, who will have to make sure that they do not change the plan after Thursday, and by operators, whose jobs will no longer include ordering materials.

9.3.6 Design a warehousing strategy and process for JDE packaging materials

The warehousing system of packaging materials at the KBU can be improved in terms of lead time reduction and improving efficacy of labor. This can be achieved best through design 3 ‘production planning integration’. This design makes use of further integration between VLC, PRS, and malfunction alert systems. The weekly production plan can be used to optimally appoint materials to the exclusive and mixed allocation strategies, whereas it can also be used to automatically generate material orders to remove human errors that can occur in placing material orders. Malfunctions can be registered by VLC as well to proactively block usage of parts of the system that are out of order, and continuously informing workers of the status of the system. Using a scanner at the entry point will remove most poorly wrapped pallets from entering the system and will thus reduce malfunctions as a result. Regardless of the chosen design, in any situation it will be beneficial to block vacuum operators from ordering during the most busy hours of PMW. These measures will meaningfully reduce lead time and improve efficient labor.

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Appendix 1: data description

Task	Freq.	Percent	Cum.
Articleinfeed	9640	23.54	23.54
CombineBatches	1925	4.70	28.24
LowFloorInfeed	2833	6.92	35.16
MatrixManualEndpointToEndpoint	1185	2.89	38.05
MatrixManualOutfeed	241	0.59	38.64
MatrixRecovery	358	0.87	39.52
MatrixRerouteFromEndpoint	30	0.07	39.59
MatrixRerouteFromTransport	4	0.01	39.60
MixedInfeed	5079	12.40	52.00
MoveExclusiveInMixedToExclusiveZone	693	1.69	53.69
MoveMixedInExclusiveToMixedZone	54	0.13	53.83
Outfeed	15591	38.07	91.90
UnblockUsed	3318	8.10	100.00
Total	40.951	100.00	

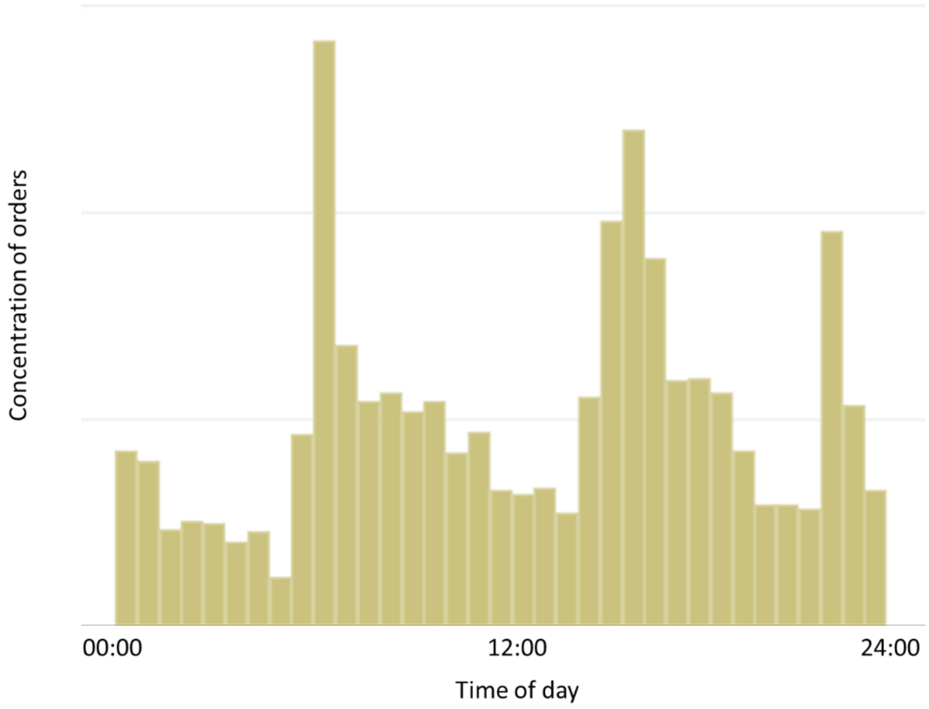
Appendix 2: Interview coding

AGV	1
Allocation	6
Buffers	15
Control	2
Fill grade	1
Information	13
Malfunctions	22
Material intake	3
Material ordering	35
Material ordering/malfunctions	1
Material ordering/Material returns	2
Material returns	8
Operator behavior	13
Planning changes	48
PMW	1
Pricing	2
Production planning	1
Shuffling	17
Stakeholder role	3

Appendix 3: allocation rules per material

Occurance	Article	Current str	Proposed s
657	10020703	Exclusieve	Exclusieve
366	10025217	Exclusieve	Exclusieve
356	10025218	Exclusieve	Exclusieve
316	10035557	Exclusieve	Exclusieve
246	10032651	Invoer lage	Invoer lage
195	10035561	Exclusieve	Exclusieve
175	10025215	Exclusieve	Exclusieve
172	10031876	Invoer lage	Invoer lage
127	10026678	Exclusieve	Exclusieve
117	10029068	Exclusieve	Exclusieve
110	10037374	Mixed	Exclusieve
103	10025216	Exclusieve	Exclusieve
103	10026677	Exclusieve	Exclusieve
102	10035559	Exclusieve	Exclusieve
81	10030800	Mixed	Exclusieve
72	10037344	Mixed	Exclusieve
68	10031878	Exclusieve	Exclusieve
60	10037353	Mixed	Exclusieve
59	10037345	Mixed	Exclusieve
55	10020702	Exclusieve	Exclusieve
54	10017438	Exclusieve	Mixed
50	10037346	Mixed	Mixed
50	10037364	Mixed	Mixed
47	10037347	Mixed	Mixed
37	10025855	Mixed	Mixed
35	10025847	Mixed	Mixed
33	10037356	Mixed	Mixed
32	10037355	Mixed	Mixed
31	28071069	Mixed	Mixed
30	10037378	Mixed	Mixed
27	10037380	Mixed	Mixed
25	10025858	Mixed	Mixed
25	28071070	Mixed	Mixed
24	10030106	Invoer lage	Invoer lage
23	10037387	Mixed	Mixed
22	10032277	Mixed	Mixed
20	10029069	Exclusieve	Mixed
19	10032875	Mixed	Mixed
19	10037379	Mixed	Mixed
19	10037388	Mixed	Mixed
18	10037368	Mixed	Mixed
18	10037399	Mixed	Mixed
16	10023859	Mixed	Mixed
16	10037363	Mixed	Mixed
14	10023025	Mixed	Mixed
14	10037357	Mixed	Mixed
14	10037373	Mixed	Mixed
13	10037151	Mixed	Mixed
13	10037354	Mixed	Mixed
13	10037371	Mixed	Mixed
12	10025848	Mixed	Mixed
12	10035563	Exclusieve	Mixed
12	10037372	Mixed	Mixed
12	10037375	Mixed	Mixed
12	10037400	Mixed	Mixed
12	10037410	Mixed	Mixed
12	10261500	Mixed	Mixed
11	10012947	Mixed	Mixed
11	10030107	Invoer lage	Invoer lage
9	10012948	Mixed	Mixed
9	10015306	Mixed	Mixed
9	10037401	Mixed	Mixed
9	10037454	Mixed	Mixed
8	10037383	Mixed	Mixed
7	10023845	Mixed	Mixed
7	10025851	Mixed	Mixed
7	10037376	Mixed	Mixed
7	10037393	Mixed	Mixed
6	10025854	Mixed	Mixed
6	10029361	Mixed	Mixed
6	10035820	Mixed	Mixed
6	10037402	Mixed	Mixed
5	10012946	Mixed	Mixed
5	10023171	Mixed	Mixed
5	10025849	Mixed	Mixed
5	10025850	Mixed	Mixed
5	10025856	Mixed	Mixed
5	10037365	Mixed	Mixed
5	10037367	Mixed	Mixed
5	10037370	Mixed	Mixed
5	10037403	Mixed	Mixed
5	28071204	Mixed	Mixed
4	10012876	Mixed	Mixed
4	10033714	Mixed	Mixed
4	10035050	Mixed	Mixed
4	10037362	Mixed	Mixed
4	10037397	Mixed	Mixed
4	10037719	Mixed	Mixed
4	28071208	Mixed	Mixed
3	10012882	Mixed	Mixed
3	10018227	Mixed	Mixed
3	10023170	Mixed	Mixed
3	10023846	Mixed	Mixed
3	10025852	Mixed	Mixed
3	10025893	Mixed	Mixed
3	10031733	Mixed	Mixed
3	10031889	Invoer lage	Invoer lage
3	10033720	Mixed	Mixed
3	10035989	Exclusieve	Mixed
3	10037348	Mixed	Mixed
3	10037369	Mixed	Mixed
3	10037392	Mixed	Mixed
3	10037435	Mixed	Mixed
3	10037718	Mixed	Mixed
3	10038802	Mixed	Mixed
2	10025857	Mixed	Mixed
2	10027930	Mixed	Mixed
2	10029508	Mixed	Mixed
2	10031377	Mixed	Mixed
2	10032770	Mixed	Mixed
2	10033710	Mixed	Mixed
2	10033712	Mixed	Mixed
2	10033722	Mixed	Mixed
2	10037361	Mixed	Mixed
2	10037366	Mixed	Mixed
2	10037386	Mixed	Mixed
2	10037405	Mixed	Mixed
2	10037409	Mixed	Mixed
2	10038803	Mixed	Mixed
2	10038805	Mixed	Mixed
1	10020052	Mixed	Mixed
1	10023853	Mixed	Mixed
1	10023855	Mixed	Mixed
1	10023860	Mixed	Mixed
1	10029360	Mixed	Mixed
1	10029365	Mixed	Mixed
1	10031625	Exclusieve	Mixed
1	10033709	Mixed	Mixed
1	10033711	Mixed	Mixed
1	10033719	Mixed	Mixed
1	10033724	Mixed	Mixed
1	10034797	Mixed	Mixed
1	10035011	Mixed	Mixed
1	10035296	Mixed	Mixed
1	10035632	Mixed	Mixed
1	10035821	Mixed	Mixed
1	10037404	Mixed	Mixed
1	10037444	Mixed	Mixed
1	28071638	Mixed	Mixed

Appendix 4: Universal materials

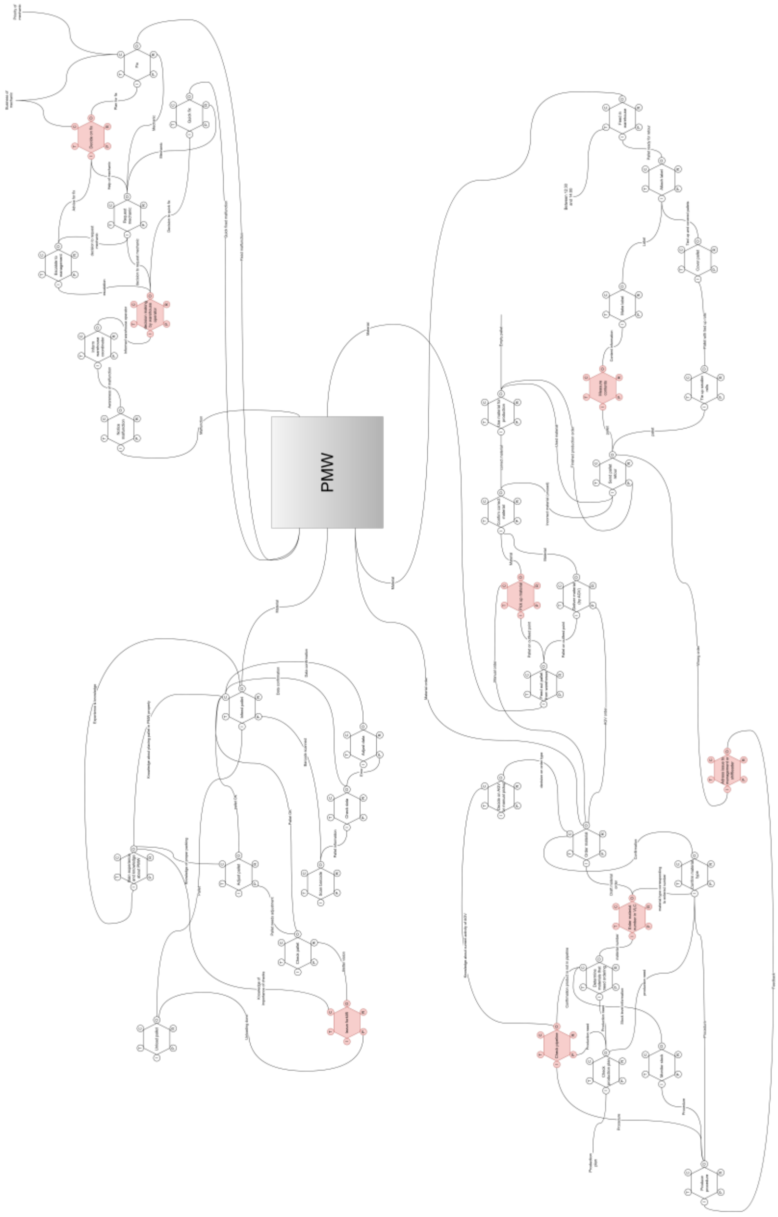


Appendix 5: Interview guide

My name is Pieter Pries and I am researching control strategies and processes for packmat warehouse. The research will focus on designing a strategy where the following aspects are taken into account:
-lead time
-integration of the production plan
-reducing human interference
This interview has the goal of creating a clear picture of the processes in and around packmat warehouse. Furthermore it has the goal of identifying bottlenecks in these processes and exploring solutions. I would also like to gain a better understanding about the stakeholders involved and their interests, and mutual relationships. I will record this meeting if that is OK with you.

1. Please describe your function within the production and packaging process of JDE.
2. What are your daily activities and how are you dependent on other workers or departments?
3. Are others dependent on you?
4. To what extent are you dependent on the functioning of PMW?
5. What problems do you see in and around PMW and do you see any potential solutions to these problems?
6. Do you keep PMW and its functioning in mind when planning your activities? Things you might consider are business, malfunctions or fill grade?
7. To what extent do you experience uncertainties in your work?

Appendix 6: FRAM (whole)



Appendix 7: description of activities and interrelations in FRAM

Firstly, all important processes that are depicted in the FRAM in figure 17 will be discussed. Entry of materials at the dock is an important subsystem of processes. This is where materials first enter the factory, are checked, and are entered into the warehouse. The steps that are taken are conducted by the warehouse operator. After the truck has docked and the loading bay is accessible (this is left out of scope) the warehouse operator uses a forklift to pick up pallets in the truck. These are then placed on the input/output point in the dock area. When this is done, the pallet should be checked for any quality issues. This is done visually by the warehouse operator, who can identify potential sources of malfunction like loose wrappings. To ensure the entire pallet is checked, the operator should leave the forklift and walk around the pallet to check all sides of the pallet. After this, the barcode that the supplier has attached to the pallet is scanned which loads the information into the system and is visible in the VLC interface on the computer in the dock area. The data have to be checked, both whether the material type is correct and whether the stated quantity is correct. When all these checks are done the warehouse operator scans a different code, attached to his forklift that confirms the entry and this prompts the system to start processing the pallet. The pallet is then moved away automatically using conveyors. By frequently performing this task, which the warehouse operator does, the warehouse operator builds a lot of experience and knowledge about how PMW works, what causes malfunctions and what does not and can therefore provide practical knowledge on how to wrap pallets to prevent malfunctions and experience of what happens when malfunctions do happen due to poor checks.

The second subsystem of processes that will be discussed is the ordering, using and returning of materials by production operators. This is the most important part of the system, since this is where value is created by creating the finished product. The production plan is the input for this system. This prompts the operator to read the plan, which tells them what materials are needed for the product that should be made. The operator then knows what materials are required, but the operator does not know what they have and what is in transit to their production line. Therefore, according to procedure the operator should first check what stock is present at the production line, and they should check whether the materials are in the ‘pipeline’. Checking stock is very attainable, since the stock for each production line is located close to the workstation of the operator that has to check the stock. Checking the ‘pipeline’ is more difficult, since there is no real time ‘in transit’ overview in the interface and therefore the only way to know whether and what pallets are coming is by remembering what you ordered, or going to check the activity of the warehouse in the visualizer which requires a lot of understanding. Then, the difference between the need on the one side and the stock and the materials in transit on the other side determines the materials that need to be ordered.

Using that knowledge, the operator can proceed to order the materials that are needed. To do this, the material code is entered into VLC. VLC then shows the description of the corresponding material, and the operator should check if that is the correct material, or that they have made a typo. Next, the operator should decide whether the AGV should deliver the material, or whether they pick up the material manually at PMW. To enable a good decision, the operator should have some knowledge about the relative lead times for both modalities. The only thing they can base this on is on the current state of the AGV; namely, whether or not there are malfunctions, and whether the AGV has many orders to fulfill (which may cause additional waiting time).

When the order is confirmed (either by AGV or manual), PMW will process it and decide on what pallet to feed out, and feed out that pallet. Since this is a complex system, which largely depends on robotics and computations and less so on human factors, this is kept out of scope and depicted as a black box system in the FRAM. The result of these processes is that the ordered material is on the output point. Then, the AGV will pick up this pallet, or the operator has to go to the output point to pick up the pallet. The AGV will not be able to pick up the pallet without a specific order, which is why this is depicted as a prerequisite; however, the operator can always go and pickup pallets, even without placing a manual pick up order, which is why this is shown as a control. After the pickup the operator will confirm that the material that he has is the correct material. Sometimes it will happen that this is not the case, which means that the material cannot be used and has to be returned. When the material is correct, it can be used for production, either until the pallet is depleted, or the production is finished. Empty pallets can be discarded, which is a system that will be left out of scope. Non-empty pallets that are left over from finished production will be returned, in the same way as the incorrect materials. To do this, the operator returns the pallets by placing them in the return area, close to PMW.

The subsequent steps are conducted by the warehouse operator. The warehouse operator measures the contents of the pallets, and enters this information in VLC, which prints an updated barcode label for each pallet. All materials on the pallets are then tied up, covered and provided with this label. After this, these pallets are placed on the input/output point and scanned into the warehouse. This can only happen during the return window from 12:30-14:00. After this, allocation and storage happen automatically and is therefore not included in the FRAM, and thus depicted as a black-box process.

The warehouse operator will spot wrong orders when returning materials. Those are usually easy to spot, since oftentimes unused pallets will be full or the same material will be in the return area on multiple pallets, furthermore the warehouse operator has plenty of experience to know what regular material flows look like in terms of quantity, and what return flows are generated by wrong orders. When wrong orders are spotted, the warehouse operator can escalate this to management and address the issue to the shift leader in charge. This should lead to better procedures and improve the quality of the operators' work.

The third subsystem is the detection, prevention and repair of malfunctions in PMW. This starts when a malfunction is noticed, usually by the warehouse operator, or by a production operator using PMW. The first person to contact in this case is the warehouse operator, who is responsible for first line troubleshooting concerning PMW. The warehouse operator can then decide what has to happen. Usually, they will escalate the problem to the material planner, or for smaller issues will can contact a mechanic, or fix the problem themselves. A quick fix can sometimes be done by the operator themselves, or a mechanic has to be brought in. When the situation is complex, requires PMW to be turned off or is something that the warehouse operator cannot or will not decide on, they escalate it to the material planner. The material planner can then decide on a plan of action and gives advice on what to do, and whether to bring in a mechanic. The warehouse operator or the material planner can then request the help of a mechanic, and give them advice on how to handle the malfunction. The mechanic then fixes the problem as they see fit, which can vary between a quick fix or a durable solution, which is driven by the business and prioritization of that mechanic.

Appendix 8: Field notes

Report on shadowing/observing activities:

Tasks:

Unloading trucks for Packmat:

Trucks dock, pallets are placed in a (too small) compartment within the warehouse using a forklift, scanned, and logged. The unloading process varies for each supplier; some pallets are easily unloaded, while others are more challenging. This depends on the placement of barcodes on the pallets and whether the pallets are loaded wide or long (in the case of Euro pallets).

After unloading, the pallets are stored wherever there is space. Some basic sorting has been done, with frequently used items placed on floor 0. However, the current organization lacks precise planning; better consideration is needed. Items are sorted into categories based on their characteristics (filters with filters, plano with plano). It might be more logical to categorize them based on frequency of use or susceptibility to malfunctions.

Processing Packmat returns:

Handling returns is chaotic. Employees simply place pallets in a designated area, leaving Packmat to deal with them. There appears to be no established procedure. Many pallets have multiple opened packages (leading to inefficient warehousing). It would be beneficial to assess the severity of this issue in the warehouse. Additionally, some pallets are returned overloaded (an employee adds leftovers to a full pallet, exceeding the maximum load capacity). Other pallets seem to be returned to the warehouse unused.

Resolving malfunctions:

Frequent method involves forcefully resetting, not ideal as it leads to false machine error reports.