

Improving Maintenance of Material Handling Systems

Matching a maintenance approach that explores the operational dynamics of the transportation industry at TNT Express.

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While writing my thesis, I experienced that my master prepared me perfectly to analyse and understand problems that were still unknown to me before. I started writing this thesis at TNT Express, without any knowledge on maintenance and material handling systems. However, this master prepared me to work in a business environment and to analyse problems with multiple interests. I really enjoyed the time doing research in at an international company like TNT Express.

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Summary

Due to automation and robotization of material handling systems (MHS) in the transportation industry, maintaining equipment and systems becomes more important, and needs to be integrated in the company's business strategy (Tsang, 2002). Implementing and investing in the right maintenance approach to keep these systems in optimum state is therefore essential for the performance of a company and more important, for the customer's satisfaction. When a company has to deal with an increase in failures and decreasing performance, it needs to anticipate to change this negative trend. In literature, most of these problems are analysed by using electronic data and condition-based monitoring (Bouvard, Artus, Bérenguer, & Cocquempot, 2011). Analysing the condition of equipment requires data monitoring which is not always possible. Besides, these analyses are often based on a single system which conditions do not apply on systems with different specifications. TNT Express (initiator of this research) is dealing with this problem within the Benelux. They are dealing with decreasing *on-time delivery* (OTD) performance and increasing costs of smaller sorting-sites without technicians. Having high OTD performance is an essential element of TNT's business strategy, and is a competitive advantage in their industry. Their time-critical processes combined with the interrelated network structure of their sites makes it hard to develop a single strategy or solution that positively affects the performance of all sites. The differences in size, work methods, level of technology, different size of freight and fluctuating demands makes it a dynamic and complex environment with a lot of variables that influence the performance of on-time delivery. That makes it hard to identify the causes and effects of these failures over time. Besides, TNT doesn't have the useful data to base their maintenance on. Therefore, finding the bottlenecks and the right variables that influence this performance most is essential for decreasing the costs of TNT. Therefore, the objective of this research is:

"Identify the constraints of TNT's Material Handling Systems in a dynamic environment, to be able to apply the right maintenance strategy that preserves TNT's delivery performance at lower cost."

Before a start could be made on finding the bottlenecks of the sorting sites, TNT's maintenance structure, operational structure, financial structure and operational structure needed to be defined. TNT's sorting operation, where freight is unloaded, sorted, measures and loaded, runs around 19 hours a day, 6 days a week all year long. That limits the time for maintenance and check-ups to 6 hours a day. Still, a fast response is needed when the sorter does fail during operation, to prevent the process getting delayed which generates extra costs. TNT's maintenance of those sites turned out to be depending on mostly corrective maintenance, and less on preventive and predictive maintenance. Mechanics are traveling from site to site to solve current incidents that cause delays, and less for preventive maintenance and check-ups. Original equipment manufacturers (OEMs) are also responsible for some maintenance activities, although these are mostly time-based and less used for trouble shooting.

When specifying TNT's *on-time delivery* performance, the performance of the sorting sites turned out to be the most important factor of the OTD. This sorting site performance is measured by the capacity of freight it theoretically can handle, and the amount of freight it is transporting in reality. This site performance is also influenced by several variables, where the *Material Handling Systems availability* turned out to be the largest influential variable. The failing devices and equipment are the cause that

operators on the floor have to sort manually, which takes a lot more time. Besides, these delays are generating extra costs, only how much and which costs is not quite clear.

TNT's limited registration of essential elements like downtime, maintenance costs and OEM activities made it difficult to link these elements, and to find possible bottlenecks. So, to be able to link the MHS-downtime with the related costs on a daily basis, three Critical-to-Quality factors (CTQs) are analysed:

- *Breakdown costs*
- *Maintenance costs*
- *MHS availability*

Because the financial impact of a breakdown was not yet specified, the most important factors are determined by interviewing business improvement experts. Some costs turned out to be different for the import or export process during a working day. For TNT, the next financial factors turned out to be important:

1. *Missed Check-Weight-Cube (CWC) revenue*
2. *Hiring extra vans and trucks*
3. *Personnel costs (overtime)*
4. *Financial consequences of lower service level (loss of customers)*

From these factors, the missed CWC revenue turned out to be largest costs factor in the import process, where hiring extra trucks and vans turned out to be the largest costs factor of the export process. These two factors are further specified and calculated, to link them to specific breakdowns.

Depending on the volume in different locations, the missed CWC revenue is varying between € [redacted],- and € [redacted],- for a single shift per day. These costs are calculated by determining the number of packages that are affected by a breakdown and do not get a second weighing check on a next location, multiplied by the average revenue missed per parcel. These calculations showed that without a working sorter or CWC on a single location comes with large financial consequences. These specific insights in CWC revenue loss show the need for fewer failures to improve the financial performance of TNT by changing the maintenance activities.

The extra costs of hiring extra vans to transport all freight towards the customers in the export process turned out to be € [redacted],- for a single shift (1day). These costs are in the same order as the CWC revenue losses, and from financial perspective just as bad. The cost analysis regarding this data showed how disperse the information is within TNT, and that it is hard to develop a strategy without this kind of crucial information.

Maintenance costs are referred as costs that are made to solve the incidents and include, service contracts, mechanics salaries etc. However, costs that are made for decreasing the number of incidents are more important. Think of hiring extra employees, changing service contracts, training current employees. Quantifying these costs is only possible when the bottlenecks of the breakdowns have been derived.

The lacking quality of the data regarding downtime and availability of the MHS made it impossible to use mathematical solutions to find the bottlenecks, so “Soft Operations Research” methods have been used to find the causes of the failures (Heyer, 2004; Masys, 2015). Using Pareto charts and Ishikawa diagrams on the incident file controlled by TNT’s mechanics, the data in this file is structured and enriched to find failures with recurring root causes that are a structural problem. First, three devices that have the most impact on the MHS availability are determined. These are the *Sorter*, *Roller track/belts* and *Check-Weigh-Cube (CWC)* and are responsible for 130 of the 210 incidents for the first 5 months in 2017, which represents more than 60% of all incidents of the MHS.

The registered incident data of these three devices is enriched by going a step further in the cause, structuring all data, and visualising them in an Ishikawa diagram. By doing so, it became clear that a high number of incidents (35%) have an operation cause, which means that they are caused by human error. These incidents are not specifically location bounded, and solving the most frequent occurring incidents will prevent a lot of future incidents. The three selected root causes that are responsible for most incidents are:

1. *Lack of system knowledge*

Operators, especially Team Leaders (TL) and Leading Hands (LH), have too little knowledge of the process, the effects of failures and simple technical solutions. Their skills haven’t been developed with the increasing mechanisation. Not knowing the impact of failures, and how simple incidents can be prevented leads to unnecessary failures.

2. *Sensor related incidents*

A large part of those operational incidents are sensor related. Because these incidents are still frequently occurring, they need to be handled separately. These incidents can be solved quite easy most of the times, and a support system to help operators to solve them is very helpful.

3. *Lack of working according instructions*

A large part of the incidents are caused by wrong choices of operators, by putting wrong parcels on the sorter, putting them on the sorter at the wrong place or working not according the given instructions. The lack of knowing the consequences results in an uninterested work attitude which results in a performance decrease of the sorting site.

For these three root causes, several improvements have been developed. For the first root cause, a training program is recommended which start with a well-communicated plan to create the urge for change. The current attitude of personnel is asking for a plan that provides support from the whole organisation. TNT needs to know the value of knowledge amongst their employees, and this needs support from top management. Combining this with low-technical training sessions and useful supporting tools will increase the employees’ knowledge, and also creates ownership with the employees. To do so, TNT needs to review its distribution between part-time employees from employment agencies, and employees contracted by TNT. Increasing system knowledge amongst employees is only effective if that knowledge stays within the company. Rewarding well performing

employees with a contract by TNT will have positive effect on the knowledge on the work floor and not only prevents, but also decreases the amount of downtime.

For sensor related incidents, a supporting manual has been developed that functions as a simple flow chart that guides TL through the process of solving these failures. Following these steps in the included manual gives simple but clear instructions how to act and what to do. Before using this supporting manual, the TL need sufficient training before they can execute the process. Although this solution is more focussed on corrective maintenance, this manual helps to solve simple incidents that mechanics do not have to solve by themselves. Not only are these incidents solved much quicker, due to direct handling of the TL, but the mechanics do not have to drive towards the location of the incident. That also gives the mechanics more time to do preventive maintenance tasks, and therefore further decrease the number of incidents of the MHS. This manual strengthens the need for more direct or *autonomous maintenance* within the sorting sites of TNT (Chen, 2013). Currently, these sites are too depended on the knowledge of external maintenance providers to repair the failures which is not desirable.

To improve that employees work more according instructions, better supervision is advised and recommendations are made to reward well-performing operators. Rewarding operators also means that they will be more responsible for their colleagues and have to make sure that they understand the instructions. They become responsible for preventing wrong parcels being put on the sorter, and have to correct their employees if they ignore the instructions because a lot of incidents are caused by wrong packages being put on the sorter. However, TNT should also improve the visibility and clarity of these instructions by using dummy parcels to indicate the allowed parcels sizes. Improving this product flow on the sorter will improve the sorters performance and lowers the number of incidents.

The effect of these improvement could only be expressed by a decrease on the number of incidents, and not on downtime due to lacking data registration. If, as a starting point, already half of these structural incidents is solved by these improvements, the total amount of these 210 incidents over 2017 would already decrease with 13%. Due to the unknown length of the breakdowns, they cannot be compared to financial results although these results definitely improve. All these improvements are based on *autonomous maintenance* which is focussed on letting operators do more maintenance and technical tasks. Finally, all these improvements will help retaining TNT's *on-time delivery* and decrease their breakdown costs.

This process of finding these bottlenecks led to an even more valuable advice for gathering data. This research showed that TNT needs to improve their data collection system, and document important factors with a computerized maintenance management system (CMMS) like time registration, downtime during operations, and weight of breakdown. This data also needs to be accessible for OEM's, so they also have insight in the failures, and can help improve the MHS performance. With this data, TNT can measure the downtime and better monitor its MHS availability to see which devices or incidents need further improvement. The importance of such data collection system is once emphasized by the fact that it was hard to determine the bottlenecks, especially with multiple locations at the sorting locations of TNT.

The goal was to identify the constraints in a dynamic environment that has a lot of influential factors that make it hard to determine the effects of these variables. Using multiple techniques based on the number of incidents and the failure history, the first bottlenecks could be derived that needed improvement. Together with a costs analysis on the most important financial factors, solutions and recommendations are developed that will retain TNT's on-time delivery at lower costs. However, the recommendations for a more centralized data-based maintenance system could even be more valuable in the future.

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List of abbreviations

AHP	Analytic Hierarchy Process
CM	Corrective Maintenance
CMMS	Computerized Maintenance Management System
CTC	Critical to Costs
CTQ	Critical to Quality (factor)
CTP	Critical to Performance
CWC	Check-Weight-Cube
DMAIC	Define, Measure, Analyse, Improve, Control
FMECA	Failure Mode, Effects and Criticality Analysis
LH(s)	Leading Hands
OEM	Original Equipment Manufacturer
OES	Operations, Equipment and Services
OTD	On-Time Delivery
PdM	Predictive Maintenance
PM	Preventive Maintenance
MHS	Material Handling Systems
RCA	Root Cause Analysis
RCM	Reliability Centred Maintenance
SLA	Service Level Agreement
TL(s)	Team Leaders
TPM	Total Productive Maintenance

1 Introduction

In this chapter, an introduction to TNT Express is given, which is the host company of this research. Next, the technique of material handling systems (MHS) is introduced, and the function of this piece of equipment is explained. A brief summary of different maintenance approaches is given, followed by a description of the research problem. The last part of the introduction is an outline for this thesis.

1.1 Company introduction

International transportation is a worldwide growing business due to globalisation and e-commerce (TNO, 2003). Improved infrastructure and large transportation networks make it possible to deliver a package the next day on the other side of the world. TNT Express B.V. (TNT) is one of those companies capable of delivering such services. The majority of TNT's shipments are between businesses (B2B), but they offer business-to-consumer (B2C) for some key customers (TNT, 2015). TNT has 56,000 employees worldwide, and has own operations in 61 countries. For further service, TNT acquires capacity from third party logistics (3PL) which allows them to operate in more than 200 countries.

Zooming more into TNT's services, they offer several transport alternatives which all carry through their network. Examples of these services are documents, conveyables (loose packages), pallets, awkward sized freight and dangerous goods. Next to these services, TNT also provides special services for freight that needs to be delivered the same day or needs extra safety services. Custom clearance, having an on-board courier or a dedicated vehicle to deliver customer's packages are all examples of these special services (TNT, 2017). However, most regular shipments are time & day guaranteed shipments and are



Figure 1: Standard Express Chain

carried through the network by the hubs and depots of TNT as shown in Figure 1. The function of these depots and hubs are merging and sorting of freight in order to continue as efficiently as possible in their supply chain. This process is also known as the hub-spoke model, which FedEx implemented and extended as one of the first door-to-door service providers (Chan & Ponder, 1979). With the merging and sorting of the packages, significant economic benefits are created due to fuller trucks to one destination and less number of total miles driven.

TNT's sorting centres are an important part of their internal network necessary to provide their multiple services. These sorting centres, and their material handling equipment, have the purpose to deliver on-time towards their network, to guarantee TNT's delivery standard of 24 hours. Guaranteeing this on-time delivery is essential for the image of their company, and for maintaining their customer base. Also,

missing the connection to further process freight in the network will produce extra costs to still deliver the packages on time. Therefore, TNT is striving for a 100% on-time delivery (OTD). They do not have a safety buffer which gives them no room for delays in their network. In conclusion, missing a connection is not in line with their corporate strategy and impacts TNT financially.

1.2 Material Handling Systems (MHS)

Essential in the business of TNT are the Material handling systems (MHS) in their depots and hubs, where the packages are sorted and distributed. Different types of equipment are used to sort and process these packages further. In each depot or hub, these processes can differ from each other, but have the same goal: delivering the package without damage and on-time (TNT, 2016). In some locations, every step of this process is done manually, but in other locations this process is almost completely automated. Examples of equipment used in this process are forklift trucks, roller and belt conveyors, scanners, weighing scales, X-rays machines etc.



Figure 2: Material Handling System of TNT (TNT, 2017)

TNT and their MHS are exposed to an increasing demand, and continuously have to adapt their operations to cope with that demand. A higher demand means their occupancy rate goes up, and their availability rate has to go up as well. Therefore, more and more locations are exposed to mechanization and automation of the material handling process, to increase their throughput. Although efficiency is going up using this mechanization, new tasks are also introduced to the operational process. Maintenance of MHS, to ensure the performance level of the MHS, is a new and essential part of the job. If the occupancy rate goes up, it directly affects the maintenance operations of a company. In literature, maintenance is mostly seen as a necessity and a costs and time consuming process (Mechefske & Wang, 2001). However, with the right way of using maintenance at the right moment, money and time can be saved. Choosing the right type of maintenance for each hub and depot is a challenge due the differences in size, volume, equipment, staff etc. This problem led to an interesting point of discussion and eventually to this research.

1.3 Maintenance concepts

In literature, several maintenance concepts can be derived. Maintenance is a topic that is widely discussed in literature and in basic terms, maintenance can be categorized in corrective, preventive and predictive (condition-based) maintenance (Horner, El-Haram, & Munns, 1997).

- **Corrective Maintenance (CM)**
Corrective maintenance is the simplest way of doing maintenance. Maintenance is only executed when an element breaks down. It covers all activities like repairing, replacing etc. Corrective maintenance is therefore *ad hoc* and unplanned.
- **Preventive Maintenance (PM)**
Preventive maintenance was introduced to solve the disadvantages of corrective maintenance. Preventive maintenance is also called time-based maintenance and refers to maintenance activities which are performed using fixed intervals of a maintenance plan. These can be time-dependent or based on operating hours.
- **Predictive Maintenance (PdM)**
This maintenance concept recognizes a change in condition/performance, and maintenance is scheduled before the system breaks down. Condition-based is therefore predictive in essence, and *“maintenance is carried out in response to a significant deterioration in a unit as indicated by a change in monitored parameter of the unit condition or performance”* (Horner et al., 1997).

The way to find the right match between an operational system and a suitable maintenance approach is often difficult. When does a company need to switch to a more predictive-based maintenance approach? Nowadays, these decisions are based on statistical analyses which identify the operational process, and look which maintenance type fits that process best. But as mentioned earlier, the business environment is changing, and so are operations which makes it harder to make the right decision at the right time.

1.4 Research problem

As mentioned above, maintenance is of strategic importance to a company and can add to a company's business success (Tsang, 2002). The reason for this research was initiated by the current problems at the hubs and depots of TNT, where they have a lot of issues with the reliability and availability of their MHS. To guarantee the OTD of the freight of their customers, TNT needs to make sure that performance of their sorting sites is not endangering these time-guarantees. The fact that TNT has to deal with daily changing volume, combined with the fluctuation in volume during Christmas etc., makes it hard to design a standardized maintenance plan usable for multiple locations. These “dynamic” operations also make it hard to develop a single strategy. Nevertheless, with the availability needs during these peaks, it is essential to adapt their maintenance in those situations. In an article by Bouvard, Artus, Bérenguer, & Cocquempot (2011), they propose an adaptive and dynamic method to schedule maintenance of a multi-component system using condition-monitoring. Using electronic data, they can adapt the

maintenance frequency by monitoring the conditions of commercial heavy vehicles. These vehicles operate in different environments with different loads, which affect the degradation of its components. Using predictive maintenance, the proper performance level can be obtained. An article by Byon (2013) also describes a condition-based approach including external dynamic aspects, like the weather, to determine the right maintenance interval on wind turbines. This approach is also based on monitored conditions and simulation models of the turbines to keep them in optimal state. These examples show how external and dynamic operations may influence the right maintenance approach.

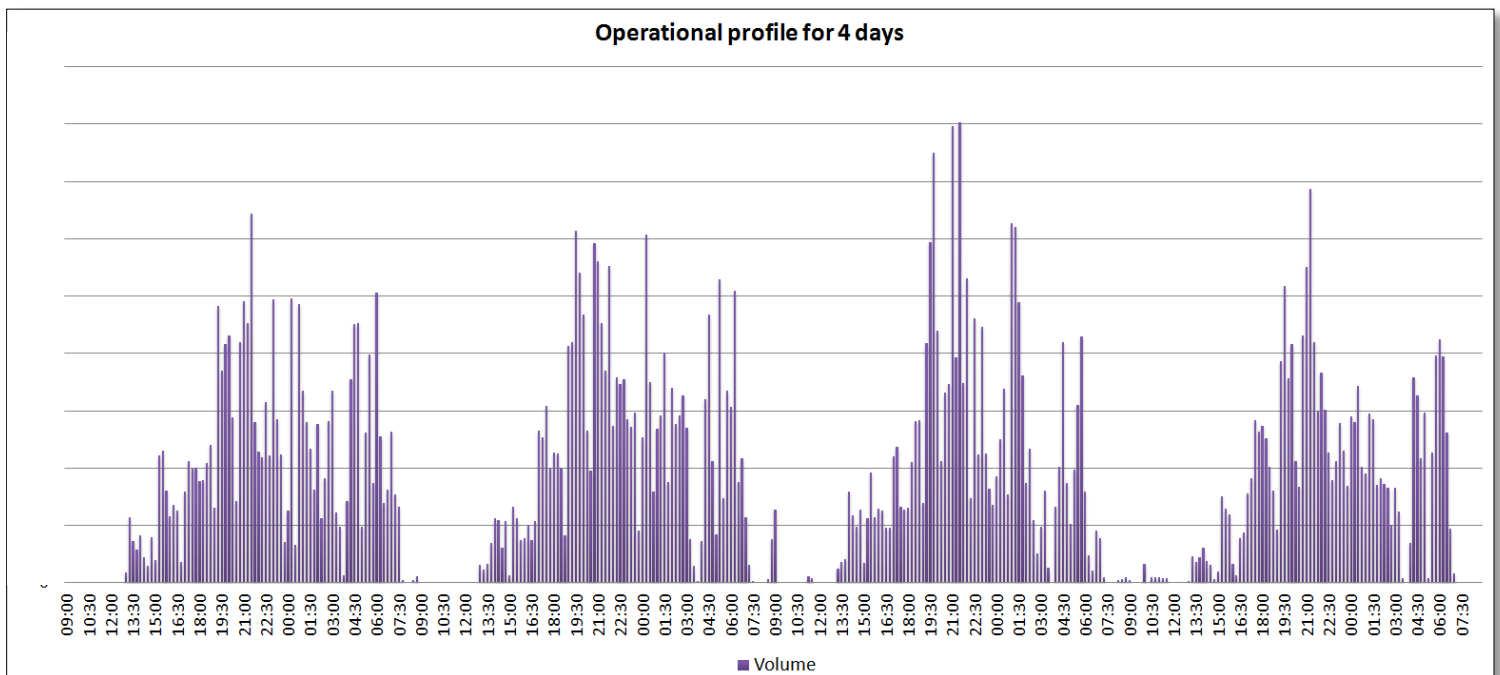


Figure 3: Operational profile Brussels hub (05-2017)

To get a better view of “dynamic” operations of TNT, the next figure shows the operational profile of a hub over 4 days. This diagram shows the number of parcels moved within one location. A trend is clearly visible, showing the process is building towards a first peak around 20:00, which continues until 3:00 in the night. After this peak, the volume is increasing again until around 7:00. This diagram also shows that the only time window when the MHS is not functional and available for maintenance, which is between around 7:30 until 13:30. Because the process runs 6-days a week, the possibility to execute maintenance is limited to 6 hours a day. This operational profile is typical for the international transportation industry that picks-up and delivers freight from business-to-business. First shift that starts around 13:00 represents the incoming freight that is picked-up from the customers and is transported to the next location. And from around midnight the export process starts where incoming goods are prepared to be delivered towards the customers. All companies that offer this service (TNT, DHL, UPC, and FedEx) will experience a same sort of operational pattern. This pattern will keep existing within in the industry as long as the customers keep operating during day time. However, in the future, the growing amount of freight and the flexibility of the market may decrease the gap for maintenance due to higher customer demands. Next to the dynamic operations, the different weights of the parcels also play a role in the

deterioration of the MHS. Other variables that influence operations are operational speed, temperature and age of the machine. This will influence the decision to do certain type of maintenance. Another thing to keep in mind is the moment when the equipment fails. If this happens before the peak, maintenance has higher priority. However, if an error occurs at the end of a peak, a back-up plan may be more efficient than waiting for maintenance to process the remaining freight by hand. All these components make it hard to distinguish the effects of a failure through the whole network.

At large locations, TNT has a maintenance team that is responsible for repairing and maintaining MHS. However, on smaller locations they don't have technicians on-site and instead a small mobile team is maintaining the MHS on these locations. The only problem is that these smaller sites all differ in size and level of technology. Spare-parts, in most cases, are not universal and the exchange of employees is hard due to different working methods. These are all examples that make it a dynamic and complex environment. Moreover, predictive information is not available to determine the state of their equipment. So, developing a generic maintenance approach for an "average" hub or depot is nearly impossible. Locations have been making decisions on their own, or guided by small regions or network departments. And with the small time-window, the mechanics don't have time to do enough preventive maintenance, and still be on-time for incidental errors.

There is a need for insight in decision making regarding the right maintenance strategy in such a varying environment where predictive information is unavailable, to preserve TNT's OTD at lower costs. TNT struggles with keeping their performance at the required level by spending too much money on unplanned maintenance. The challenge is how and where to improve TNT's maintenance, and how to make the right decisions if there is no monitored information available about the current state of the equipment. This research delivers a contribution towards this problem. This will be in the form of improvement suggestions for current problems and recommendations for future improvements on this area.

1.5 Thesis outline

The thesis follows a step-by-step structure to present the research. Previously chapter 1 describes the introduction, where the research problem is defined followed by some background knowledge regarding the problem. Chapter 2 explains the research methodology and methods, which include the objectives and questions followed by a comparison of several theoretical frameworks. Chapter 3 introduces TNT's equipment and current maintenance activities which are developed into several factors for analysis. Chapter 4 goes deeper in these factors and tries to quantify them. Making these factors measurable enables TNT to measure the effect of improvements. In chapter 5, the factors are further analysed by using analytical tools. This will create an overview of the problem's bottlenecks. Chapter 6 suggest possible improvements to overcome these bottlenecks and also provide a supporting tool that can be used as example. Chapter 7 discusses possibilities for TNT to control and implement these recommendations, and elaborates how to use this failure analysis for future improvements. The last chapter concludes this thesis and discussed the findings of this research. This chapter concludes with recommendations for further research.

2 Research Methodology & Methods

This chapter describes the research methods that were used, and the methodology to execute this research. Previous chapter gave an introduction on the research problem, and the challenge of this research. Choosing the right methodology is important to efficiently solve such complex problem. Part 2.1 will go deeper into the decision-making methods found in literature which are used to determine the right maintenance approach, to get a better understanding on these processes. Part 2.2 will define the scope of this research, followed by the objectives, deliverables and research questions. Part 2.3 will elaborate the research questions and part 2.4 goes deeper into the research methods and methodology of this research.

2.1 Previous research

Looking at this practical problem of TNT, it is interesting to see how previous research handled such problems. For a company to survive, it needs to assure its product quality, makes sure its production continuity is good, and its process is safe and produces on-time (Ferreira, Farinha, Barbosa, & Fonseca, 2009). All these essential indicators can be traced back to the monetary value of maintenance. A well implemented system can lead to severe costs savings and higher production, as seen with the implementation of Total Productive Maintenance (TPM) at Aviko where they saved 5 million Euros within 5 years (van Ede, 2012).

Looking at one decision tool found in literature, an article by Waeyenbergh and Pintelon (2002) discusses the need of having a custom maintenance concept to reduce life cycle costs and ensure smooth internal logistics. This model uses several modules to identify the whole system, and goes through several steps to provide an advice. However, these modules do not yet contain every aspect and may therefore not be applicable on every system. There are also some other issues with the implementation of a maintenance strategy. Alignment of the maintenance process with the corporate strategy is important so that one knows what should be measured, why it should be measured and how it should be measured (Parida & Kumar, 2006). A mismatch between these two can lead to lower customer satisfaction, lower productivity etc. Next to that, carrying out wrong or to less maintenance can cause dangerous situations for employees. In a changing or different operation scenario, executing the right maintenance strategy leads to a more safe and healthy workspace (Ferreira et al., 2009). Breakdowns can be dangerous if the knowledge needed to deal with these failures is not available. Therefore, matching the right maintenance method to its operations is important for a company.

Matching a maintenance approach to sorting equipment is a decision that depends on many variables. A recent article from de Jonge, Teunter and Tinga (2017) compares two maintenance strategies on several factors. This research used costs as an indicator to see how they are affected by factors changing the situation. They visualize the turning point to go for one strategy over the other using costs as a deciding factor. Although this research gives insight in the advantages using a maintenance strategy over another in different scenarios, it is based on a single system with a calculated deterioration rate where they

assume that corrective maintenance is more expensive than preventive. Besides, this research does not take into account the factors that influence the deterioration rate, due to different usage.

A research approach by Tahir, Burhanuddin, Ahmad, Halawani and Arif (2009) investigates the failure rates and downtime to categorize equipment in a decision making grid. However, this research does not take a dynamic profile perspective into account, but only looks at historical failure data to come to a conclusion. In a following article from Burhanuddin, Halawani and Ahmad (2011), they continue their previous work by not only looking at the failure rates and downtime to decide what type of maintenance is necessary, but also take the costs of maintenance into consideration. This article is already more focussed on combining several factors, but it still is a rather static approach to analyse the system.

Another process that is used for choosing a maintenance policy is an Analytic Hierarchy Process (AHP). This process uses a pair-wise comparison where scales are prioritized by the judgement of experts (Ierace & Cavalieri, 2009; Maletič, Maletič, Lovrenčić, Al-Najjar, & Gomišček, 2014; Shahrabi & Shojaei, 2014). This process does have a broader look upon choosing the right maintenance policy by including more factors. Though, the data is based again on historical data and not so much on dynamic operations. The article of Maletič et al. (2014) does include a sensitivity analysis to see if the outcome changes if the priority rankings are raised with 25%. This research already addresses the changing situations, but this is not yet worked out. Therefore, it is important to find the factors that do affect the maintenance strategy.

Previous research has been focussing on failure analysis, and finding preventive measures to stop these failures to occur. As discussed in the first chapter TNT does not have the availability of condition-based information to develop a solution from. Therefore, finding the bottlenecks will be a first step. That requires some deep knowledge about the structure of the company and its environment. Combining literature approaches that analyse (sorting) equipment with expert reviews may provide insight in how to match the specified system to the right maintenance policy.

2.2 Research Scope, Objectives & Deliverables

In this part, the research scope, objectives and deliverables will be discussed. The scope will define the boundaries of the research followed by the objectives and deliverables of this research. These objectives and deliverables explain the goal of this research.

2.2.1 Research Scope

Maintenance in general, is a broad concept. And the factors that create a unique scenario are also enormous. Therefore, a scope is set to prevent getting lost. Even though this research delivers improvement opportunities that TNT can use to improve their performance, implementation and measuring of the results is out of the scope of this research. These two steps would take too much time and cannot be executed within 5 months. These steps are interesting though for further research. Further, this research is focusing on maintenance of material handling equipment, which contains of a

lot of parts which is difficult to analyse, and therefore does not produce a lot of data. Qualitative research is therefore core in this research. To measure quantitative data, a long period of manual measuring would be necessary. This would occupy too much time. To narrow the scope down geographically, locations within the Benelux are analysed for this research. To validate the possible improvement opportunities, expert reviews on the improvements strategies will determine the usefulness and validate if these improvement opportunities serve the determined goal. Furthermore, this thesis is hopefully completed before the 6th of October.

2.2.2 Research Objective & Deliverables

After the introduction and elaboration on previous research, this part will describe the objectives and deliverables of this research. From the research problem and previous literature, one can conclude that a broader view on operations is needed to help TNT to adapt their maintenance strategy. The objective of this research is therefore:

“Identify the constraints of TNT’s Material Handling Systems in a dynamic environment, to be able to apply the right maintenance strategy that preserves TNT’s delivery performance at lower cost.”

For TNT, this analysis is useful to see at which technologic level their sites operate, and what level of maintenance they use. Central engineering can use this analysis to see if the current maintenance practices fit operations on their sites. Site managers are then able to see these results, and they can reflect if their operations are maintained accordingly. When the current practices do not fit the advised policy, sites managers know which improvements can be made to increase their site’s performance.

Before developing improvements, some performance indicators have to be derived that really express this problem. A part of this research will be the determination of these performance indicators. Categorizing the level of mechanisation and throughput of packages per site is a first step. Differences in the level of mechanisation can vary from manual sorting, weighing and loading, to fully automated sorting, labelling and weighing. The next step is looking at factors within sites. Impact of failure, usage of equipment, age of equipment, and duration of operation can all play a role with the selection of the right maintenance strategy. That may be a more preventive strategy by executing more check-ups, or advice to have more technical skilled employees on site.

The fact that TNT is operating in a dynamic environment, including fluctuating demands, different sizes of packages, changing network structures, changing types of products and varying levels of technology, makes this a complex problem, and therefore most research is going to be explorative and qualitative. A few locations that use these MHS will be visited for this analysis. Data received from these locations will give insight in the bottlenecks of these MHS, and helps identifying parts that need improvement. This led to the following deliverables:

- Identification of TNT's performance indicators and maintenance activities
- Defining the factors that influence TNT's performance of on-time delivery
- Analysis of TNT's incidents, and develop recommendations for improvement

2.3 Research questions

From the previous research objective, the following main question is formulated:

“How can the constraints of TNT's Material Handling Systems in a dynamic environment be identified, and how does TNT preserve its on-time delivery performance at lower costs?”

To be able to answer this main research question, several sub-questions have been formulated. They are each briefly discussed. Some of these questions will have an overlap, especially in the first phase which is about gathering data.

- SQ1. Which research approach can be used to identify the constraints, and is suitable for the development of improvements?
- a. What are the different types of research approaches?
 - b. Which one is appropriate for this research?

Knowing which approach is appropriate for the analysis and improvements for this problem, is essential for the beginning of the research. This theoretical approach will provide the steps towards creating improvements. It is important to know the added value of such framework and its possibilities for the development of different types of improvements.

- SQ2. How can the operational environment of TNT be described?

Definition of the environment and processes is a first step that is needed before improvements can be developed. Knowing the current situation and activities is needed for understanding the needs and performance issues within TNT.

- SQ3. What does the literature say about different types of maintenance/operation?
- a. Maintenance approaches
 - b. Maintenance at TNT

This question elaborates the different types of maintenance and their advantages and disadvantages. Knowing the relationship between the type of operation and maintenance gives insight in what maintenance type is beneficial in which situation. A clear theoretical background is needed for the development of possible improvements.

- SQ4. Which factors should be analysed for improving TNT's site performance?

For the development of improvements and a decision tool, critical factors have to be defined. These factors are needed to focus the analysis on.

SQ5. How can these factors be analysed to develop useful solutions?

It is essential to know how these factors can be analysed using the right analytical tools. These tools will point out the parts that need to be examined for improvement.

SQ6. What maintenance approach matches the improvement needs of TNT's operation?

Implementing a maintenance approach may help improving TNT's performance. New insights can lead to an increase in performance.

SQ7. What effect will these improvements have on the dynamic environment of TNT?

When improvements have been developed, it is interesting to see what effect these improvements may have on the performance and selected factors.

2.4 Research methods

In this research, several methods are used for receiving information. After that, several approaches are evaluated to see if they fit to use as a framework for this problem. The framework is essential for analysing the problem, and is used for the development of possible improvements. It needs to be fit for this problem, and is more used as a practical framework for this research.

2.4.1 Literature Study

This thesis started with a literature study on the different theoretical frameworks. A lot has been written on these frameworks and getting to know the differences between them makes it easier which framework will contribute most in developing solutions. Next, a literature study on the different maintenance approaches is done to get a clear view on the possibilities of maintenance. Knowing the differences, and the fields within they are applied is needed for the development of possible solutions.

Another literature study is used to select the right analysis tools for the problems at TNT. The level and amount of data influence the decisions to choose for one or the other tool.

Potential sources that may be useful for this research include academic journals, scientific papers, unpublished articles, databases and internet resources. These sources can be found by using Google Scholar, Scopus, Web of Science and IEEE Xplore Digital Library.

Limitations:

Performing a literature review on the implementation of a maintenance policy might be case specific, which makes it harder to use it for this research.

2.4.2 Desk research

A large part of this research will contain of *desk research* to get to know the process and structure of a large company like TNT. Desk research is used by gathering files and papers which include information gathered by someone else (Verschuren & Doorewaard, 2013). This differs from a literature study, where the goal is to gather theoretical knowledge. Desk research is used for gathering existing facts and data. For this research, desk research is used to look into existing processes of TNT, and to see until what level of detail these are described. Desk research is also used to look into the services TNT offers, to be able to see if these services affect the operations at the warehouses.

Desk research, in combination with interviews, is also used to partly examine TNT's revenue model, to get to know the seriousness of some incidents. Knowing which activities are affecting the costs of transporting packages the most is needed for the development of solutions.

Limitations:

Desk research also has some disadvantages. Processes could miss the practical orientation, or information could be too outdated. Of the information is therefore not accurate, wrong assumptions could be made using this data.

2.4.3 Interviews

Some information cannot be gathered using literature or by existing information. Interviews are a part of *field research* which is a more empirical way of doing research. It is about gathering new data that is not described yet. Using field research, is useful when the researcher is looking for certain requirements that are needed for specifying the problem (Verschuren & Doorewaard, 2013).

Interviews will be held at service providers of the MHS. These interviews are processed into transcripts, to be able to use these interviews as qualitative information. Managers are asked for their maintenance procedures, and the way they choose for certain maintenance. These interviews will also contain questions regarding changing environments, and how they anticipate on that. Because these interviews go into depth on certain topics, the interviews will be semi-structured (Sekaran & Bougie, 2013).

Another set of interviews will be held with improvement managers and site managers at the several locations of TNT. This will give insight on the current issues within these locations, and what is done (or not) to solve these issues. The results of these interviews form, together with a failure analysis of the system, a base for developing the right solutions.

Limitations:

Due the unstructured setting of these interviews, some interviews will provide less useful data than others.

2.5 Research approaches

As mentioned before, the right research approach contributes to the development of the final result. In this case, it is important to find a framework that allows a side-step for the design of a possible supporting tool. Furthermore, choosing an appropriate approach for the analysis of the problem will contribute to the repeatability of the research. That is especially important when the research has an explorative character. This chapter will deliver an approach on which the rest of the thesis can build, and argues why this is useful in this situation. These approaches will be compared, and chosen based on their practical implementation possibilities for this research.

Four research approaches are compared for this research. These four approaches have their strengths and weaknesses, and by looking at the needs of TNT, the right method is chosen. These four methods are:

1. **Prescriptive approach** (Dym & Little, 2008)
A more design based framework, with the development of a conceptual design and final design at the end of the process. Uses technical information for the development of the design
2. **General 8-step Decision-Making** (Baker et al., 2001)
Uses the development of goals as starting point, and often an Analytic Hierarchy Process (AHP) to develop a grounded decision.
3. **Design-focussed business problem-solving** (Aken, Berends, & Bij, 2007)
This approach uses state-of-the-art knowledge from literature to develop solutions. This is a rather theory-based approach.
4. **DMAIC-framework** (Breyfogle, 2003)
A framework used by the theory of Six Sigma. A more problem-orientated approach in essence focusses on quality.

A full description can be found in Appendix A, where the steps of each framework are elaborated. Next paragraph will briefly discuss the differences between these four approaches, and compares them by the level of structure, improvement perspective etc.

Differences between approaches

In Appendix A, the four proposed research approaches have only been discussed on the way they work. The general 8-step approach, Prescriptive approach, Designed-focussed business problem-solving, and DMAIC (Six Sigma) do have different strengths and weaknesses that need to be compared. Some of these approaches are less suitable for functioning as framework than others. Summarizing the differences on several areas makes it easier to choose the right approach. This summary is shown in Table 1 on the next page.

Table 1: Comparison of research approaches (Commandeur, 2017)

Improvement approaches compared	8-step Decision Making (Baker et al.)	Prescriptive Approach (Dym & Little)	Design-focussed business problem solving	Six Sigma (DMAIC-framework)
Improvement Perspective	Process improvement	Design orientated	Process / performance improvement	Quality improvement
Level of structure	Clear and detailed prescribed steps	Open for design interpretations	General and open for theoretical input	Clear and prescribed steps
Types of data used	Qualitative / Quantitative	Qualitative / Quantitative	Qualitative / Quantitative	Qualitative / Quantitative
Advantages	Transparent decision-making approach	Detailed and tested design requirements	Performance is central, and theory based solution	Good problem analysis and proactive approach
Disadvantages	Misses detailed problem analysis	Less suitable for decision-making	No concrete analysis tools or solutions	Result based on numerical data.
Results	Final document with conclusions and final solution	Final design with specifications & documentation	Implemented and finished project	Recommendations and measures for quality improvement

First step in comparing these approaches is to look at the underlying thought of the steps. One thing that the four approaches have in common is that they use a version of the Plan-Do-Check-Act framework developed by Shewhart and Deming (Breyfogle, 2003; Tang, Goh, Yam, & Yoap, 2006). These four approaches have in principle the same structure. They define the problem, analyse it, act towards it and evaluate it. This structure has the advantages of being straightforward, clear and easy to follow.

An area where these approaches differ is in the situation they are used. Looking at the implementation of the 8-step approach, several researchers (Ierace & Cavalieri, 2009; Maletić et al., 2014) used this approach to find the right maintenance policy using AHP selection. They looked at the scenario of the company, and weighed several factors to discover which parts are important to them. Their analysis was based on the company, and not on failures and complications within the company. The Prescriptive design approach looks from another angle towards the design process. It really focuses on the design requirements and to produce a final design with fabrication specifications and documentation (Dym & Little, 2008). This approach is more used for the design of a technical product, instead of maintenance recommendations. The Design-focussed approach by Van Aken et al. (2007) is also business based, and

not necessary focussing on a technical design. This approach is theory-based instead of being based on experience and common sense, which means that the approach should be critically judge values of existing literature, and be able to creatively use theory. Six Sigma is focussing on process improvement by reducing the errors and bad quality of the product/service. Besides, the DMAIC-framework is quite structured in the way failure analysis are executed, and the way quality is measured. Nevertheless, the simple structure of the DMAIC-approach gives the possibility to include other methodologies for improvement.

Appropriate approach for TNT

After having reviewed the different theoretical frameworks, the next step is linking them to TNT's problem description. The problems and objectives of TNT should fit the approach, and the approach should be easy enough to conduct within TNT. Without the correct framework, the goal and solution may not be suitable and will not provide sufficient solution.

As discussed in the introduction, their goal is to deliver a package on-time on the right place. TNT puts the customer central, and aims for a reliable network. Their performance level is based on this on-time delivery and is together with the quality of delivery their main performance indicator. Their goal is to preserve or increase this performance, but at lower costs. However, the improvements are impacted by the variation of sorting location of TNT.

A first problem is the diversity in the level of technology within these locations. To develop solutions, and apply the right maintenance strategy, a well-structured analysis of these sites is needed. Next to that, TNT needs to find the causes of the problems with their MHS. Without knowledge of the causes, it is hard to subscribe a maintenance plan that makes sense. Within each location, different factors can lead to issues with the MHS. When TNT can control these issues, money can be saved by having better site-performance. The differences in size of the locations could also play a role. In theory, locations with higher volumes may have a higher chance on defects, but wrongly installed equipment can contribute to these numbers. An approach that includes these aspects is therefore favourable.

Another aspect to consider are the consequences of the breakdowns. To be able to give proper advice on what to do, these need to be known. The cost of losing production needs to be clear, and the amount of downtime needs to be visible to know how big of an impact certain breakdowns have. This process of finding out the consequences and causes points towards a proper failure analysis. Identification of these causes is just a first step. However, the framework should be able to give room for the development of potential improvements.

What does this mean for the research in this thesis? The objectives of TNT point towards a framework that finds the root causes from each location. The prescriptive design approach by Dym & Little (2008) will be an approach aiming for a design that encounters all the problems, with the design of a "perfect" depot as conclusion. Although the concept of a "perfect" depot can be useful, it will be impossible to compare all locations with that depot due the fact that the differences between the depots are too

large. Making design requirements is only possible on high-level which may be less useful for TNT. Therefore, will this approach be not suitable as framework for this thesis.

Using the design-focussed business approach will lead to another design. This approach is theory-based, but the problems within TNT are really diversified, which makes it hard to apply a certain theory. The openness to use and contextualize certain theories makes this approach suitable and interesting for this business problem (van Aken et al., 2007). In this case, TNT benefits from an approach that delivers more pre-defined analysis tool, which focuses more problem identification. This approach is also aiming for implementation and evaluation of the project, which is not doable within the time-period of the thesis.

The two frameworks left are the general 8-step approach by Baker et al. (2001), the DMAIC-framework. Both approaches have clear and prescribed steps towards their solution. The 8-step approach is focussing more on process improvement and well-argued decision-making, where Six Sigma is focussed on quality improvement of the service or product. The 8-step approach also offers describes some decision-making tools to compare several designs, and is clear on improving the selected process. Six Sigma on the other hand, is often used in the production industry, and used to define the current status of equipment or service. Six Sigma can start operating at higher level and builds towards a lower level solution. With the 8-step approach, the process that needs improvement already has to be defined, where Six Sigma looks at the quality but indirect also towards finding the process responsible for the quality. Six Sigma is therefore focussing more on problem identifications, which connects with the problems within TNT. So even though the two remaining approaches both have a simple and clear framework, the approach towards problem identification makes the DMAIC-framework a better framework for this thesis. Its *Define, Measure, Analyse, Improve* and *Control* approach makes it possible to translate the performance indicators to lower levels, and improving their quality of their service and equipment.

DMAIC and TNT

With the decision to use the DMAIC-framework in this thesis, the problem can be defined and analysed in a structured way. The added value of this circular approach is not only a thorough root cause analysis,

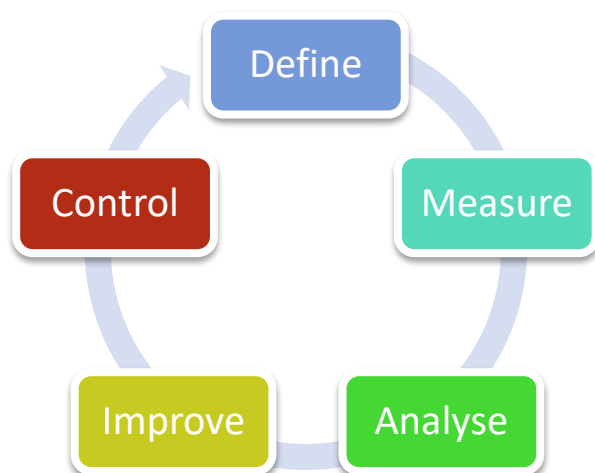


Figure 4: DMAIC-framework (Breyfogle, 2013)

but a solution that can give recommendations on several levels. The DMAIC is used as a practical framework in this research. The first phase in the DMAIC-approach is *Define*. This part will exist of a company analysis to explore their operations and their maintenance activities, and identifies the CTQ of the sorting process. These CTQ's need to be known because in the *Measure* phase these CTQ needs to be traced back to qualitative or qualitative data. And if there is no available data, processes have to be measured and to provide this data. The analysis of this data will lead to root causes, which are responsible for the lacking performance of TNT. These root causes will be eliminated by the

development of recommendations and a supporting tool in the *Improve* phase. The *Control* phase will provide guidelines on how to implement the suggested improvements and how to use this research for future improvements related to TNT's performance.

2.6 Research framework

This research is executed at TNT at the department of service & maintenance. An overview is provided in figure 5. The first part will be gathering theoretical knowledge. The literature reviews will provide knowledge on the maintenance approaches, and on theoretical frameworks. A theoretical background is needed for further research, to be able to get the right content from interviews in further stages. Sub-questions 1, 2 & 3 will help with the development of this knowledge. Next, the analyses phase is where the problem is analysed. Derived factors are analysed for the development of the right solutions. In the final phase, the recommendations and supporting tool will show their value and impact on the situation.

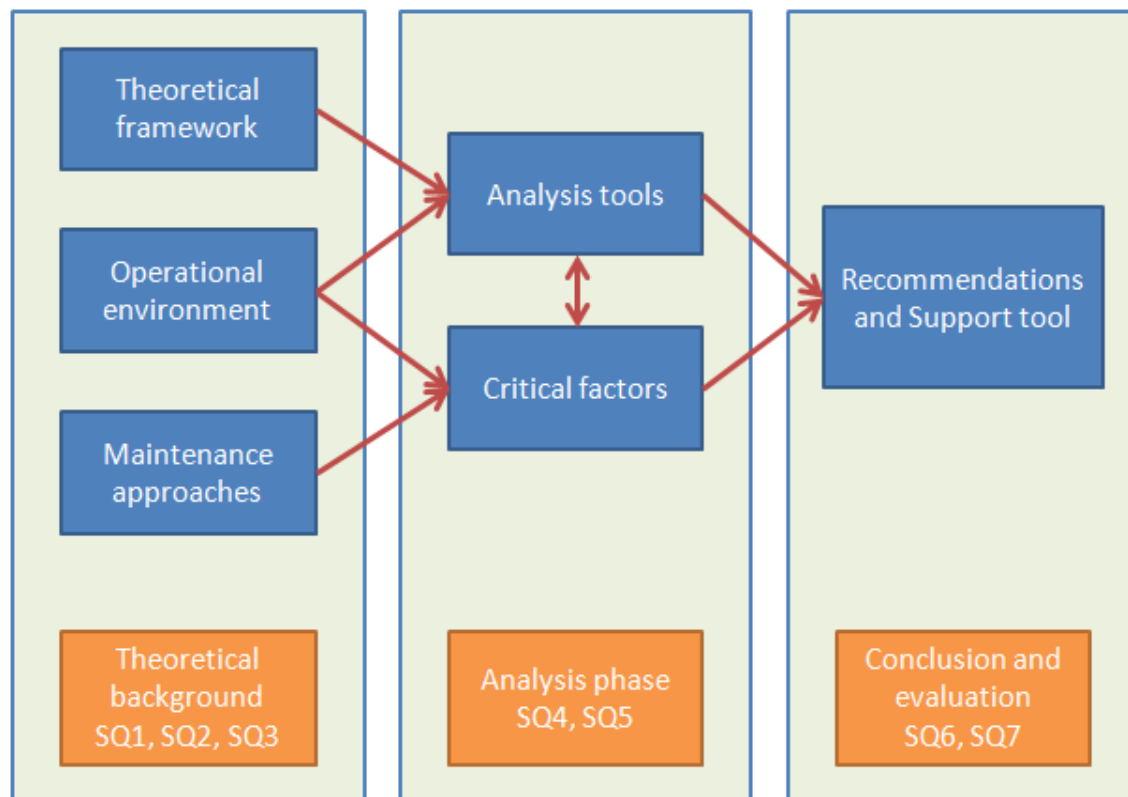


Figure 5: Research Framework

This framework concludes this chapter on research methods and methodology. With a research approach chosen for this problem, a start can be made on defining the critical quality factors and exploring TNT's processes. This is discussed in the next chapter.

3 Needs & Requirements

This phase is first in the DMAIC-framework. Defining the problem and CTQ is essential for working towards a solution. To be able to understand the problem of TNT it is necessary to know what effect the incidents have on TNT's performance. Also, knowledge about maintenance in general and maintenance at TNT is needed for this research. Knowing the material handling processes within TNT, and seeing the differences per locations also provides useful information for the failure analysis. Finally, knowing the relationships with the suppliers and their responsibility in maintaining the systems can lead to interesting discoveries.

3.1 TNT and its Material handling process

First step is to analyse TNT's network and structure. To be able to develop recommendations and a supporting tool, it is important to understand the technical and operational maturity of TNT's locations. As mentioned in the introduction, TNT uses a network that mostly transfers parcels from business to business (B2B). These travel through hubs and depots to get to their destination. The packages and pallets enter the network via their depots. TNT has a standard ICOM (Inputs, Controls, Outputs,

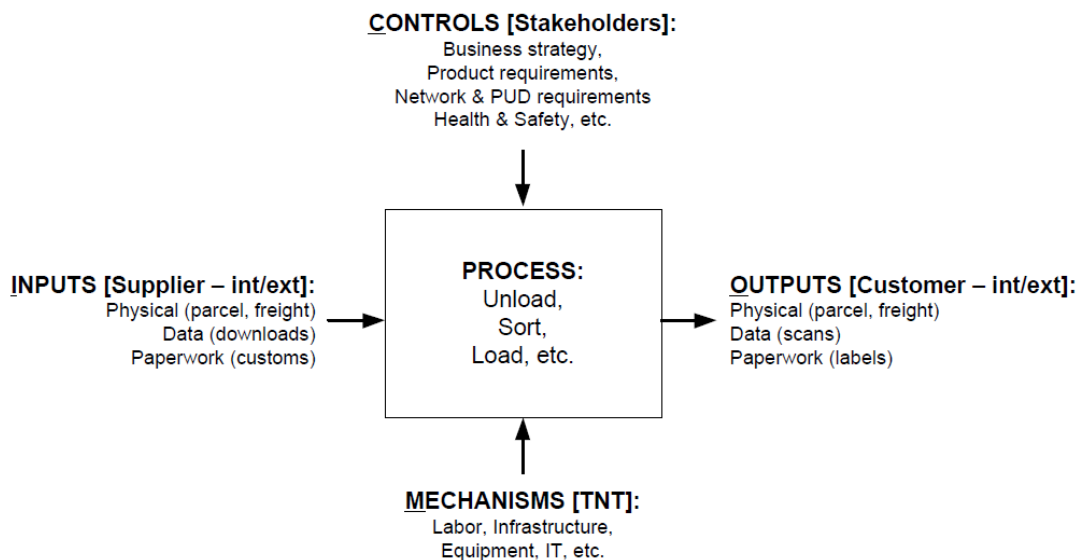


Figure 6: ICOM standard (Waissi et al., 2015)

Mechanisms) model which describes a standard operations process (Waissi, Demir, Humble, & Lev, 2015). This ICOM standard is used in the industry to develop a process with multiple inputs and outputs. As shown in figure 6, the inputs stand for parcels, data and paperwork delivered by internal or external suppliers. Controls are the process requirements that needs to be meet during the process. Think of health and safety during work and product requirements during a process. Mechanisms are the inputs by TNT which are necessary for the process. These can usually be found at the area where the real operations take place, like labour, sorting equipment, infrastructure and IT. This part also contains

services provided by 3th parties like maintenance and sorting. Finally, the output represents the transformed input which is delivered to internal or external customers. This ICOM standard is present in every stage which creates a standard process for TNT's sorting locations shown in figure 7. This standard process contains all the different steps that are usually taken in a depot or hub. TNT created standard requirements for each step to distinguish the different performance indicators with unloading, infeed

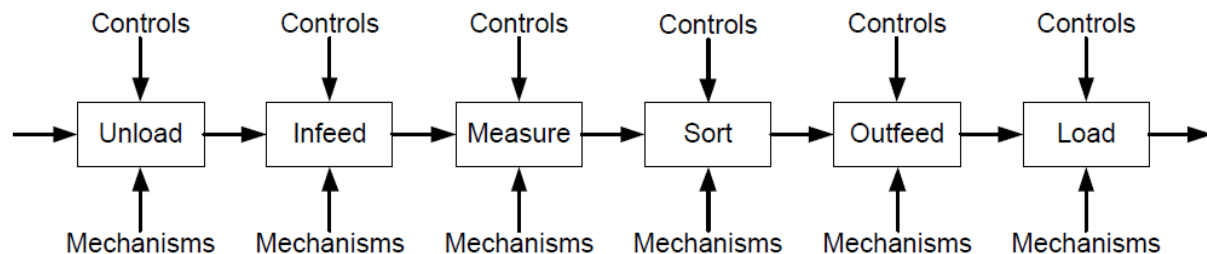


Figure 7: Standard process with linked ICOMs (TNT, 2016)

etc. Advantages of such standard are a faster and more efficient design of processes for hubs and depots, adding discipline in a work culture and serving as a basis for continuous improvement. This ICOM standard is especially useful for new locations and re-design of old locations that needs to be updated.

For each of the six steps shown above, the ICOM standard digs deeper into operational scenarios with different types of unloading. Examples are by a flexible conveyor, roll containers and pallets unloaded with forklift trucks. For each of these situations TNT has defined the inputs, outputs, controls and mechanisms are determined. Describing these different settings in each step in the process gives clear and detailed information on how the area and working conditions should look like. Analysing the process of a package gives insight in the process, and where things can go wrong. Within TNT internally, packages can be roughly separated in three product streams with some sub-streams. These three product streams are separated and use different equipment. It is therefore interesting to see if issues differ related to these product streams. Or that same root causes are responsible for likewise errors amongst different equipment.

1. Conveyables

These are the packages that can be sorted by the material handling systems and have specific dimensions and weight. Minimum dimensions are 0.0m x 0.00m x 0.00m with a minimum weight of 0.00 kg. If the package has smaller dimensions or lower weight, the package falls under Smalls & Documents. The maximum dimensions are 0.0m x 0.0m x 0.0m with a maximum weight of 0kg. If the package is bigger, it becomes a non-conveyable. There are some restrictions within these dimensions, but they are irrelevant for now. Most of the packages are covered under this product stream. These dimension restrictions are necessary so that the sorter can handle the packages without causing a malfunction.

2. Smalls & Documents

As the name already suggest, this products stream contains small packages and documents. This is a relative small part of the business but nevertheless an important one. Their

dimensions and weight are an issue for the material handling systems and therefore need to be handled separately.

3. Non-Conveyables

Non-conveyables are all other products that don't fall into the previous categories. Pallets are one of these non-conveyables. They have to be dimensioned and weighed on a special scale. This also applies to "awkward freight" which are the packages with different dimensions or weight. Think of round objects or bags. A last sub-stream is "dangerous goods". Goods that need special attention or special handling are also processed separately.

Firstly, a package (or conveyable) enters the unload process. These can be unloaded using a conveyor which is placed in the truck or van, where an employee scans the packages first with a wrist scanner and puts them on the conveyor. They could also enter in roll containers with an average of 30-35 packages at the same time. These cages are then transported to the sorter by pallet jacks or forklift trucks to the infeed location within the depot or hub. Besides the inputs, controls etc. does the ICOM standard also provide Critical to Quality (CTQ), Critical to Performance (CTP) and Critical to Cost (CTC) requirements. TNT defines CTQ as "doing the job right", CTP as "doing the job on-time", and CTC by "doing the job efficiently" (TNT, 2016). These requirements are designed to guard the quality of the packages and to keep the focus on the important goals of the process. These requirements can slightly differ in each phase to match the requirements for that particular process. A summary of these requirements can be found in table 2.

Next step in the process is "Infeed". When packages are not directly loaded on conveyors they are placed from the roll containers or pallets on the conveyor if they contain the right dimensions. The employees have to separate the packages that are too small and light or too large and heavy. After this infeed, the packages are measured. Different packages are measured in different ways. Conveyables on the sorter are weighted and measured by a Check-Weigh-Cube (CWC) system from Vitronic (see figure 8). This modern system is able to scan and weight the parcels that move on the conveyor with high



Figure 8: Check Weigh Cube Vitronic (Vitronic, 2017)

speed. Checking the dimensions is an important process, because the customers are billed on the dimensions or weight of the package. Although the customer has to register the dimensions and weight before they send their package, some of them put (unintentionally) lower dimensions on the shipping slip which may save them some costs. A case study within TNT found out that weighing and measuring the parcels saves more money due to the fact that the customer is billed afterwards if the specified information is wrong. Measuring is therefore important in the standard process. Non-Conveyables are

measured using special scales and cameras that scan the packages. For pallets the same applies, although they are weighted on special floor scales in the ground.

Next step is sorting. As mentioned before, sorting sites are more and more automated, and in most cases the sorter undergoes the biggest change. Each sorter within TNT is different, which makes it hard to make a standardized process. Some locations have a simple straight-line conveyor, where packages are just put on the conveyor, scanned and manually have to be sorted on the right cage for the right destination. This sorter only makes sure that the package moves from one side to the other side. With a fully automated sorter, special infeed locations are defined, and output/outfeed chutes are designed for each location. The sorter reads the barcode and knows where to push the package on to which chute. There are several technical systems that can separate and sort packages.

- Shoe sorter

This sorter uses small sliding blocks on a conveyor. These blocks have the ability to slide from left to right and can sort therefore on both sides of the conveyor the number of shoes can differ, depending on the size of the package. The sliding blocks push the package to the right chute. Disadvantage of this system can be the number of moving parts. But its simple design makes it quite robust.

- IQ-grid sorter

This sorter uses a series of wheels on every cross-section. They can also turn to both sides of the sorter and sort the packages to the right chute. Packages are transported by belts and pushed on the IQ-grids and they push the package the right way. Advantage is that the system can work in two ways. Although this system has less moving parts, it is a more complex design. That can lead to more issues.

- Cross-belt sorter

This system is a combination of a (chain driven) system that has a package on separate small belts. These smaller belts have the possibility to turn left or right which makes it again possible to sort on both sides. Advantage is this system is that parcels are already separated at the beginning, and that issues with parcels stacked or too close to each other are eliminated. This system has the possibility to sort at high capacity.



Figure 9: Different types of sorters

Some sorters do also have a loose load chute. This chute can be placed directly into a truck where parcels can be loaded directly into the truck without being placed on a roll container or pallet. The other parcels remain on the other chutes where they are ready for outfeed. This process is rather small because the packages only need to be moved from the conveyor onto the right pallet or roll container. Right after that, the loading process starts. The packages are loaded into the vans and trucks by forklifts trucks and pallet jacks. If the truck is full, or everything for that specific location is in the truck it is ready to go to drive to the next hub or depot. To see how all these different parts are connected, next figure shows a lay-out of depot Eindhoven. In this set-up, the blue parts represent the infeed areas where

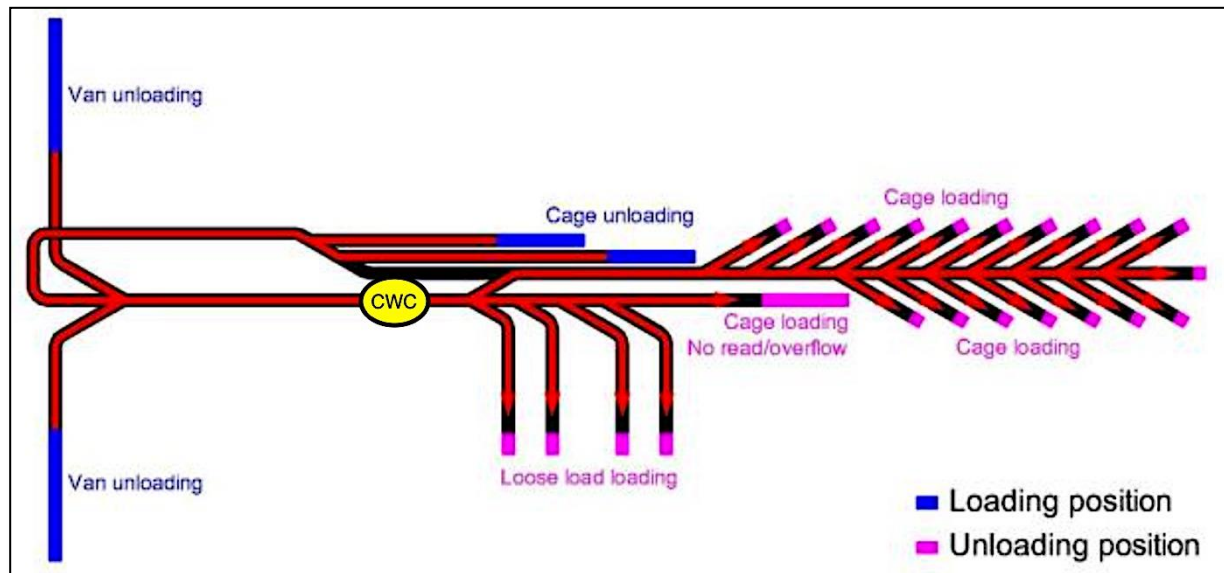


Figure 10: Overview sorter of depot Eindhoven (TNT, 2016)

parcels are unloaded from the vans and trucks. Four clear infeed lines show the multiple possibilities of unloading parcels. These four lines are merged into line that passes the CWC for measuring the parcel. When it is measured, it can go towards the loose loading belts, which can be extended all the way into the truck, or it goes to one of the separate chutes with specified location codes. This also shows that the importance of the centre of the sorter is most important, because that would completely stop the operation. When only one chute is not functioning, only a small part of the operation would be delayed. Therefore, different parts have different weights regarding the consequences of failure. Forklift trucks are driving around this sorter to transport blue cages with parcel into trucks, or move around the pallets that need to be transported as well. So, if the sorter stops working, the transportation of pallets is also hindered.

Describing the process in the hubs and depots makes it clearer what goes around at TNT's operations. As mentioned earlier, every process has several CTQs, CTPs and CTCs. In this Define phase is it essential to find the CTQs which are important for TNT to improve. A CTQ that catches the attention is *Perfect condition*. This CTQ is present in every phase the ICOM-standard. TNT defines *perfect condition* as a package with no damage and handled with care. However, looking at TNT's problems with their MHS, one can conclude that maintenance and breakdowns have no effect on the physical condition of the package. This CTQ is therefore not the right indicator to research in this thesis. Working *accident-free* is

also one of the main CTQ indicators. Looking at the problem statement of TNT and the first causes of downtime, it shows that this indicator is not related to maintenance and service. Nevertheless, it could play a part in manual sorting, which is sometimes needed when the material handling process is disrupted. Hence, the CTP *on-time arrival* is important. When processes are delayed, the on-time delivery of the packages to the customers is also in danger. Because they are striving at a 100% on-time delivery, this CTP should be taken into account.

Table 2: Criticality indicators ICOM process (TNT, 2016)

<i>Criticality indicators per phase</i>	CTQ	CTP	CTC
Unload	<ul style="list-style-type: none"> Perfect condition Accident-free unloading 	<ul style="list-style-type: none"> On-time arrival of vehicles Scan response time Uptime of standard equipment 	<ul style="list-style-type: none"> Unit cost
Infeed	<ul style="list-style-type: none"> Perfect condition Barcode visibility Accident-free <u>infeeding</u> 	<ul style="list-style-type: none"> On-time arrival of vehicles Uptime of standard equipment 	<ul style="list-style-type: none"> Unit cost
Measure	<ul style="list-style-type: none"> Perfect condition Barcode visibility 	<ul style="list-style-type: none"> On-time arrival of vehicles Uptime of CWC-system Scan upload time (<u>msec</u>) 	<ul style="list-style-type: none"> Unit cost
Sort	<ul style="list-style-type: none"> Perfect condition Barcode visibility Accurate data Accident-free sorting (pallets and non-conv) 	<ul style="list-style-type: none"> On-time arrival of vehicles Sufficient availability of electrical power Scan upload time (<u>msec</u>) Data download time (<u>msec</u>) Availability of roll containers, carts, etc. 	<ul style="list-style-type: none"> Unit cost
Outfeed	<ul style="list-style-type: none"> Perfect condition 	<ul style="list-style-type: none"> On-time arrival of vehicles Availability of roll containers, carts, etc. 	<ul style="list-style-type: none"> Unit cost
Load	<ul style="list-style-type: none"> Perfect condition Last in - first out (proper loading & stacking) Accident-free loading 	<ul style="list-style-type: none"> On-time arrival of vehicles Scan response time (<u>msec</u>) Uptime of standard equipment 	<ul style="list-style-type: none"> Unit cost

Next to the MHS, there are also the employees that have to work with the equipment. They are responsible all task on the floor like sorting, loading, driving, repacking, weighing and labelling. This is most of the time a low-level job that doesn't require much education. Nevertheless, salaries are not too low due to working often in the evenings and nights. Within the Benelux, most of these operators that execute these tasks are flex-workers provided by employments-agencies. To guide the operators on the

floor, TNT has team leaders (TL) and leading hands (LH). These TL and LH are responsible for the operators and have to guide a team on their tasks. They have to make sure that the tasks are being performed and that late incoming freight is still sorted. The TL and LH are often contracted by TNT, and not by employment-agencies.

That concludes the first part that describes TNT's MHS, and the equipment used to sort the packages. Knowing the types of sorter, and the lay-out helps understanding the importance of the system, and why TNT is striving for a high performance. Part 3.2 will describe maintenance in general and some new insight in monitoring and determining the right maintenance interval. Part 3.3 will describe the current maintenance activities within TNT.

3.2 Maintenance

After having described the sorting process at TNT, it is time to discuss maintenance. This part will first describe maintenance in general, what it is, how it can be used and how it is developing. After that, the maintenance method and procedures at TNT are explained. This gives insight in the structure and solution TNT has for handling issues and downtime.

3.2.1 Maintenance in general

Maintenance is becoming more and more important in the business environment (Maletič et al., 2014). Companies are integrating maintenance into their corporate strategy to gain competitive advantage. Maintenance costs can range between 15 and 40 percent of the total production/operational costs. With this in mind, the financial impact of maintenance can therefore be substantial (Waeyenbergh & Pintelon, 2002). Besides, proper maintenance contributes to the overall performance of a company and helps achieving the business objectives.

As discussed briefly in the introduction, maintenance can be categorized in several groups. According to Horner et al.(1997), maintenance can be divided into 3 groups; corrective maintenance, preventive maintenance and predictive (condition-based) maintenance. First concept discussed is corrective maintenance, also known as failure based maintenance. CM only happens after an event or breakdown occurs, and the goal of CM is to correct this event and restore the piece of equipment or system to the original state. CM doesn't undertake any action to detect or prevent failures happening in the future (Maletič et al., 2014). Corrective maintenance is often preferred if the non-availability costs are relatively low compared to the maintenance costs. If the impact of an event or breakdown doesn't affect the whole process, it could be beneficial to use CM as main strategy.

The second concept is Preventive maintenance. PM was introduced to reduce the probability of occurrence of failure. This can time-based, planned maintenance or cyclic maintenance (Horner et al., 1997). Planning maintenance at regular intervals, gives insight in the current condition of the equipment, which can be planned outside the operating times of the system. Preventive maintenance is not just replacing and overhauling before something breaks down, but also conducting lubrication,

cleaning and inspection (Maletič et al., 2014). Advantages of using PM are a decrease of downtime. This is the time that the equipment is out of service, which can have large effects on the company's process. Second, health and safety of the employees can be improved by having less spontaneous breakdowns. Third, if the severity of a breakdown is high, it is often beneficial to execute preventive maintenance (Horner et al., 1997). An example is a large production process, where an event or breakdown leads to stagnation of the whole process. Here, a failure is way costlier than PM.

The third concept is predictive maintenance (PdM). This concept aims for the prediction of maintenance. PdM is about measuring the condition of a system on deterioration rate, and acting on it when it passes a certain limit. Gathering data on the usage profile will help replace or repair only the necessary parts. Measuring the condition (Condition Based Maintenance), is helpful for planning, analysis and conducting maintenance actions cost-effectively (Maletič et al., 2014). Collecting this data is possible using several technologies. Measurements based on vibrations are one of those options. In a study by Al-Najjar (2000) showed that measuring real-time data, and in this case frequencies and amplitudes, helps developing effective diagnosis and prognosis to detect defects. This method does require collection of data, and a platform that has the possibility to link this data with different operational settings. Knowing frequencies is one thing, but the connection has to be made with the causes of these fluctuations.

The hardest part is to make a trade-off between these maintenance approaches. This trade-off all comes down to the benefits and costs of implementing one strategy over the other. To make a well-considered decision, a cost-benefit analysis shows what is best to do from a financial point of view. Doing too much

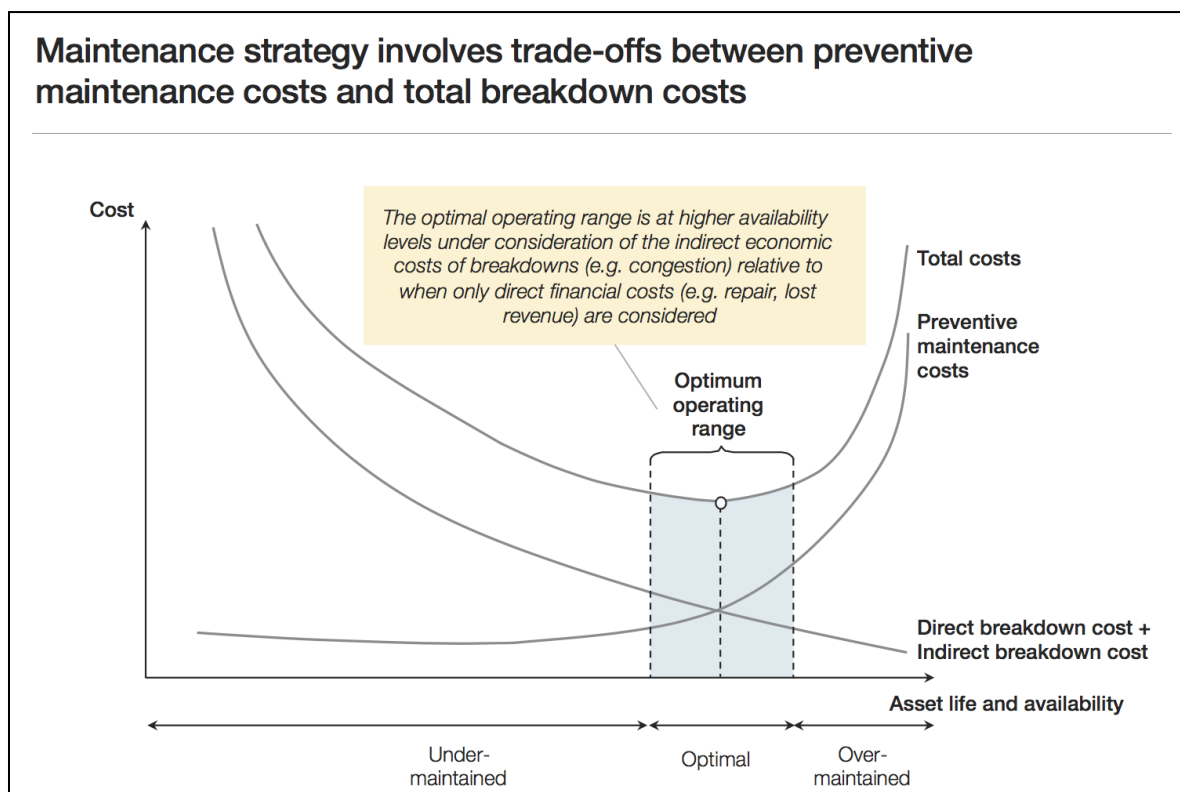


Figure 11: Trade-off between Preventive and Corrective maintenance (retrieved from: World Economic Forum, 2014)

preventive maintenance will lead to better performance, but also to high costs by checking and replacing more parts than necessary. Doing too less maintenance will lower a company's performance, but also its maintenance costs. Figure 11 shows the effect of an increase in PM compared with breakdown and repairs costs (CM) and its typical shape is known in the maintenance industry. The optimum range is a combination of CM and PM which leads to better performance (fewer breakdowns) at lower costs. The associated costs of CM (breakdown costs) in general consist of several factors:

$$CM (\text{€}) = (MTTR(h) + \text{Mechanic delay}(h)) * \left(CM \text{ downtime rate} \left(\frac{\text{€}}{h} \right) \right)$$

Where MTTR stands for the time needed for it to repair. Mechanic delay stands for the time needed by an employee or OEM to get to the breakdown before starting with the repair. CM downtime rate is a factor that can include multiple factors that influence the rate. For TNT, think of costs of damaged goods, late deliveries, dissatisfied customers, spare parts and labour costs of employees that cannot work. For preventive maintenance, this general formula looks a bit different:

$$PM (\text{€}) = (\text{Costs of expected breakdowns}(\text{€})) + (\text{Costs service contracts}(\text{€}))$$

With PM (and PdM), the unexpected breakdowns are prevented, so the costs exist of expected breakdowns. These could be separated again in the downtime rate times the MTTR, but because this maintenance is planned, this is often lower. It does include costs of service contracts. This factor consists of the costs for extra maintenance (before failure) by third parties or by own mechanics. These could also include training costs and extra data systems to monitor equipment. To be able to make a trade-off and choose for an optimum solution, all these costs aspects need to be known.

3.2.2 Dynamic maintenance

A more recent development in maintenance approaches is “dynamic” maintenance. In this approach, maintenance relies on the actual usage or system degradation (Tinga, 2010). PdM as discussed above is already a form of dynamic maintenance, where sensors and measuring the condition of parts give a good indication of the state of the system. Also using historical failure data is an example of simple dynamic maintenance. These are experience-based because they rely on previous events. Using modelling tools to predict failures of a system is also a form of dynamic maintenance. The advantage of modelling is that with the knowledge of material behaviour like creep, fatigue and corrosion, material failures can be predicted quite well. Disadvantages of historical based predictions are that loads and usage do not change in the future. Otherwise it is hard to predict failures of the system when these loads change. Disadvantage of condition based maintenance is that one has to implement sensors and measurement tools, and have a data platform to collect and analyse this data. This is not always feasible either because technology or economic reasons.

A different approach within dynamic maintenance is based on usage and load measurements, i.e. load-based or usage-based maintenance. Measuring loads and usage is often easier. Examples loads and usage are operating hours, start-stops, operational speed, temperature and weight. The relation between usage and remaining life still has to be defined. Knowing what affect the loads and usage have on creep, fatigue and wear and tear is required to give an accurate prediction. A Failure, mode, effect and criticality analysis (FMECA) is needed to determine the critical parts or components in the system. A schematic representation of getting from usage to remaining life is visualized in figure 12. Knowing the physical failure mechanisms and linking this to the load is essential.

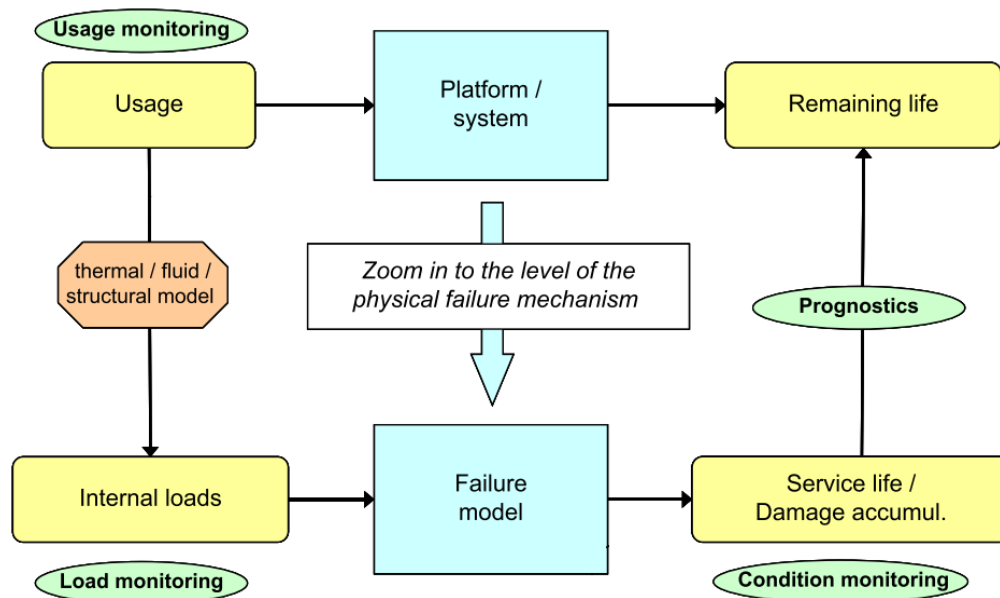


Figure 12: Relation between usage, loads and remaining life (Tinga, 2010)

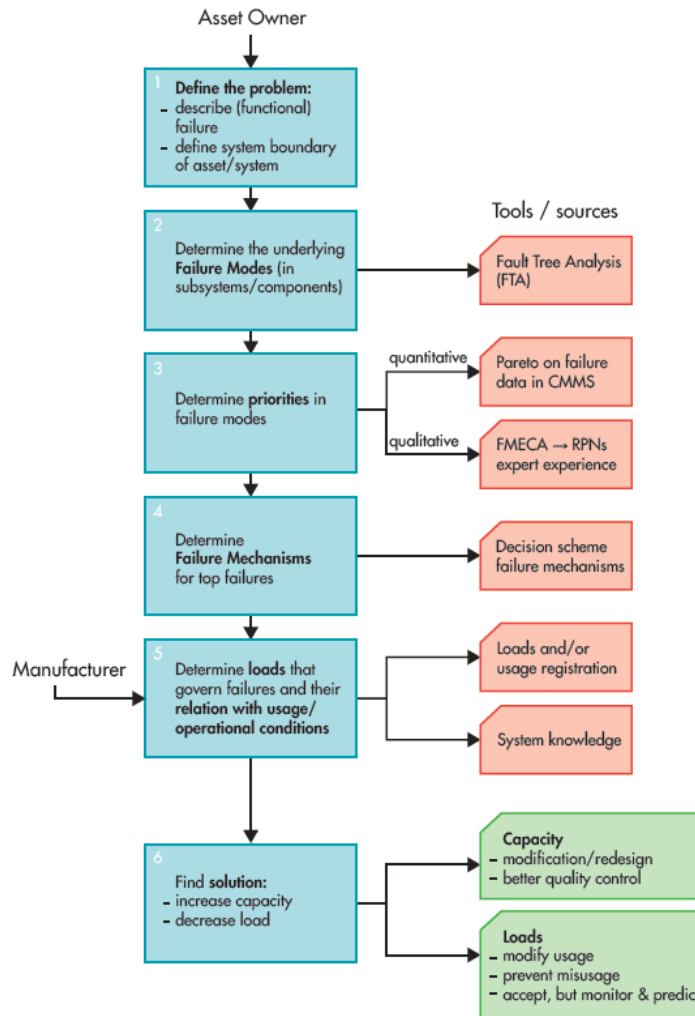


Figure 13: Failure analysis process (Tinga, 2013)

relationship between usage profile and degradations rate. This case didn't base its analysis on a detailed physical model. They identified the critical components of the military vehicle and identified the usage and loads that affect this component. First, this part had to be replaced every 800 km at normal usage. But with different surface types and roughness of the terrain, the wear and tear increase and the lifespan becomes shorter. They determined the impact of these changing situations and developed weightings for the different terrain types. The results showed a simple but clear overview on the distance a combat vehicle could drive, before the critical component fails. The good thing from a failure analysis like this is that measuring the number of kilometres and type of terrain is much easier than measuring the creep and fatigue of the given component. Maintenance can be adjusted to the situation where the combat vehicle is being used. And this way maintenance can be executed in a more "dynamic" way. The advantage is that maintenance is performed at the right interval, and that no unnecessary costs are made by doing too much maintenance, but still be on time before failure. If monitoring the actual conditions of material is difficult, using loads and usage may be an interesting technique to determine the right maintenance interval.

Zooming a bit more into the selection of critical components is required. There are several methods to find the root cause of a failure. A fault tree analysis, Pareto analysis, root cause analysis and FMECA are all examples of methods to analyse failures. To be able to get a sufficiently deep level analysis of the failure a procedure is proposed that does the advantages of the methods named above (Tinga, 2012). This process is shown in figure 13, where step by step the failure modes, priorities, failure mechanisms, loads and solutions are developed. Step 5 in this process can be a hard step. Manufacturers often have knowledge about the failure mechanisms, but don't have insight in the operation process. Therefore, a link between the failure mechanisms and the loads is necessary to find suitable solutions.

In an article by Tinga (2013), they tried to find this relation between failures and loads. They apply this process on several cases. One of these cases describes a military vehicle. In this particular case, the research is on a more high-level

3.3 Maintenance at TNT

This part will describe the current maintenance activities within TNT and how maintenance is set-up in new locations. Maintenance within TNT is a combination from corrective, preventive and small amounts of predictive maintenance. In some locations maintenance is completely outsourced, and some locations have own mechanics on site. The essence of having a maintenance team on-site depends on the size and criticality of the location. This criticality can depend on various factors like the number of locations connected to that site, the number of process packages and the network function. In the data of Table 3: Package Pieces, the amounts of packages of most locations in the Benelux are visible. The only large location missing in this data is Liege air hub, which is processing the most packages within the Benelux. However, this location is due its size and function such an important chain in TNT's network that it is covered by another entity within TNT.

For large sites, TNT has dedicated mechanics on site that perform preventive and corrective maintenance. These mechanics are either TNT's own employees, or mechanics from suppliers. The advantages of having technicians on site are the availability and speed of executing maintenance related activities when needed. These mechanics have the ability to check and inspect the MHS more often, and perform related preventive maintenance if needed. New large locations within TNT's network are

Table 3: Package Pieces (2016)

Number of pieces 2016		
Location:	Total	%
Arnhem hub (QAR)		0.0%
Brussels hub (BZQ)		0.0%
Eindhoven depot (EIN)		0.0%
Brussels depot (BRU)		0.0%
Antwerp depot (ANR)		0.0%
Arnhem depot (ARH)		0.0%
Kortrijk depot (KOR)		0.0%
Rotterdam main depot (RTM)		0.0%
Schiphol-Rijk depot (SP8)		0.0%
Liege depot (LGE)		0.0%
Amsterdam global transit hub (AMS)		0.0%
Zwolle depot (ZWO)		0.0%
Luxembourg depot (LUX)		0.0%
Nieuwegein depot (NW7)		0.0%
Heerlen Health depot (HH6)		0.0%
Grand Total		0.0%

equipped with the latest MHS where control rooms monitor the process and flows of the parcels. Besides a trained mechanic who is capable of repairing these MHS which are based on control technology, a process engineer is needed to analyse these flows and processes to look for improvement. These types of jobs are so specific and have to be able to change alongside technology, that TNT

outsources these jobs. These mechanics and engineers are still on-site, but owned by a third party who (mostly) designed the MHS. It is often too expensive to train own TNT personnel to do these jobs, because they require a lot of training, where the employees from the supplier or third party have the latest information that they can directly apply. Looking at the sites in Table 3, the only site with a dedicated team on site is the Arnhem hub (QAR). This location processes relative many packages compared to the other hubs and depots.

When mechanics are not on-site, maintenance practices have to be executed by mobile mechanics either from TNT or from the supplier. For all other locations within the Benelux TNT has a protocol for issues within these hubs and depots (figure 14). When a breakdown or failure occurs, the TL of the hub or depot make a call to the Operations, Equipment and Services (OES) -team. TL are responsible for a team of operators on the work floor and are the first point of contact when a failure occurs. These TL are not technical skilled, and are instructed to call the OES-team first.

This team consists of four mechanics stationed across the Benelux. They are a mobile maintenance team that is responsible for maintaining the MHS at the locations within the Benelux without dedicated mechanics. They carry out corrective and preventive maintenance and judge whether to call the supplier for maintenance or do it themselves. Although this OES-team is not working as dedicated on-site

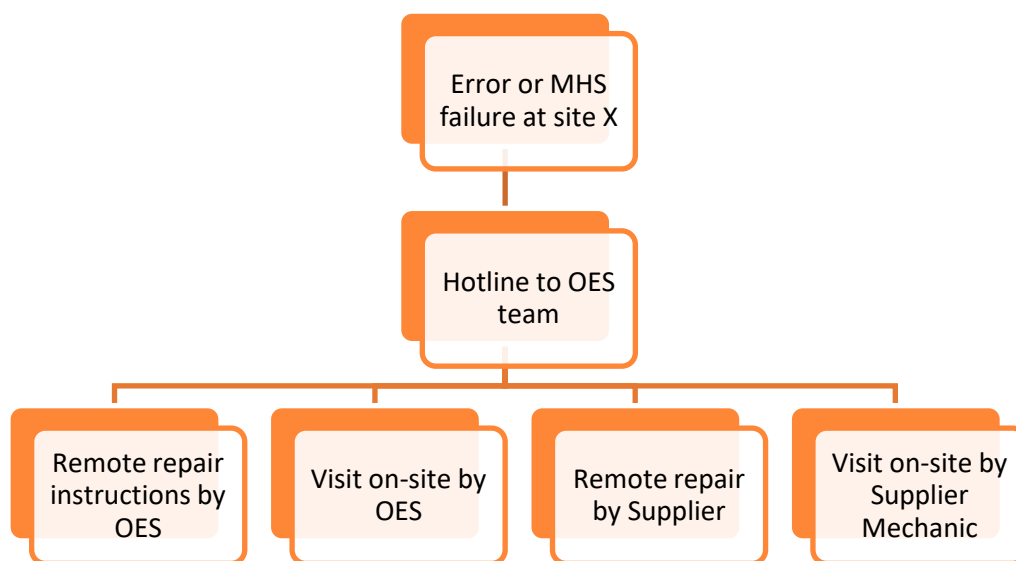


Figure 14: Breakdown procedure

mechanics, they do have a “base” location from where they operate. Two mechanics have Brussels as base location where the hub BZQ and the depot BRU are located in the same building. This allows them to be their quickly and have a better view on the state of the MHS systems. Although the hub BZQ and BRU are based in the same building, they operate as independent entities in the network. This scenario also exists in Arnhem, where the depot Arnhem and hub Arnhem are also located in one building. However, due to the separation of entities, the in-house mechanics or QAR do not execute all the maintenance in the Arnhem depot.

Looking back at the breakdown procedure, the OES-team's first attempt is to guide the TL or LH with instructions to solve the issues on their own. If the OES-team judges the problem to be too difficult to be solved by the TL, they drive towards the site to repair the MHS by themselves. The OES-team works outside office hours with 24/7 emergency service. So, if a breakdown occurs in the evening process, they need some time to get to the site depending on the location. This increases the downtime of the sorter. If the OES-team knows that they need supplier service (remote or by a visit) they make the call towards the supplier. The OES-team being responsible for the communication with suppliers regarding the issues keeps them informed with the state and problems of the MHS. The supplier tries to solve the issue remote, by restarting the system or checking and updating the software. If the supplier arrives on-site, they execute repairs that the OES-team is not capable of, or not allowed to do. Reasons for that can be the special equipment the supplier uses for the repairs, special knowledge of the system of the supplier, or by legal reasons. TNT uses the Check-Weigh-Cube (CWC) to bill their customers if they give up wrong dimensions and weight, and therefore they are not allowed to replace or repair the machine by themselves, to prevent that they manipulate the system in TNT's advantage. When they do, seals of the CWC are broken and TNT is not allowed to bill their customer anymore until it has been checked by an independent third party.

3.3.1 Preventive maintenance & Service contracts

Besides the corrective maintenance actions by suppliers and own employees, PM is also executed by suppliers and employees. The OES-team had the goal to do PM every month at every location within the Benelux. From an interview with Edwin Veld of the OES-team (Personal communication, April 3, 2017), they have trouble with reaching this goal due to the fact that a high frequency of issues at other locations takes over their time. During their preventive maintenance tasks, they inspect, clean, and lubricate the MHS to see if there are any upcoming issues and prevent them from happening. For replacement of roll-conveyors or belt-conveyors, spare parts are available at the location which gives the mechanics the possibility to replace parts if necessary. Other parts regarding the CWC and other measurement equipment is not available at every site, but centralized at depot EIN. Due to the lower failure frequencies, there is no need to decentralize this. The number of spare parts is determined by the suppliers, but can be adjusted by the advices and insight from the OES-team mechanics.

Next to the preventive maintenance tasks by the OES-team, TNT has service contracts with suppliers to maintain their equipment. From the interview with Edwin Veld (Personal communication, April 3, 2017), contracts differ between location by the fact that the projects were locally organized. However, the shift to a more centralized focus of TNT led to some agreements that apply on most locations within the Benelux. For the sorter itself, the manufacturer is responsible for the preventive maintenance. At smaller and simpler locations like Schiphol-Rijk or Zwolle, the supplier of the sorter only comes twice a year to do a check and preventive maintenance. They make a rapport regarding the parts that need to be replaced, and make an order to do so. The OES-team can decide to execute these activities themselves, or to let the supplier do it when it is too complicated. At larger and more complex locations, suppliers come more often due to the complicated character of the sorter. In Eindhoven, the supplier Van Riet comes every two weeks to check on the sorter and perform PM. For other equipment like the CWC,

pallet scales and scanners, TNT has other contracts. The CWC supplier Vitronic is visiting each site twice a year for PM. Vitronic will mostly clean, check and lubricate their system. The pallet scale in the floor is also cleaned by removing dirt and dust. The OES-team also cleans the pallet scales once a year at each location, due the fact that they require a more frequent clean-up.

Next to the PM that the suppliers have to do, the service contracts also contain agreements on the emergency service that TNT wants. When the MHS fails, the suppliers have a certain time-limit when they should support remote support or have to be on-site. TNT has in depot Eindhoven a contract with Van Riet that they need to give hotline support and software support within 15 minutes during office hours. When Van Riet needs to be on-site because they cannot repair the sorter remotely, they need to be on-site within two hours after it is called in. These agreements however differ in each location, due the fact that they are made within different periods. For the equipment besides the sorter, TNT made Vitronic responsible as first contact during a breakdown. So, when the OES-team decides to bring a supplier on-site for maintenance they call-in with Vitronic. Vitronic is responsible to forward the service call to the other suppliers. This creates a simpler communication structure for TNT, and puts more responsibility at the supplier.

In the latest large new projects of TNT, they used Service Level Agreements (SLAs) and outsourced the maintenance activities more than usual. An example is the new TNT site in Tremblay, France. The sorter is built by VanderLande B.V. and uses a SLA for its performance. In this example VanderLande is responsible for the delivering a 00% mechanical availability of the sorter. VanderLande uses data of the whole system to analyse its availability, something that is also a step too far for TNT to do it themselves. An advantage of such a contract is that the almost all responsibility lies at the supplier which is comfortable thought. Such an agreement does ask for mutual trust between the companies. These agreements and guidelines are used in more projects and are initiated from a more central point within TNT. This helps in measuring performance, and reviewing the efficiency and availability from multiple sites.

Looking again to figure 15 that describes the trade-off between PM and CM (breakdown costs), one can conclude that the existing locations within the Benelux are located at the left side of the optimum operational rate (orange line). The breakdown costs and corrective maintenance costs are currently too high, and there is not enough preventive maintenance available to turn this around. This

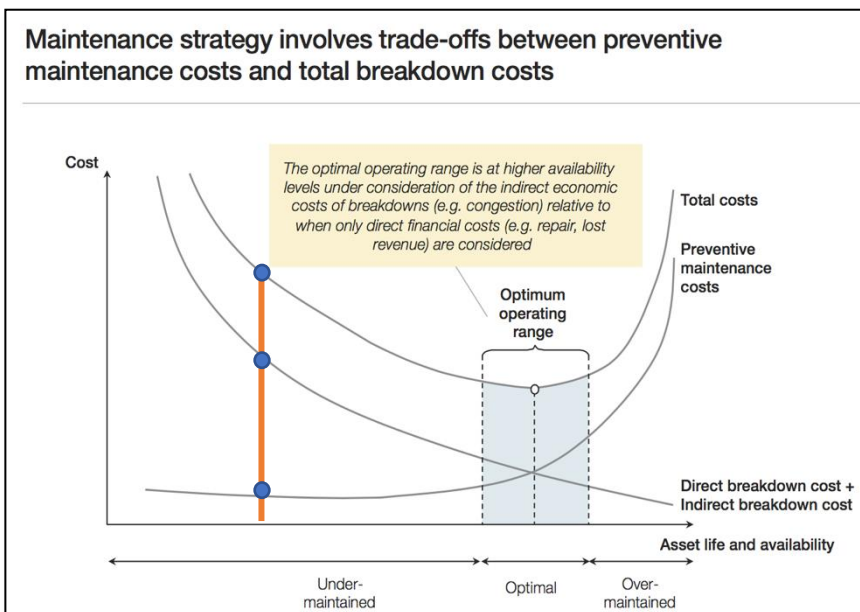


Figure 15: Position maintenance TNT on PM vs CM diagram

does not however explain the causes of these high breakdown costs. That requires more insight in the operations of TNT.

This part described the maintenance activities within TNT and the corrective and preventive maintenance activities executed by the OES-team and the suppliers. Next part will describe the operational profile during of a sorting site.

3.4 Operational process TNT

To find the critical factors influencing TNT's performance, a closer look on operations is needed. The factors or "needs of the customer" need to be found before one can start with the development of improvements (Breyfogle, 2003). In this case, the customer of operations and maintenance is TNT. They are responsible for the functionality of their network, and transforming the needs of the end-customer into internal needs. Analysing the process will help with the formulation of these CTQs.

First look at the operational times within TNT. At most locations TNT works with two shifts a day, where the process described in chapter 3.1 starts all over. The morning shift starts around 1:00 and ends around 7:00. The evening shift starts around 14:00 and ends around 23:00. Between the evening shift and the morning shift there is a small gap, and it depends on the location if these shift flow into one another. Figure 16 shows that these shifts do blend and that there is no real break between these shifts. This means that for some locations, the only time-window to perform maintenance related activities

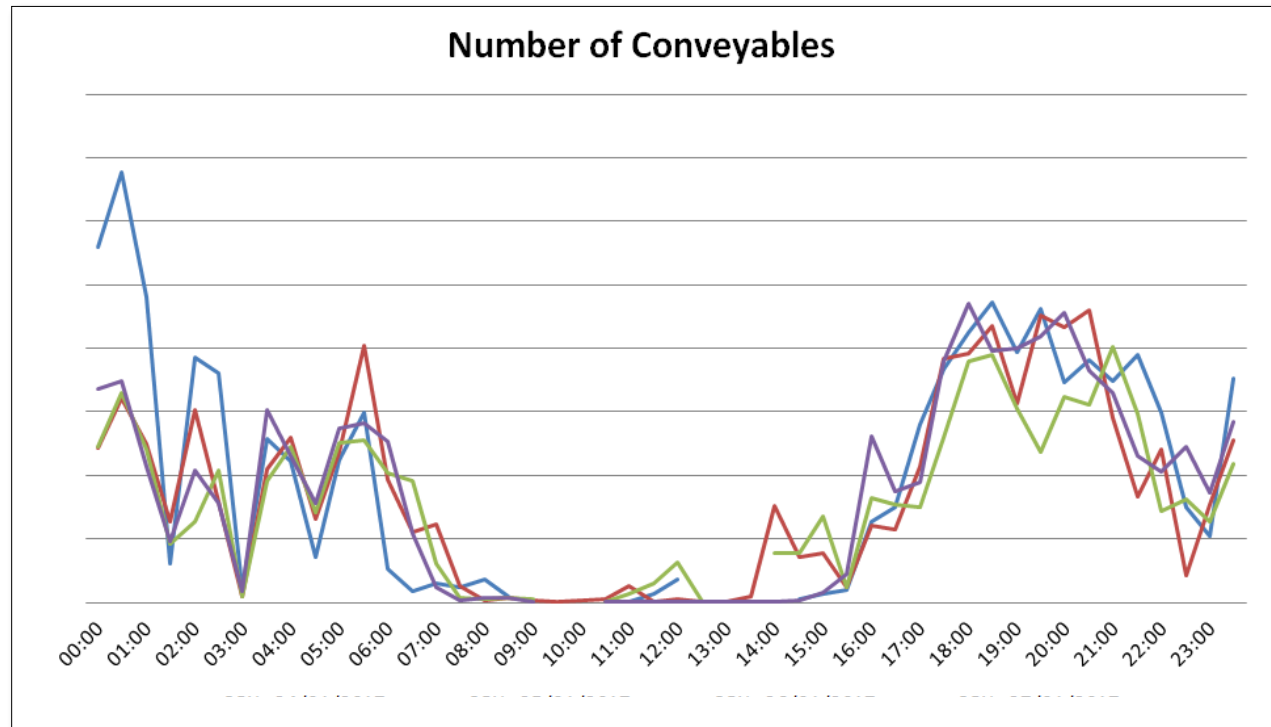


Figure 16: Number of parcels and infeed times for 4 days

that do not have an effect on the availability on the machine is between 08:00 and 13:00 (given this example). Although the operating times are long, the volumes build up towards a peak in the middle of the shift. The impact of failure during that peak is therefore larger than at the end of a shift. The need and sense of urgency for PM or maintenance before the shift itself is therefore higher to prevent downtime during that peak. This profile is typical for the transportation industry (TNT, FedEx, DHL, and UPS), where packages are picked-up and delivered on daily bases. This profile will keep showing this flow in the future, as long as companies will stay operational in normal working hours. However, the gaps for maintenance could decrease in the future, when customers demand a more flexible service from the transportation companies. On top of this profile runs a yearly profile that increases towards the Christmas holidays due to increased transportation. However, the fluctuation on daily basis, combined with inflood of all sorts and sizes of freight makes the yearly profile less interesting.

When a breakdown does occur, it is good to review the procedure and to see the effects on the activities within the site. If a MHS breakdown occurs, all sorting processes have to be changed to manual sorting. When working at full production rate, changing the process to manual sorting will take some time and effort. Next to this time to rearrange and set-up for manual sorting, manual sorting is also significantly slower than using the sorting equipment. This slower process is increasing the chance that packages do not make their time-slot in the network depending on the amount of delay. The consequences are slightly different from the evening process and morning process. In the evening process, all packages that are picked-up by vans from customers are entering the distribution network. Customers pay for a certain time- or day-guaranteed window for delivering and TNT has to make sure it gets there on time. For the processing in the network, it travels from depot to hub and back. These routes are all planned and a delay in one depot cannot cause a delay in the whole network. When working at a slower rate due a breakdown, these packages and pallets will not make their connection and the trucks have to wait for all the packages to be loaded. To still get on-time to the final destination is to skip a point in the network and drive to the next point in the network. Driving straight to an air hub to send the packages by plane is then a possible step. However, deviating from the planned route is costly and not desirable in a business with small profit margins.

In the morning process, all the packages enter the hubs and depots to transfer them towards the receiving client. Instead of filling trucks that travel to other hubs and depots by merging them by location, the packages are sorted in a way that a driver can bring them to clients within the same area. When a sorter equipment breaks down in this process, the packages have to be manually sorted again which is just as inefficient as with the evening process. A difference with the evening process is the hiring of extra capacity to transport the packages to the customers. Because the packages have to be delivered before a guaranteed time, extra trucks and vans are hired to get the packages on-time to the customer. That also means that new routes have to be planned with fewer stops, which makes the routes inefficient. Finally, the employees sorting and scanning the packages work overtime to process all the packages. This overtime has to be taken into account too.

When a breakdown occurs, the repair process has to be analysed as well. There are not just extra costs due the slower sorting process, but repairing the MHS is also expensive. With more complex and larger systems, repairs are more complicated and have to be executed by mechanics from suppliers. These

specialized repairs are therefore more expensive than a simple repair by a TNT-mechanic. A well negotiated service contract and performance agreements have to prevent that these costs become sky-high. At older locations within TNT, these contracts may not include these performance agreements and therefore it is important that these locations maintain their MHS to avoid high expenses.

3.5 Performance of TNT

Before looking into the CTQs that are interesting to further investigate, an overview of TNT's performance is needed to understand the contradictions and factors that influence that performance. As mentioned in the previous chapters, TNT wants to retain or increase its OTD service level but at lower costs. But which variables do influence that performance exactly? After having analysed TNT's material handling systems, maintenance activities and operational process, these variables can be determined.

On-time delivery performance

The percentage of *on-time delivery* as performance indicator can be described by the ratio between:

$$\frac{\text{Number of on-time delivered shipments (pc)}}{\text{Total number of shipments send (pc)}} \times 100\%$$

For TNT, there are various factors influencing this performance indicator. These are all contributing to the performance of OTD. These are determined by analysing the business of TNT using internal documentation. These are shown in the figure below.

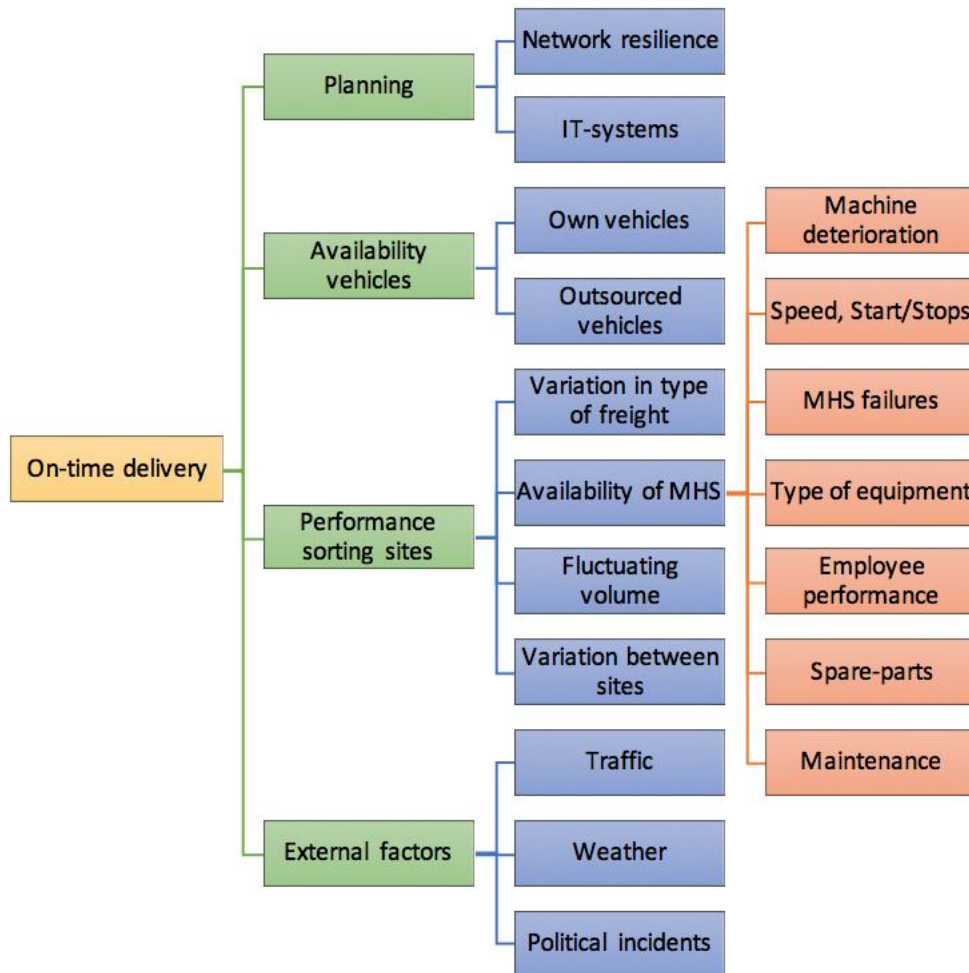


Figure 17: Performance of on-time delivery (Commandeur, 2017)

Planning is a factor that makes sure that there is an available route available at a certain price, so that TNT can transport the package and still makes a profit. Planning of thousands of packages a day asks for a system that can handle these volumes, and is able to move these packages through the available locations. Planning the right route is also important for the work pressure on the different locations. Moving too much freight over one location will initiate problems, which affects the performance of delivering on-time.

Vehicles are important for the actual transport from customer to customer. Without sufficient capacity, either of own vehicles or of a third party, freight may be delayed. Same goes for the external factors that influence OTD. Unpredictable weather or large traffic jams are factors where a company has little influence on. Same goes for political incidents like a war or a strike. Though, they do affect the performance of OTD.

The part that is endangering the OTD performance is the overall performance of the sorting sites. This site performance is based on the ratio of capable capacity, and used capacity. However, the differences between small and large sites create a skewed view on the performance of some sites due to different machines. With a more mechanized sorting system, the average capacity per employee is higher. Like mentioned before, TNT has trouble maintaining them to keep the site performance sufficient. The fluctuating volume and different types of freight will change over time, but these processes are hard to influence. It is one of TNT's strengths that they have the capacity to handle all sorts and sizes of freight, so changing their policy on this item would not benefit the company.

Although these MHS vary between locations, their availability is essential for performing well. There are a lot of factors influencing this availability, and some of them contradict. A higher operational speed will increase the total amount of freight processed, but also increases the deterioration rate and increases the risk of failures. Increasing maintenance activities, spare-parts and updating equipment will increase the availability of the MHS, and therefore also the OTD of TNT. However, this will also significantly increase the costs, which leads us to a next performance indicator that is linked to the performance of OTD.

Financial performance

TNT's financial performance is another performance indicator that is important and needs to be considered when making investment decisions. A flowchart with the most relevant cost indicators is shown in the next figure. TNT operational revenue is a combination of their paid services and are essential for the financial income. For this research, it is important to understand the relationship between the performance of the sorting sites, and the operational revenue. Like discussed before, the decision for more maintenance depends on the trade-off between the downtime-rate (so the impact on operational revenue) and maintenance costs. Knowing the costs (and missed revenue) therefore needs to be determined to be able to make valid arguments regarding the maintenance strategy.

However, the operational revenue is also influenced by the customer satisfaction. Happy customers are customers that know that by using TNT for their transport, their products will be delivered on-time.

Extra services like Track & Trace and customs clearance only increases the customer satisfaction. Nevertheless, the importance of having a high on-time delivery performance is the main service and most important for the customer. As shown in the chart above, consists OTD of many influential factors. One of them is maintenance that contributes to a high performance, but as seen in the chart below, that also affects the financial performance in a negative way.

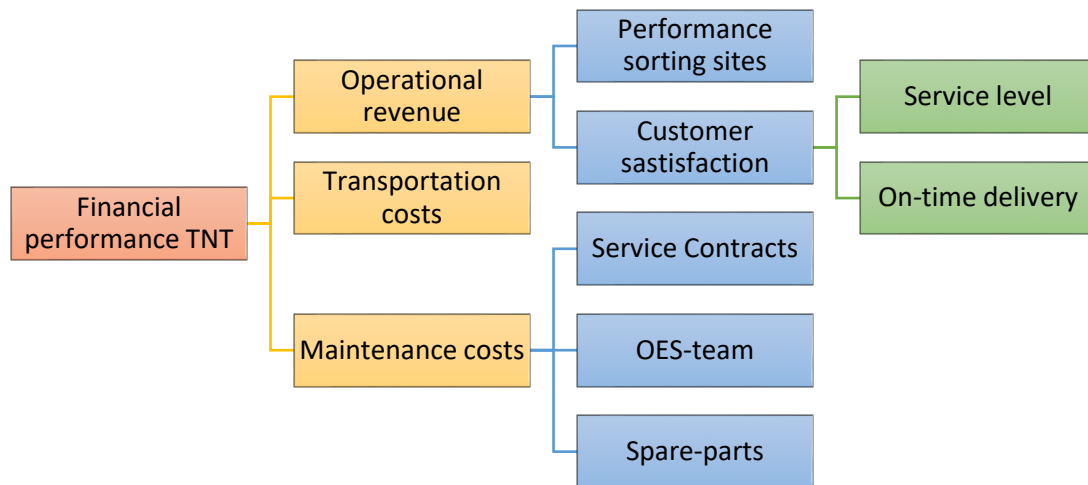


Figure 18: Financial performance TNT (Commandeur, 2017)

Maintenance costs can be split up in several parts, but the most important ones for this research are described above. Service contracts costs increase when more maintenance activities are outsourced. Some larger locations completely outsource maintenance which increases these costs, but also decreases the risk of breakdowns that affect the availability of the MHS.

For the Benelux, spare-parts are essential to fix incidents and to get operations back on track. With the MHS heaving more breakdowns, the number of spare-parts in stock also has to increase to prevent that an incident cannot be solved through a missing part. Nevertheless, having too many spare-parts in stock is unnecessary spend capital if the number of breakdowns can be decreased. That negatively influences the financial performance of TNT.

TNT's OES-team is an expense that is necessary for maintaining the sorting sites within the Benelux. These expenses are for the largest part salaries of the mechanics. Nevertheless, they are together with the OEMs responsible for keeping the performance of the sorting sites up, which also can be seen in figure 14. Their costs are therefore responsible for a large part of the performance.

Transportation costs are also costs that influence TNT's financial performance. With possible delays, causes by either traffic, bad weather or lacking site performance, will increase the transportation costs. Extra (external) vans and chauffeurs have to be hired to pick up and deliver freight, or to drive other routes to catch up with the gained delays. These transportation costs are also linked to TNT's site performance. These ad-hoc transportation costs can really influence TNT's financial performance because these are not included in calculating the selling price.

3.6 Critical to Quality Factors

After reviewing TNT's operations and performance structure, criticality factors need to be defined according to the DMAIC-framework (Tang et al., 2006). These factors are essential for the financial performance, and on-time delivery performance of TNT. Knowing which factors need improvement helps in setting goals and developing solutions.

Critical-to-quality factors need to be aligned with the demands of the customer. As mentioned in section 3.4, the customer is TNT so the CTQs should represent the needs of TNT. Having evaluated TNT's problem, the need for TNT is to retain or increase its *on-time delivery* at lower costs. Having looked into the relationship between preventive maintenance costs and corrective maintenance costs, there is a need for insight in these costs to be able to compare these with each other. TNT has trouble quantifying these costs, and is therefore not capable to make improvement decisions. A first costs factor that needs to be known is related to the revenue gained, or even better, revenue missed during a breakdown. That requires insight in gained operational revenue, to be able to say something about the financial performance of TNT. TNT needs to know the costs of a breakdown to be able to prioritize between the seriousness of failures from a financial perspective. The decision to take *breakdown costs* as a first CTQ is also noted as important in TNT's ICOM-standard summarized in Table 2: Criticality indicators ICOM process. Measuring these costs makes it possible to compare them with maintenance activities to increase the financial performance of TNT.

To compare the costs of breakdown with (preventive) maintenance activities, these costs need to be made clear as well. The optimum operational area in figure 15 is again a combination of the right amount of maintenance compared with breakdown costs. Therefore, the *maintenance costs* also have to be defined to develop the right maintenance strategy. Maintenance costs directly influence the company's financial performance, and potential improvements have to be justified and earned back by having less breakdowns. Therefore, *maintenance costs* will be used as second CTQ. Quantifying these costs will create awareness amongst management, and shows them the importance of the right maintenance strategy. This is also known as a cost-benefit analysis.

Having looked at the two contradicting costs factors, TNT is also looking for the causes of their breakdowns and which specific improvements can be developed to prevent these incidents from happening. Looking back at figure 17, the performance of the sorting sites is the indicator that affects the OTD performance most. The other indicators like vehicles and planning are also contributing to the OTD performance, but are not interesting for this research. Several variables influence this performance like the different types of freight that enters the location, fluctuating volume etc. However, the performance of the site (the ratio between the used and theoretical capacity) is mostly determined by the availability of the Material Handling Systems. Without useful equipment, sorting processes are delayed which eventually affects the OTD. The fact that TNT cannot pinpoint the causes of these breakdowns and incidents makes the availability of the MHS a valuable CTQ factor to analyse. And more important, a factor that negatively influences both financial as OTD performance.

These three indicators both impact TNT's performance on financial and operational aspect and are the indicators needed to solve the research problem. To be able to analyse these factors, they need to be explored to see which variables influence these indicators. In case of the breakdown costs, the company's earnings model has to be analysed. To be able to quantify these costs, the most influential factors that are responsible for these costs need to be determined. Due to diversifications within the sorting sites, countries and product streams, these factors will differ between locations and are hard to generalize to a single number. However, to be able to use the data and compare it with possible maintenance costs, a costs range has to be found for an hour downtime. Knowing this costs range will still indicate in the impact of these breakdowns.

To be able to quantify the costs of maintenance, not only the current expenses have to be analysed, but also the costs of implementing possible new maintenance activities. The current CM and PM expenses can be used for comparing them with breakdown costs. The costs of new or extra maintenance can be compared with the possible gains, to justify their investment. However, to know the costs of possible improvements, the causes of low availability of the MHS need to be known. Otherwise would new improvements affect causes that are less responsible for a low performance.

That leads us towards explaining the third CTQ which is responsible for affecting the performance of the sorting sites. Like discussed, the site's performance is influenced by several factors, where the availability of the MHS is not only responsible for a decreasing site performance, but also to a low financial performance. Availability can be defined as the capability of the system to deliver the required functions under given conditions for a given time-interval (Ferreira et al., 2009). In this research, availability is measured by:

$$availability \left(\frac{hours}{day} \right) = \frac{Uptime}{(Uptime + Downtime)}$$

With uptime being the time between failures and downtime being the time that is needed to repair the system. Monitoring the length of downtime by hand to measure the availability is not an option, due the fact that this would take too much time. First step is to find the causes that decrease the availability. In new large locations TNT demands an availability rate of 99%. With a dedicated maintenance team on-site, and a well-designed MHS with the possibility to monitor the process and gather data of the availability, this goal is a realistic and feasible. For locations without maintenance on-site, this goal is not realistic and will need another goal. Nevertheless, *availability* may not be the right factor to analyse. For TNT, it may be more interesting to look at the *operational availability*. This factor doesn't only look at the uptime, but compares the uptime when needed with how long it should be available. As seen in the operational dynamics of TNT (figure 16), there is a time-window where the system may be ready for operations, but where it is not needed. Calculating the operational availability will then give a better representation of the MHS availability. For the locations of TNT, the *availability* expressed in number of hours per day then becomes:

$$operational\ availability \left(\frac{hours}{day} \right) = \frac{(24 - x) - (downtime\ during\ operations)}{(24 - x)}$$

Where x represents the number of hours that the MHS does not have to operate. This can differ per location. Subtracting this number from the daily number of hours gives the *total operational time* or the *operational cycle*. The downtime during operations means the hours of downtime during the time that operations really needed the MHS. Although this is a more interesting way of looking at availability, the data quality and registration has to be accurate so that the data is really useful for these calculations.

Summarizing, for developing a maintenance strategy the costs and causes of a breakdown have to be found. For now, the focus will be on 3 CTQs: *breakdown costs*, *maintenance costs* and *MHS availability*. First priority is to identify and explore these factors, and afterwards quantifying the most important ones.

3.7 Summarizing Needs & Requirements

This chapter started researching TNT's process and equipment. It became clear that the sorter and CWC are systems that are highly technical. Also understanding the order of the processes gave a clear view on the possible bottlenecks of the sorter. Next, maintenance concepts were described, and new insights in the determination of the right maintenance frequency were explored, which may be of interest of TNT. TNT's own maintenance structure became clear, and the position of the OES-team in the whole part. That also led towards the discovery that most maintenance is purely corrective.

Insight in the operational profile showed the fluctuating pattern during the day, and how typical this fluctuation is for this industry. This profile showed when maintenance activities could take place, and how this could change in the future. Next TNT's OTD performance indicator and financial performance indicator were explored, to see which factors and variables affect these indicators most. From these most influential variables, a set of CTQs is developed that need to be further analysed. Next chapter will start with some first measurements related to these CTQs.

4 Measuring the existing problems

After having defined the CTQs for the analysis, measuring them is the next step. This is the second step in the DMAIC-framework and is all about collecting data that can be analysed. Gathering data is important for the development of the analysis. Without decent quality data, a well-argued decision cannot be made on what to improve. These measurements can lead to interesting discoveries that need to be analysed further.

4.1 Operations research

To measure and analyse the data, a more mathematic point of view helps comparing these conflicting performance indicators. This mathematical point of view is also known as operations research (OR) where mathematical formulas can help making complicated decisions (Winston, 2004). Practical examples of OR are simulation models, stochastic models and other data driven models. Using OR has turned out to be successful in cases that looked for optimization concerning spare-parts and maintenance (Everingham et al., 2008). When applying OR in this research, several components that describe the problem have to be defined (Winston, 2004). These components are:

- Objective function(s)
- Decision variables
- Constraints

First, the objectives have to be defined that describe the outcome of the formula. These objectives have already been defined in the previous chapter. The two objectives are:

(y1) = Improve the sorting sites' MHS availability

(y2) = Improve the financial performance of TNT

As discussed, these two objectives conflict with each other, and need to be compared to find the optimum trade-off between them. Decision variables are the components that influence these objectives, and can variate to maximize or minimize these objectives. Some of these variables have already been mentioned in the previous chapter. Variables influencing the first objective are:

D = Deterioration rate

EP = Employee performance

Eq = Type(s) of equipment

Mt = Maintenance

Sc = Service Contract

These variables also depend on other factors or constraints. The deterioration rate is in turn influence by *Temperature, Age, robustness, Speed, Start/stops and Dust*. Most of this data is unknown within TNT, or based on specifications from OEM's. Next to these constraining factors there is the large variation in

equipment. The decision variable “*Type(s) of equipment*” includes *sorters, pallet scales, forklift trucks, wrist scanners, Vitronic CWC and roller tracks*. These equipment specifications are unique for each location because different manufacturers were involved. Even when specifying these decision variables for each sorting site, it will create a more location bounded solution instead of a more general solution.

Although OR is capable of handling that much data for the development of multiple solutions, it is depending on the available data of these factors. As mentioned in the introduction, TNT does not have a system that monitors the current state (and deterioration) for the use of predictive maintenance. Simple factors like temperature, age and speed is relatively easy to measure, but that cannot be used to relate these factors to previous incidents. Using OR to mathematically calculate the MHS availability is therefore to complex.

The second objective (y2) includes also several variables that influence the financial performance. Several of these variables are already defined in figure 18. These variables are still rather general, and to know how they influence the objective, deeper knowledge about the operational earnings model, and maintenance costs is needed. To mathematically calculate their impact, these costs need to be able to be allocated to a specific part, process or amount of time. Otherwise it is hard to compare the data with each other. Nevertheless, it is going to be difficult to express the financial impact of on-time delivery on customer satisfaction for example. Or the financial impact of delay in one locations towards another location.

Soft Operations research

Although OR is a data-driven research method, there is a difference between “Hard and Soft” OR (Heyer, 2004). The OR based on quantitative data (described above) is known as “Hard OR” and used when most factors can be quantified. “Soft OR” is used more often used for complex problems with conflicting objectives and when quantified data is not present. This “Soft OR” approach is much more appropriate for this research. This approach uses several ways of getting to know the causes of this complex problem by using flowcharts, diagrams, root causes that structure the problem (Masys, 2015). Using these methods of structuring the problem fits also in the DMAIC-approach, which is about narrowing down and structuring the problem (Tang et al., 2006).

In the performance flow chart in figure 17, the variable *MHS failures* provides more information regarding the incidents that affected the MHS. This variable is also influenced by deterioration, employee performance etc., but provides more tangible data which is more useful for this research. When these incidents are structured, they can provide more useful information regarding the bottlenecks of this complex problem. Finding these bottlenecks also supports the approach of “Soft” OR that tries to discover as much as possible on the problem situation (Heyer, 2004). To still be able to develop improvements for these bottlenecks, sufficient data regarding downtime is still needed to measure their impact on *operational availability*. This more simplified view on *MHS availability* in combination with a structured problem identification, will provide much more useful information.

The impact on the financial performance will always be a mathematical calculation of costs and benefits. However, it is hard to link the financial performance with *operational availability* if one of both is not quantifiable. Nevertheless, measuring these costs will generate a clear view of the impact of failures on both financial performance and on-time delivery.

Next part will continue with using “Soft” OR to structure the problem and to find the bottlenecks. This will give insight in the data quality and usability. First, the data regarding the MHS incidents is analysed before looking at the financial data.

4.2 Incidents and availability

As defined in the first step of the DMAIC-framework, measuring the MHS availability is not just about quantifying the specific availability by monitoring the downtime of every machine, but about gathering data about the causes that influence the availability. This is also in line with the problem identification

F	G	H	K	L	M	N
WAAKDIENS	DEPO	s/n of itemnr	PROBLEEM	OORZAAK	AFSLUITDAT	OPLOSSING
	EIN	Sorter	Riem IQ-grid item 001.090 slipt door	Slecht hersteld door Van Riet	06-01-16	Van Riet heeft de riem vervangen
x	BRU	Vitronic	Weegschaal lijn 2 werkt niet meer	onbekend	05-01-16	weegschaal opnieuw opgestart
x	BZQ	Sorter	Loose load chute 10 werkt niet meer	sensor stuk	06-01-16	Sensor vervangen
x	EIN	Sorter	Persluicht lek ter hoogte van item 010.060	onbekend	06-01-16	Van Riet heeft dit nagekeken

Figure 19: First version incident log (TNT, 2017)

used in OR (Heyer, 2004). TNT needs to find the reasons of their lacking performance in a more general way, and try to implement general improvements that can help all sites. TNT started in 2016 with the creation of an incident log where they made the OES-team record the incidents in the locations within the Benelux. At first, they registered basic information about the causes of the breakdowns (figure 19). In the figure above, column K describes the problem with a possible cause in column L. This data is not always known, and sometimes left empty if the OES-team does not know the cause. The last column N described the solution to the problem. These solutions do not always tell the whole story. In some cases,

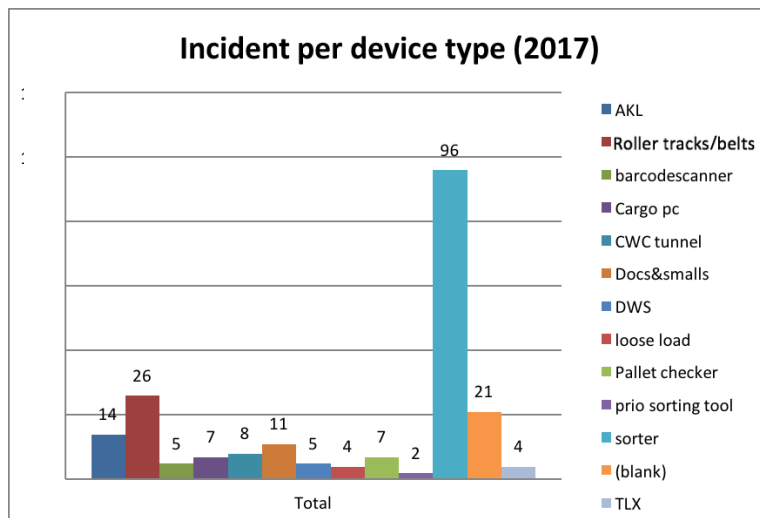


Figure 20: Incidents per device (TNT, 2017)

the solution is just simply “Supplier repaired the breakdown”. This doesn’t give any information on the real repair activities, and if the repair will prevent it from happening again. Next to basic information like date, year and who repaired or handled the breakdown, the incident log is extended during 2017 (Appendix C).

Column G in figure 19 describes the depot or hub where the breakdown/issue is located. Column H describes the item number or device that has issues. The first data entries in

this column contained small items up till more general term like “sorter”. To be able to pinpoint the breakdowns better, an updated log sorted first on device type, like sorter, pallet scale etc. and afterwards on more detailed level like item number of part. For the incidents in 2017, figure 20 shows the distribution of the different devices including the number of incidents. This is a confirmation of the

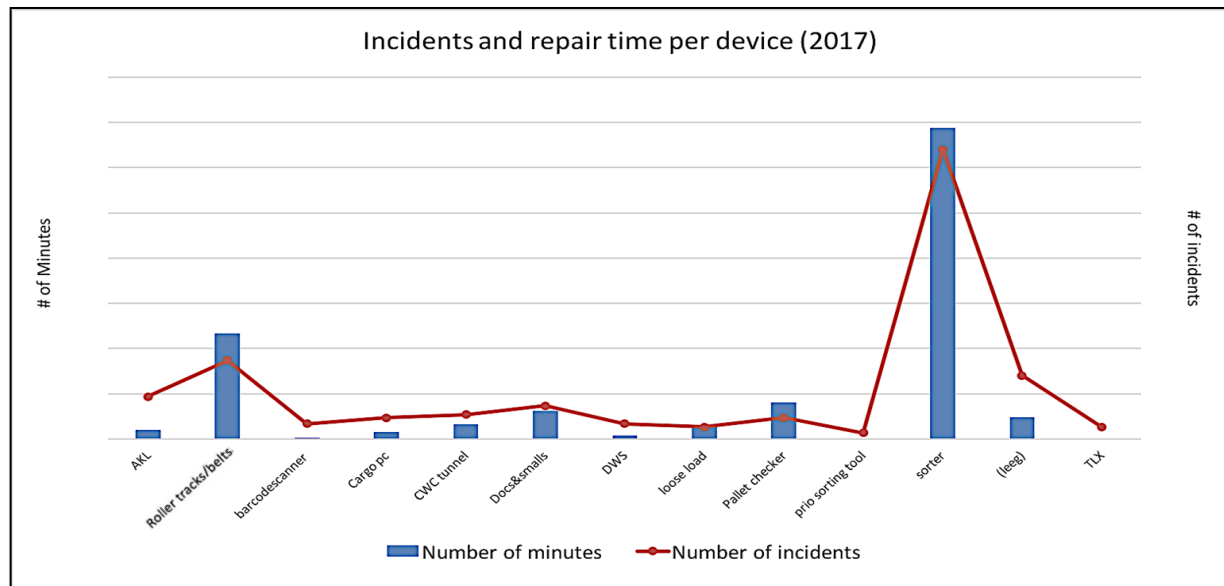


Figure 21: Number of incidents vs. number of minutes per device (TNT, 2017)

thoughts within TNT that the sorter is responsible for most incidents. The sorter is responsible for 46% of all incidents within the selected locations. This number does not mean that every incident is causing the whole sorting process to fail. However, it does mean that it takes the most time to repair if the number of incidents is plotted against the total number of minutes to repair for the selected devices (figure 21). There is a visible relationship between the number of incidents and the total repair time. The number of minutes to repair the “roller tracks/belts” is in comparison to the other devices one that cost some more time to repair. These are the belt and roll conveyors which need more time to repair. The total repair time is also added for registration during 2017.

The figure above leads us to the two other added columns in the incident log: *Total repair time* and *Travelling time*. The first column is for the registration of the total repair time of the incident. This is essential for monitoring the total downtime of the system. Without these numbers, an indication cannot be given on the impact of the breakdown. The other column is for the registration of the travelling time. When the MHS fails, the total breakdown is a sum of the (travel time + time to repair). It is not only interesting to see the repair time per device, but also to see the repair time per location. This will be explained further in this chapter.

As seen above, the devices are clustered and generalized for an easier identification, and an extra parts/device column is added to give more specific information about the part that is affected. This is a first step towards a root-cause analysis by the fact that it is isolating a smaller part of the system. A root-

cause analysis is designed for finding the real reason of failure. In addition, a column is added that helps with finding the first reasons for failure. This column categorizes the incidents into four categories.

These categories are:

- **Operational**
Incidents that can be traced back to operations incidents on the work floor. Think of human errors when working carelessly.
- **Electrical**
Issues related to electrical errors, like broken sensors, electricity disruptions and other power-related issues with non-moving parts.
- **Mechanical**
Incidents with mechanical causes due to wear and tear of bearings, belts, wheels etc.
- **Control**
Issues related to network connectivity, data processing and other controller related problems.

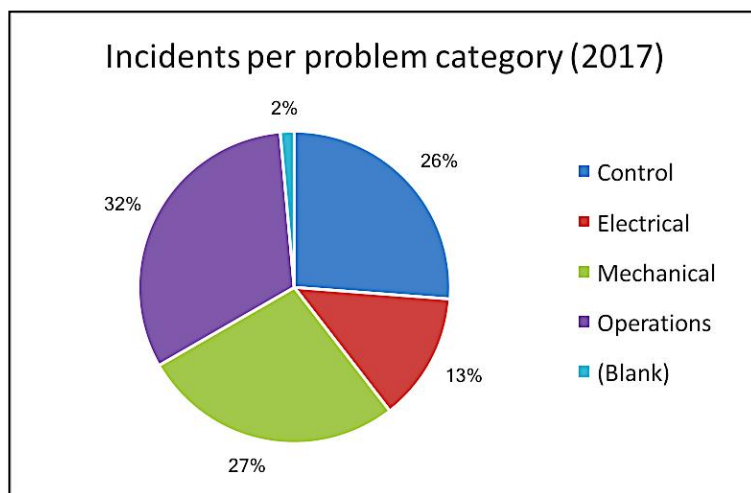


Figure 22: Incidents per category (TNT, 2017)

This categorization of incidents is very helpful to get a quick view into the basic reasons for failure. Figure 22 shows the incidents with a categorization by the OES-team. Interesting to see is that from the incidents 32% is related to operational issues. With the categorization of the incidents, priorities and solutions can be found that aim for solving a specified category. The objective is to minimize the incidents affecting the MHS availability, and solutions affecting the problems with the highest

impact on availability are the most effective. First interesting part is to analyse the incidents with an operational cause. The amount of these incidents can be decreased by reviewing the performance of the employees, and introduce change plans to stop these incidents from happening. Improvements in this category are likely more related to training and implementing new procedures and less concerning technical solutions. Incidents in the control, electrical and mechanical probably need a more technical improvement plan.

Final important column in the incident log is Column F. This column describes if the mechanics were executing maintenance during their normal working hours (no X), or if they were on stand-by. This term describes if the mechanics were stand-by on the 24/7 emergency service (X). This simple column is of great value due the fact that any incident during the emergency service directly impacts MHS's process.

TNT's sorting processes operates mostly in late afternoon and evening/night. So, a breakdown at this time will decrease availability directly and a mechanic needs time to get to the site.

The added value of the incident log can be of great value. However, to get a realistic view of the performance of the sites, proper and strict registration of the incidents is essential. As explained and visualized in figure 14, some incidents are forwarded to the suppliers because the OES-team is not capable or authorized to repair the issue. Monitoring the travel time and total repair time of an issue

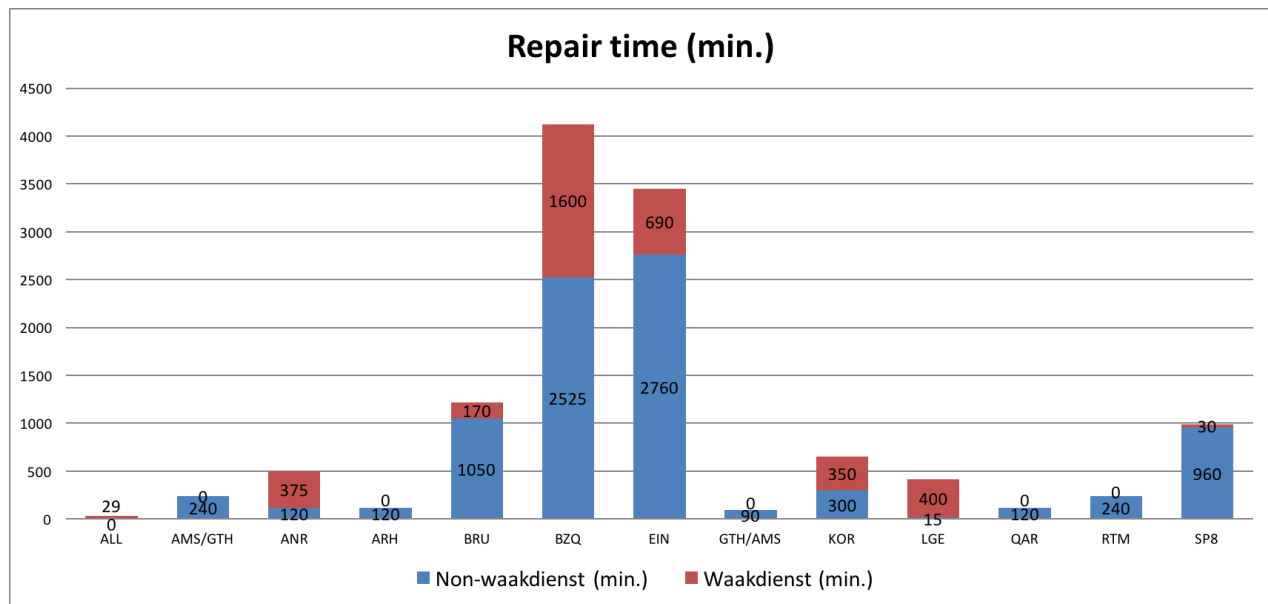


Figure 23: Repair time per location separated by emergency service (TNT, 2017)

handled by an OEM is hard to register. Several incidents are monitored but without registering the total repair time and the time for the OEM mechanic to arrive. Only a few repairs executed by OEMs are indeed registered by the mechanics of the OES-team. Besides, the total repair times do not indicate if these repairs were executed in the time-window without sorting activities, or during operation. Again, without a strict time-registration, data can easily get worthless.

After visualizing the repair time per device, figure 23 describes the repair time per location with a separation by emergency service. The incidents in 2017 with registered repair times show the same trend with a large portion of maintenance activities in Brussel hub (BZQ), Brussel depot (BRU) and Eindhoven (EIN). These are also the locations with the largest volumes after Arnhem hub (QAR). However, more volume should not a guarantee for more maintenance. With more automated and larger MHS, sorting should be easier and better protected against wear and tear. Altogether is the incident-log a useful file with over 200 registered incidents in 2017 which where a large part include data considering repair time. This data categorizes the incidents into first causes, and form base for a further root cause

analysis. Although the repairs times can provide some estimations, the still lacking registration of the incidents may be a problem for further analysis.

4.3 Breakdown costs

After collecting data on the repair times, incidents per device and locations where they occur, it is time to look at the financial variables. As mentioned in chapter 4.1, it is hard to use “Hard” OR if the data quality is lacking. Nevertheless, it is helpful to get some deep insights in costs to emphasize the seriousness of the problem, and to express the urge for improvements. Knowing which variables influence the financial performance most is helpful before quantifying them.

To find costs associated with a breakdown of the MHS, internal research is executed within TNT. Observations at different sites like Schiphol-Rijk, Arnhem and Eindhoven led to some first costs indicators. When quantifying these first indicators, it became clear that within TNT knowledge and secondly data is very scarce. Internal communication and data sharing within the different entities of TNT is difficult and retrieving information from these different entities even harder. To be able to define the different associated costs interviews are held with business improvement managers from the Benelux.

4.3.1 Interviews Business Improvement Managers

To be able to get more information about the costs of breakdown and downtime, interviews are held with several employees. These interviews are semi-structured because some question go deeper into the processes of TNT and need further questioning (Sekaran & Bougie, 2013). A summary of the interview can be found in Appendix E. The interview confirmed some of the observations picked-up at several locations of TNT, but also gave some insight in other costs. The operational process described in chapter 3.4 already explains the two processes during a single day, one evening process and one morning process. According to H.L. and T.V. (Appendix E) costs associated with downtime also differ with these processes. Primarily, the costs of the evening process will be defined.

During a breakdown of the MHS, the first thing operators do is switch to the manual sorting mode. A disadvantage of manual sorting in the evening process is that the packages do not cross the CWC. As explained, customers are billed afterwards if their specified size and weight differ from reality. So, when the CWC is not used due to a breakdown, revenue that would have been generated is missed. With missed CWC revenue, only conveyable packages are mostly affected by a breakdown. These packages move over a CWC as described in chapter 3.1, which is integrated with the sorter. As seen above, most incidents occur with a sorter and therefore affect the CWC revenue of the conveyables. This is also the most important costs variable where the most revenue is lost during the import process because from the minute it stops working, revenue is lost. Next to the missed revenue of the CWC, extra costs are also made with personnel working overtime to process all the packages. Normally, with the number of personnel scheduled, all pieces are transported at the right time and employees sometimes are sent home earlier. However, when the packages are buffered they need to stay in longer which increases the

total number of labour hours. For the evening process, the time-slots for departure of the trucks are important for a good flow through the network. Trucks cannot wait too long, and will depart to get to the next point in network. These times are fixed, and if the truck is only half full, it will depart. The packages and pallets that are ready after the time-slot, need to wait for the next truck. This next truck has the option to arrive late at the next point in the network, or to skip a location (in the road network) and go straight to the air-hub to make sure that the parcels will arrive on-time on their final destination by plane. However, the overall transportation costs of by air are significantly higher than by road. Within TNT there are some more possibilities to handle these delays in this shift, making it less frequent costs. Summarizing, the identified costs variables during a breakdown in the import/evening process are:

- (x1) Missed CWC revenue
- (x2) Operational personnel costs
- (x3) Cost of extra trucks/routes

In the morning process, sorting is focussed on exporting the parcels and pallets towards the final customer. A MHS breakdown in this time span has some different associated costs. First of all, there is no missed revenue from the CWC. TNT is only allowed to bill the customer with the data from the CWC if the package is weighted in the original country. Because most transport crosses a border, the packages are only weighted when they enter the network. So, a delay in the evening process does not produce missed revenue from the CWC. Costs that do arise are the extra labour costs. All parcels need to be processed and transported into the vans to go to the receiving customers. When the vans have to wait, they are not capable to deliver TNT's on-time delivery service. They leave with lower number of parcels and make less stops. Extra vans are hired and extra routes are planned to be able to deliver all packages. Where in the morning process the trucks have the possibility to wait and take to take another route to solve the problem, the vans in the evening process don't have that possibility. These extra costs for vans are the largest costs variable in the evening process. Next, the level of service and the loss of customers of bad service is therefore another possible expense. Quantifying these costs are hard, by the fact that they are based on subjective responses from the customers. However, the possible impact on the service level of TNT has to be taken into account. Hence, the costs variables in the export/morning process are:

- (x4) Costs of extra vans and routes
- (x5) Operational personnel costs
- (x6) Possible impact on service level (and the loss of customers)

H.L. and T.V. also pointed out some hidden costs within the company due to a breakdown in both processes (Appendix E). When a sorter breaks down, negative status codes are being communicated throughout the internal network. Receiving depots and hubs are then aware of the possible late arrivals of trucks and vans, and can start procedures to be able to process these late incoming parcels. These status codes are also communicated to the customer service department, who can contact the customer

on the status of their consignment. The communication and the people involved in the communication during a breakdown are also “extra” costs. Although these employees are already contracted, they could be focussing their attention on other things.

Six main variables are derived from the interviews with the improvement managers (x1-x6). These variables influence the financial objective (y2) most during an incident. However, these variables do not affect all operations the same. That creates more variety which makes it harder to link these costs with a breakdown. Nevertheless, these costs are further specified below.

4.3.2 Quantification breakdown costs

After the interviews and site visits, it is crucial to quantify these costs to get some insight in the seriousness of a breakdown. From TNT’s viewpoint, this data is still unclear. To measure this data, real-life cases has to be analysed and checked on their costs.

Import/evening process (x1, x2, x3)

Starting with the CWC revenue (x1), within TNT it is clear that the lost revenue regained by using this piece of equipment is significant. Previous business cases showed the added value of the CWC and proved that they are worth the investment. From the interview with H.L. and T.V. (Appendix E), the estimated returned revenue regained due to the CWC with on the parcels on € [redacted] per kilogram of volume. That means that on every kilogram of weighted volumes they return € [redacted] on top of their price determined on the customers specified dimensions. Although this amount is very precise, it is a rough estimation on the average returned revenue. Depending on destination zones, customers pay more if the packages are send to a further destination and therefore also for the extra weight. This price-effect is out of our scope and calculations are based on the average of € [redacted] per kg. Nevertheless, the effect of this costs indicator can vary due to different operational reasons. First of all, not all incidents cause the CWC to completely miss its revenue. The two most incidents that affect this costs indicator are incidents to the CWC itself, and incidents on the sorter that feed the CWC. These two incidents are responsible for the loss of revenue of the CWC which makes the impact either 100% or 0% on the loss of revenue. However, the billing system of the CWC allows packages to be weighted a second time within the original country and use these data to still charge the customer for the potential extra volume/weight. This way, the impact of a CWC or sorter breakdown will not impact the gained revenue by 100%.

Although in theory the missed revenue is much higher on pallets due to their heavier weight, the missed revenue caused by failures of the pallet checkers and AKL devices is not examined. The focus will be primary on freight that falls under the category “conveyable” due the fact that a first indication shows that most incidents are related to conveyables. That’s also because conveyables represent on average [redacted] % of the total volume (Appendix B).

To be able to calculate the impact of missed revenue by CWC, volume data from an average day of three depots is analysed to find out the possibility for a second volume and weigh check in a next depot or hub within the same country. Average is described as a day with an average amount of volume in that year without strange or deviant numbers. The decision for 3 depots and not a hub is a logic choice. In hubs,

the packages are merged and therefore already had a check in a previous location. The impact on CWC revenue would therefore always be 0% because no packages enter without a previous CWC check. These average days have been selected from a database and are analysed using Excel (Appendix B).

The impact of a breakdown on CWC can be represented by calculating the parcels that already have been checked or will get a second check. You then automatically know which parcels do not, and are affected. When you know the number of parcels that will get a second check, you also know which parcels are not affected. The percentage of revenue loss in the import process with the CWC is:

$$\% \text{ revenue loss} = \left(1 - \left(\frac{e*d + (b - c) + (a - b)}{a} \right) \right) * 100\%$$

Where the factors *a*, *b*, *c*, *d* and *e* stand for:

a = volume between 14:00 – 00:00 (pc)

b = volume with NL origin (from parcels in range of *a*)

c = volume with original depot as first location (from parcels in range of *b*)

d = volume next location in NL + (end location NL – own location) (from parcels in range of *c*)

e = performance CWC

To receive this data from the excel file, first the volumes are filtered by only selecting COYS which are the conveyables that are processed using the sorter and CWC. Next the packages are selected that enter the depot after 14:00 pm when the import process starts, because those packages are in principle available for the CWC. This time separation is also visible in figure 16, where one can see the differences between the import/evening process and the export/morning process. A separation is then made between the parcels with original country NL or BE, to see how many parcels are new in the network and capable for a CWC in the origin country. From those parcels, the depot origin is analysed to see if they are really entering the network there, or if they already did anywhere else in the origin country. Finally, if the parcels have the depot and country as origin, the parcels that have the same depot as destination are filtered, because they don't travel further in the network and cannot have a second CWC. This sorting and filtering selection delivers the final batch of parcels that is capable and legal to have a second check, which means that this is the number of packages that is affected by a breakdown with the CWC or sorter.

From all three locations, the variables *a*, *b*, *c*, *d* and *e* are determined by using pivot tables in Excel.

ARH	SP8	LGE	Description
			Percentage of import parcels appropriate for CWC (Orig. Country)
			Percentage of parcels without first CWC (new in network)
			Percentage that goes to next location within Orig. Country
			Parcels in total
			2nd CWC possible (with probability of 85% that it will pass that CWC)
			Percentage that already had 1st CWC + possible 2nd CWC (Orig. Country)
			Percentage of No lost revenue in Orig. Country + Not Orig. Country
			PERCENTAGE OF REVENUE LOSS FOR COMPLETE IMPORTPROCESS DUE TO CWC/SORTER BREAKDOWN

Figure 24: CWC revenue losses for multiple locations (Commandeur, 2017)

These numbers for all three locations are summarized in figure 24. This figure shows a possible revenue loss of % up till % on the total volume during the import process. The difference between Arnhem depot and Schiphol-Rijk depot is primarily caused by the number of parcels that were already in network. In depot Arnhem only % could have a 2nd CWC, which would look like the impact would be about 95%. However, a large part of the packages arriving at the import process should already have a previous check in a previous depot, and no revenue is lost when these packages miss the CWC in Arnhem. Nevertheless, when a depot receives almost only packages without a 1st CWC (SP8, LGE), the impact is still only %- % due to second CWC possibilities. Next step, to further measure the financial impact, is to calculate what these percentages of revenue loss mean in terms of average parcel weight.

Knowing the percentage of loss during an import process and the lost revenue per kilogram, calculating the real loss in Euros is about calculating loss in kilograms. To do so, the average weight of the parcels labelled as conveyable (COY) is taken of multiple locations in the Benelux. Table 4 gives an overview on the number of parcels and their total weight. This data represents an average day on every location. Data from several locations is used to outbalance the possible differences between locations. Some locations have large customers that influence the average weight. Therefore, to get a representable average weight in the Benelux, a large dataset is used. The average weight of these parcels is the total number of kilograms divided by the total number of packages which results in an average of kilogram per package.

Table 4: Total weight conveyables

	Total weight (kg)	Packages (#)
QAR	<i>Private data</i>	
ARH		
LGE		
SP8		
LGG		
TOTAL		
Average Weight		

Table 5: Example CWC revenue losses

	Revenue loss per parcel	Number of conveyables during import process (1 day)	Revenue loss import process (%)	Possible revenue loss (€)
ARH	€		%	€
SP8	€		%	€
LGE	€		%	€

In the table, the first grey column represents the revenue loss, the second the number of parcels of an average day on that location, and the third the range of revenue loss. The results in the last column are calculated by multiplying all possible situations with each other. The best case for Arnhem for example is:

$$\frac{\text{€}}{\text{pc}} \cdot \text{pc.} \cdot \% = \text{€}$$

A quick look tells that missing the CWC revenue just for a single day already costs several thousand Euros. Even in the best scenario the failure of the CWC/sorter will cost over a thousand euro. Let alone if it's the worst scenario, where the costs double at least. A remark has to be made on these losses. As explained, conveyables represent around % of the number of parcels, but only represent around % of the total weight. Using the past calculations means that even more revenue is gained at the heavier parcels, and the missed revenue of breakdowns could possibly be much higher. However, these heavier parcels do not use the sorter and are not "conveyable" and therefore are excluded from this calculation.

Although these results are partially based on expert assumptions, they still provide a realistic overview on the possible missed revenue. To strengthen and use of this assumption, a wide price range (€ - €) has been chosen to reduce uncertainties in these calculations. That reduces uncertainties in the calculations. Still, if this method of calculating the possible revenue loss is used for future calculations, further research on this variable is needed to make the calculations more robust (Saltelli et al., 2008). The rest of the data is gained from TNT's internal servers, and is therefore more reliable. Though, the selected data is analysed for one average day, and to strengthen the results more days would decrease possible uncertainties. Nevertheless, the results fit the expectations of TNT regarding these costs. This verified by the senior Service & Maintenance engineer of TNT.

Personnel & vehicle costs

Other costs during the import process are the extra operating personnel costs (x2). When an import process is disrupted manual sorting can lead to extra hours of work. CWC failures have no effect on the personnel costs, because parcels are not weighted manually when the CWC does not work. The average hourly rate of an operator within the Benelux is set on €. TNT works a lot with flexible workers, and planning is using that flexibility for eventual work out. They schedule the employees in longer than needed, and if some finish earlier they just can send them home already. This way it is prevented that

these workers are charged at a higher rate. However, this also causes that the registration of the extra hours made due to an incident are hard to trace, because the employees could also be working longer due to more volume that day. Due to the parabola shaped curve of the incoming parcels, the seriousness of the impact depends on whether the sorter fails in the beginning, middle or end. Having downtime during a peak of the process will quickly create a backlog that has to be processed later on when the sorter is working again. That will lead to more personnel costs if they have to stay in longer. The amount of extra work is very depended on the location, level of automation and cooperation between employees on the floor. That makes the identification of this costs variable complicated and location depended. Due to a scarcity of data it is impossible to give an accurate estimation on the financial impact of this costs variable. Although these costs need to be known, they are left out for further calculations.

The last cost indicator in the import process is the costs of extra trucks. As explained in the previous paragraph, it does happen that often that the process takes longer and that extra trucks are needed. From an interview with business improvement manager G.G, it became clear that this is rarely the case (Personal communication, May 17, 2017). This costs indicator would again only be of interest when the sorter is down during a whole process. This is however not an interesting factor to analyse any further.

Export/morning process (x4, x5, x6)

During the export process different operations play a role compared to the import process. Instead of merging the packages, freight has to be broke down spread amongst the vans. This process is slower in general because all freight has to be divided over more trucks and routes. First of all, the export process has more time after their shift to solve potential back-logs and late sorts by the fact that after the morning process a time-gap arises until the next import process. This process relies on trucks bringing in freight from further distances, where travel delays are more common than local vans picking up parcels around the depots. So where extra personnel costs in the import process may not be a large costs factor, it could be in the export process because this shift has a time-gap. Yet again, this is hard to quantify due to data scarcity and the different factors playing a role on the total length of the work out.

Other costs during the export process are hiring extra vans to serve all customers on-time. Routes and vans are calculated on the capacity and within the time-span they have to bring all packages and freight to the customers. Due to TNT's time-based services, vans have to depart on-time and they directly influence TNT's service level if they do not arrive on the agreed time. When the sorter or other equipment fails and processing these packages takes longer, extra vans are hired to do less stops per vehicle, to still deliver the service TNT demands. The number of vans and how long they need to deliver all the parcels depends on the number of downtime. A data example of depot Eindhoven showed on a sorter breakdown of 2.5 hours led to extra ad-hoc costs of € [REDACTED] for hiring extra vans and planning extra routes. In this example, the sorter was down only 1.5 hour, but switching back would cost even more time and therefore they continued using manual sorting (contingency mode). This breakdown occurred towards the end of the export process and sorting was just finished at 11:15 am. With finishing so late, TNT's service level was at risk and the delay also affected the pick-ups for the next import process. The

extra vans were needed to help in both processes due to the delay. Leading these costs back to the exact failure or downtime is hard by the small amount of information on these costs. Besides, the data for these costs is not easily accessible and stays “hidden” within the depot and hubs of TNT. Nevertheless, having a realistic example of € [redacted] already indicates the order of magnitude of this costs variable. Having this magnitude visible can already work as an eye-opener for the management of TNT global.

Last defined costs variable during the export process is the possible impact on the service level. TNT’s service is all about the people network and puts the customer central. Delivering or picking-up packages not on the agreed time can be a possible reason for customers to switch provider. Customers cannot see the reasons for delays and do not have compassion with failures on TNT’s side. Although customer satisfaction may be measurable, measuring the impact of failures and the financial consequences is a lot harder. This costs factor is based on subjective standards that differ between customers. Nevertheless, the impact on TNT’s financial performance becomes larger with customers that transport more freight. Failing to deliver on time may have bigger consequences with these customers because they demand a higher level of service because they offer TNT more business. Besides, TNT has *Express* and *Economy* as separate services, which creates a different expectation amongst customers. With *Express*, customers pay more for faster service, which means that they value agreed delivery times more than with *Economy*. Nevertheless, this potential cost factor needs to be taken into account for as a result of late deliveries by breakdowns.

Result quantifying breakdown costs

There were six costs variables determined from interviews with business improvement managers. From these variables (x_1 , x_2 , x_3 , x_4 , x_5 , x_6), the most important two concerned the CWC revenue loss (x_1), and hiring of extra vans and routes (x_4) in the different processes. The lack of quality data made it not possible to quantify all variables, but the most interesting variable (x_1), could be specified to a level that it can be used to relate it to downtime and MHS performance.

4.4 Maintenance costs

When TNT wants to improve their efficiency, and reduce the number of breakdowns, they need to increase their maintenance activities within their hubs and depots. These increased activities can be used to solve the corrective maintenance activities quicker, or to improve the preventive activities that cause these incidents. These maintenance costs also effect on the financial performance and as explained in chapter 3.2.1, do these costs have to be compared with corrective breakdown costs, to find an optimum balance. To quantify these costs, the improvements area’s and causes of incidents have to be known, to know what to improve. Therefore, just the improvements possibilities are gathered, which all can contribute to better MHS availability and financial performance.

Thinking of maintenance costs, the first thought goes to extra maintenance employees to simply do more maintenance. Expanding the OES-team to reallocate and decrease the area’s they have to cover

will improve the response time needed to get on-site. With a larger team, more hours are available for preventive maintenance during the hours that the sorters are down. Putting a mechanic on a fixed location with large volumes or a lot of breakdowns can also increase performance of TNT. The question arises if a larger OES-team of more mechanics the solution is to the breakdown problems of TNT. Looking at the chart of figure 22, a large part of the incidents has other causes than mechanical/electrical breakdowns, and an extra mechanic will not solve these problems. For these problems, other solutions need to be found. Practical training programs for operators will teach them how to work carefully with MHS equipment and explain the importance of working according these standards. Continuously emphasizing these working methods may be more effective than an extra mechanic in reducing the number of failures. Employing an extra team-leader or leading hand to watch over these processes is sometimes a better option than an extra mechanic. Other options are technical training programs for LH and TL. When local employees are capable of solving first level breakdowns, they are less depended on the knowledge from the OES-team. This will make them able to perform some basic maintenance and keep the operations running. This will also develop a form of ownership amongst the employees which contributes to better care of the MHS which increases it lifespan.

Besides investing in ways to prevent incidents by increasing the number of employees in any way, technical solutions may also help preventing failures. Updating equipment, making parts fool-proof, increase safety barriers that prevent incidents of occurring are all options that also decrease the number of failures. Perhaps a complete re-design of the sorter is the best solution. These are examples of PM and PdM. This may be a drastic choice, however if the breakdowns are largely caused by mechanical failures that are almost impossible to prevent, or just not build for the job, it may be the right decision.

These solutions are all based on improvements within TNT, or hiring extra TNT employees. However, if the systems just require more specialised preventive maintenance by suppliers, revising service contracts is an option that has to be reconsidered. Although contracts are hard to revise within the current term, suppliers should be open to discuss new contracts because they can benefit from them as well. If they provide more frequent services due to increasing volumes, they will increase their revenue too.

All these options can increase TNT's availability of the MHS and improve on-time delivery performance, but are only effective on certain failures. Combinations of these solutions are needed to eliminate every type of failure, regardless of whether they are structural or incidental.

4.5 Summary measurements of CTQs

After defining the CTQs, some very interesting measurements were extracted by combining different sources. Not all CTQs could be measured and defined to the right level. The incident file did provide useful data on the number of incidents per location and piece of equipment, but not all these incidents were registered with total time spend on maintenance. Without complete and accurate data regarding repair times and downtime, further conclusions build on this data would be worthless. Therefore, the

total repair time is ignored for further research and analyses are only executed on the number of incidents.

Variables regarding breakdown costs are defined, and the most influential variables (x_1 , x_4) are measured. CWC costs are based on average historic data of three locations. By using sensitivity analyses, and realistic error margins, these costs give a realistic representation of the possible losses. The calculation method for measuring the missed revenue has been verified, and is interesting to use for further measurements. The costs of hiring extra vans, is based on a single example. The lack of data made further measurements not possible. Nevertheless, this one example already gave insight in the magnitude of this costs variable.

The different aspects of (preventive) maintenance costs are defined by looking at improvement opportunities. The large diversity in current maintenance costs due to separate service contracts at each site, made the quantification difficult. Also, the large amount of improvements options made it hard to quantify them. Nevertheless, the insight in the options that increase maintenance costs is useful for the development of possible improvements.

5 Analysis of CTQs

After the analyse part, it is time to go deeper into the real causes of downtime. Having measured and defined the costs that are affected due to breakdown, it is time to analyse and connect the impact of the failures to such costs. Previous part gave some first insight in the costs with some data calculations on possible costs variables. This part will go deeper into the CTQ *MHS availability* to find structural and incidental failures, and looks for first solutions towards these failures. These analyses are focussing more on narrowing down and structuring the problems, which is in line with “soft” operations research of Masys (2015).

5.1 Pareto analysis

To be able to look into depth of the causes of the failures, an analysis to do so needs to be applied. Within Six Sigma and the DMAIC-framework there are several RCA tools available. Analysis like FMECA, Cause-and-effect and Pareto are all examples of tools to find the root cause. An FMECA is a method used to look for possible failures that can occur in a system and go deep into the material conditions of the system (Waeyenbergh & Pintelon, 2002). This is a rather pro-active approach, and useful for systems that are just implemented or going to. With the current availability problems within TNT this is a less suitable tool. A more suitable tool is a cause-and-effect method, that uses an Ishikawa diagram for visualization (Breyfogle, 2003). This diagram is also better known as a fishbone diagram due to its shape. This diagram has the advantage of being an industrial standard, and is therefore widely accepted and known for problem-solving and quality improvement (Tang et al., 2006). This tool is more suitable for reactive problem analysis and answers the question why something breaks down. The Ishikawa diagram goes hand-in-hand with the 5-why method for the analysis of the problem (Benjamin, Marathamuthu, & Murugaiah, 2015). The diagram is more a visualisation of the 5-why method and useful for finding the causes. The 5-why method continuously asks *why* on every answer. A simple example is:

Q: Why is the car broken?	A: The engines failed.
Q: Why did the engine failed?	A: There was oil leakage.
Q: Why was there an oil leakage?	A: A rubber filter was broken.
Q: Why did the rubber filter break?	A: It had not been replaced with the engine service.
Q Why wasn't the filter changed?	A: The mechanic forgot it.

This example goes several steps back to find the problem, and leads to a cause in human error. The goal of such a tool is to find the causes of the *effect*. This *effect* of the analysis is already known, and is the *availability* of the MHS. To get these, a start already has been made on the causes in the analysis part. Normally would the fishbone diagram split the effect in pre-defined categories like:

- Methods, Materials, Machinery and People

- Surroundings, Suppliers, Systems, Skills
- Policies, Procedures, People and Plant

However, a separation on the categories Mechanical, Operational, Electrical and Control has already been made in the incident-file. These categories would better fit as a first separation on the incidents because these categories touch upon human error, material failure, process failure and resource (environmental) failure which show many similarities with “standard” categories. Therefore, these categories are chosen to analyse the MHS.

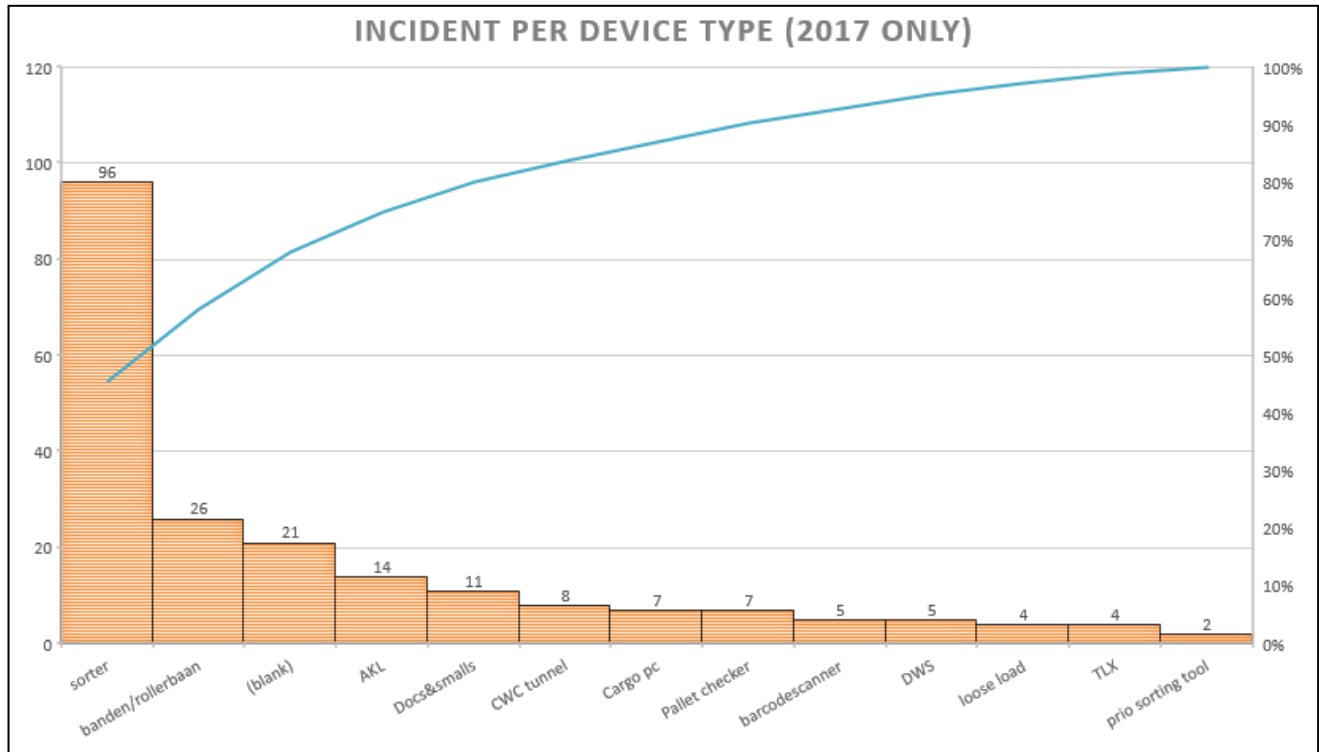


Figure 26: Incidents per device type (2017), (TNT, 2017)

Before starting with a root cause analysis on the whole MHS, it is better to narrow the MHS down to have a better insight in the root causes per device/equipment. Using a Pareto analysis on the frequency of failures helps identifying the most critical parts (Burhanuddin et al., 2011). Looking at Figure 26 above, most incidents are related to the *sorter* (96) and *belts/roller tracks* (26) in 2017. These two devices are quite related to each other, because they have the same function: moving parcels from A to B in the warehouse. However, roller tracks and belts are different from the sorter because they are just a sub-system and do not represent a whole sorting system. Belts and roller tracks are in most cases part of the sorting system, but important enough to analyse separate. Together they are responsible for almost 60% of the incidents in 2017. After these two devices, the category *(blank)* is the largest, but it contains multiple devices that do not fall under a specified piece of equipment. The *CWC tunnel* has 8 registered incidents, but due to its importance in lost revenue, this device has to be analysed using a fishbone diagram as well. Due to the small number of the CWC incidents in 2017, an analysis on the incidents of the CWC in 2016 is included to see possible relationships between these errors. The total

number of CWC incidents over 2016 and 2017 combined is 69. This gives a better overview on the causes on the CWC tunnel. The next part will discuss the three root cause analyses that include the sorter, roller track/belts and the CWC.

5.2 Root cause analysis sorter

As mentioned, the root cause analysis is based on the incident-file and the included data. A large sample can be found in Appendix C. The incidents are registered by the OES-team. They have briefly written down the problem that they found, what the problem was, and how it is solved. Although there are several incidents with a structural character, these cannot be connected due to the current registration. Using the 5-why method helps to structure and improve the data quality of the incidents (Benjamin et al., 2015). A data example with the registered data is given in the table below, including the added data (blue). Interesting to see is that this example doesn't include the repair time which is lacking in more cases.

Table 6: Example incident analysis

Date	26-01-17
Year	2017
Location	BRU
Device	Sorter
Category	Operations
Problem	"Reflectors afgebroken"
What?	Wrong operations
Cause	"Opgooien op een plaats waar het niet mag"
Why?	Not working according instructions
Why?	No knowledge of consequences
Structural/ Incidental	Structural
Solution	"Reflectors vervangen"

This example concerned a broken reflector at the depot of Brussels. The OES-team described the cause as *"throwing parcels on the sorter at a place where it is not allowed"*. By asking *"what"* to begin with, the incidents can be generalized by giving them a shared problem. In this case it is *"wrong operations"*. By asking *"why"*, a reason that goes a step deeper into the cause can be described. For this incident, the reason is *"not working according instructions"*. When parcels are thrown on the sorter at the wrong locations, the operators simply don't follow their work instructions. By asking *"why don't they work according instructions?"*, can lead to answers like *"no knowledge of consequences"* or *"lack of supervision"*. These answers cannot be traced back, and the final cause for the incidents is *"not working according instructions"*. Another category is added to highlight if the problem happens or will happen more often, or that it is an incidental issue. That can help recognize the selecting the incidents that will occur more often without a decent solution.

This process is repeated for all 191 incidents of the three selected devices. The decision to use causes like “*wrong mounting, not working according instructions, design failure, wrong parcel*” for renaming and structuring the incidents is based on the researcher’s experience. From site visits and interview with multiple employees, the problems and issues regarding different devices became known. Besides, some causes could be simply structured with the available data. The pre-defined categories (*mechanical, operational, electrical, control*) also helped in defining the right root cause. Nevertheless, all incidents had to be analysed multiple times to find the common factor between the incidents. Also, some incidents didn’t provide enough data to structure them and are left out of the fishbone-diagrams. Some likewise incidents were registered under different categories because, and some incidents could not be exactly categorized. These incidents are checked and discussed with the Service & Maintenance manager and excluded of no reliable answer could be given. After the analysis on all these incidents, they are put together in these fishbone-diagrams to get an overview of all incidents per device in one view.

5.2.1 Control

Starting with the root cause analysis on the device Sorter, all incidents are analysed to look for correlations. The fishbone diagram below visualises the sorter incidents and shortly describes why they affect the sorter. All these incidents influence the performance of the sorter, but this doesn’t have to mean that these failures completely stop the sorter. The diagram shows the four different categories that are mentioned before to get deeper into the root causes of the incidents. A root cause of an incidents is considered as the smallest arrow flowing from an incident. Sometimes incidents have multiple root causes or different incidents have the same root causes. These correlations can be interesting because a single solution may solve multiple root causes. The four categories are discussed separately to have better insight in the type of root causes.

First category is *control*. These are related to issues that network connectivity and data processing. From the data, a number of incidents showed no data in the BCI files, which register volumes of parcels. A Cargo pc that was jammed was often the cause of the failure occurred frequently. This incident is usually solved by resetting the Cargo pc and therefore not a huge problem to resolve and therefore doesn’t have a big impact on the performance of the sorter. Hence, the OES-team does have to resolve this simple incident to get this data available. Other problem is that the sorter sometimes sends some or all parcels to the overflow/reject area. These parcels have to be moved all the way back to the infeed area and are therefore not sorted to the right location. From control perspective, two reasons caused problems with the sorter. First reason is that the right location data is not loaded into the system causing that the sorter does not know where to send the parcel to. The other reason is that the server is not responding. Although the data is loaded, it is not connected to the sorter and parcels are not sorted. Besides sending the parcels to reject the sorter sometimes does not work at all or sorts bad by moving the parcels to the wrong chutes. Server errors are most of the times the cause of the sorter to malfunction. These incidents do have a larger impact on the performance of the sorter because it is directly related to the main function of the sorter. However, these incidents are harder to notice and need a deeper sense of the system to recognize these problems.

5.2.2 Electrical

Electrical incidents are more related to environmental effects like electric disruptions and failure of electrical components. As seen in the figure, overflow and reject of parcels are also related to electrical incidents. However, the cause lies with the scanner head which was in breakdown and therefore could not provide scanning information to the sorter. A defect frequency controller also impacts the

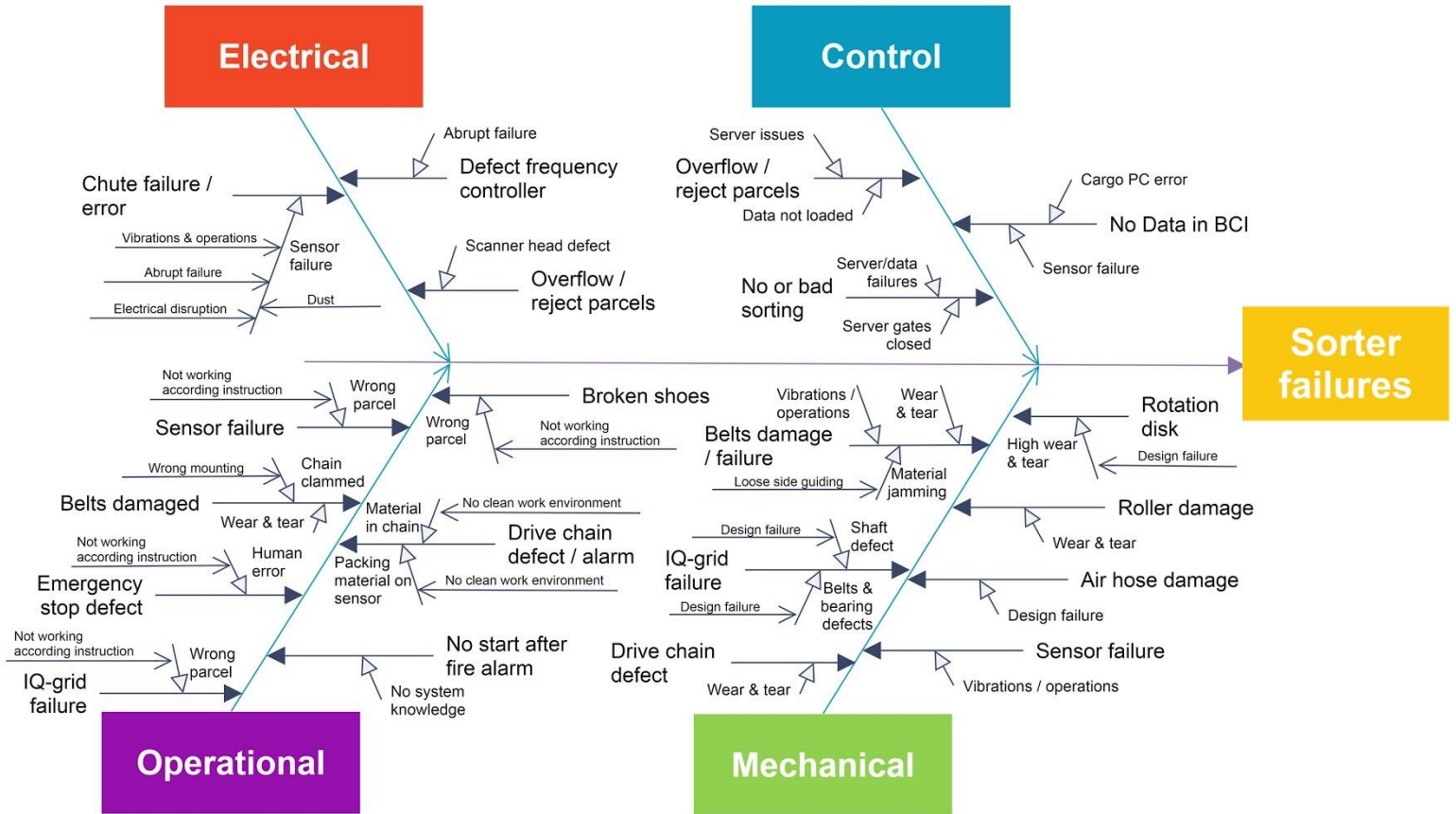


Figure 27: Ishikawa diagram representing incidents related to the Sorter (Commandeur, 2017)

performance of the sorter. These controllers control the speed and make sure these are regulated at a certain pace. Failure of these parts is harder because their failure rate is less depended on actual wear and tear of material. Then a more frequent electrical failure is concerning the chutes of the sorter. And more specific, the sensors around the chutes. These sensors register if a chute is full with parcels, and a next parcel cannot enter that chute and has to go to the overflow area. From the incident file, these sensors fail due to multiple reasons. Sometimes the sensors are moved or out of positions, and sometimes they are completely broken. This can be due to an electrical disruption, failure of the components in the sensor, dust or vibrations of the sorter. The fact that the diagram gives a view of all incidents of the locations within the Benelux, may give a skewed view on the reliability of the sensors. Most incidents regarding these sensors are within 2 locations, Brussels hub and depot Eindhoven, and could be influence by machine age or design failures too. Nevertheless, these sensors are important in the automation of the process and can easily cause a relapse in sorter performance.

5.2.3 Operational

From the fishbone diagram, one can see that the operational ‘bone’ is rather large. Incidents have an operational cause and can be traced to human error. First incident to notice is the failure of sensors in this category too. Someone or something broke or moved the sensor causing it not to function anymore. This can be due to putting parcels at the sorter where it is not allowed, or bumping into the sensor. But often it is broken due to a wrong size parcel that is not allowed on the sorter but still is put on by the employees. All these incidents can be seen as “not working according instruction” which stop the sorter from working completely or partially by blocking a chute. Interesting to see is that a “wrong parcel” also causes shoes of the shoe-sorter to break and also to break IQ-grids on the sorter in EIN. Not knowing the consequences of wrong working methods makes it difficult to change these methods. Furthermore, drive chain defects/alarms are caused by packing material that block a sensor, or gets stuck in the chain itself. Working organised and clean is important for smooth operations. When this is not the case, it is again not working according to instructions that cause these incidents. Last operational incident to point out is the failure to start the sorter after a fire alarm. The lack of system knowledge has caused that the OES-team has to reset/restore the system before it can operate again. The asked level of system and technical knowledge form a problem because new technologies are becoming more important in the operation. Knowing how the system works, how to solve simple (technical) issues and working according instructions may help to reduce the number of incidents. This will be further explained in the *Improve* phase.

5.2.4 Mechanical

Last category of the sorter incidents are those with a mechanical cause. First to notice is that, like with the electrical sensor failures, most mechanical failures can be traced back to one specific location (EIN), which is a location with a recent sorter (2 year). Nevertheless, this high number of failures in Eindhoven also ensures that the OES-team can do less (preventive) maintenance at other locations. An example of one of those failures is the IQ-grid. This part ensures that the parcel is moved to the right direction. However, due to the wide variation in size and weight of the parcels, they have a too high deterioration rate and fail. Excessive wear & tear is the cause of the failure, which means that the design fails to quick. When asking *why* again, one can see that the IQ-grid in Eindhoven is caused by a design failure. Looking into the other incidents tells that this same design failure is also responsible for incidents with rotations disks and air hoses.

Failures that occur at more locations are belt related failures. Due to wear and tear these belts fray and holes may appear. Also, when the tension gets lower they can slip from the end rolls or scrub against the side which causes a delay in operation. Loose side guiding makes packages or material clamp between the belt and the guidance, and that causes the belt to rip or jam too. Next to this kind of incidental failures, preventive maintenance on these belts is relatively easy by the fact that simple visual inspection can detect a belt in bad condition. This will be discussed in the next chapter too. Final incident discussed is the failure of the drive chain. This part drives the whole sorter and when this part breaks, the complete sorter is unavailable. This chain is subjected to wear and tear and may be hard to maintain using visual inspection.

That concludes the root cause analysis on the sorter. Before looking into parts that need improvement and that can increase the availability of the sorter, the other root cause analyses of the CWC and roller tracks are discussed in the next part. Some parts incidents have common root causes and are therefore interesting for improvement.

5.3 Root cause analysis: Roller track/belts

This part discusses the root causes of the incidents regarding the roller tracks and belts. This is done in the same way the sorter's incidents are analysed and starts with the incidents in the category *control*. The fishbone diagram of this part of equipment can be found in the figure below.

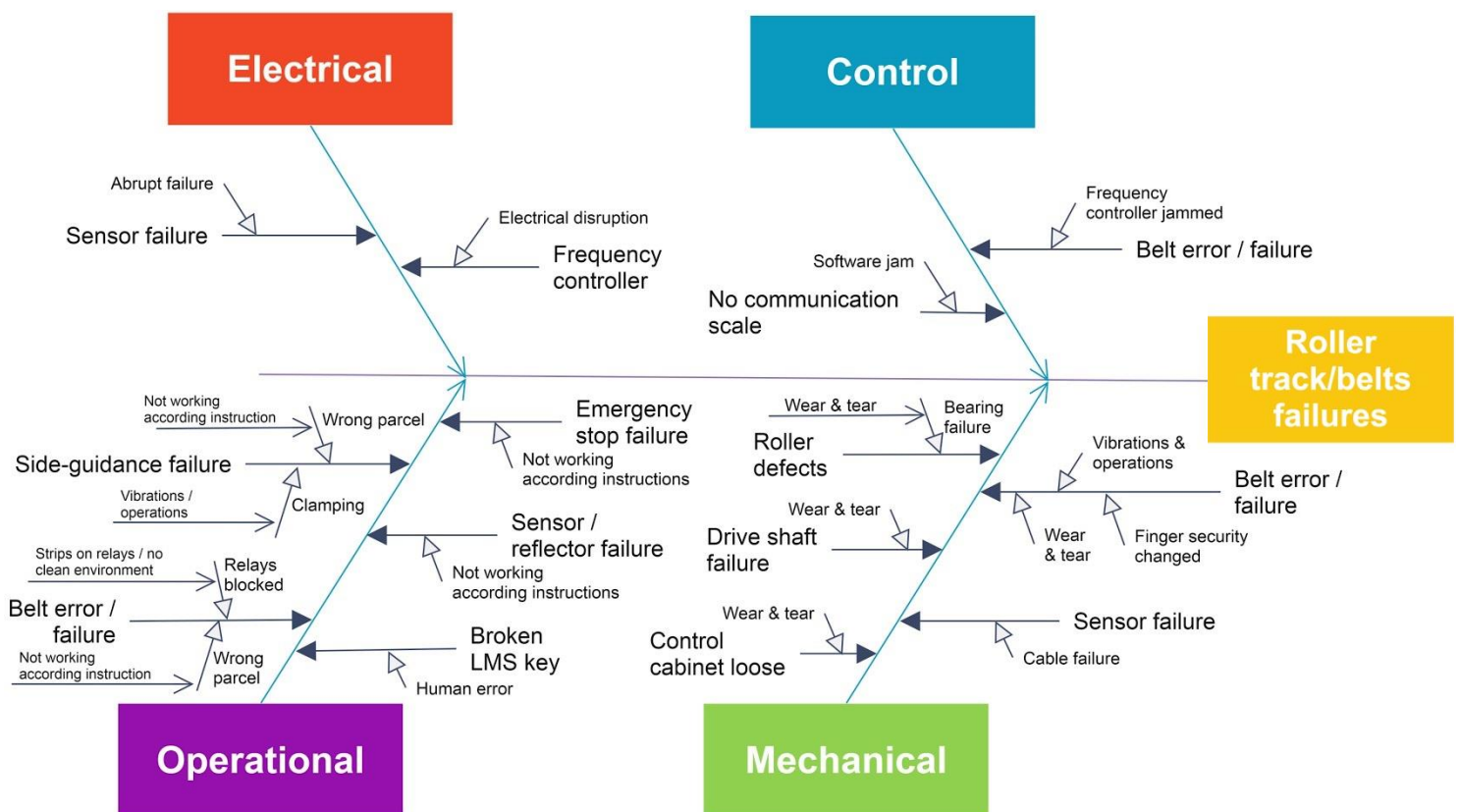


Figure 28: Ishikawa diagram representing incidents related to the Roller tracks and belts (Commandeur, 2017)

5.3.1 Control

So far, only two incidents with an operational cause were logged. First incident caused the belts to stop due to an error in the frequency controller. An error in the frequency controller jammed stopped a belt from moving. The cause why the controller jammed may be a software jam. However, deeper analysis is not available. The other control related incident was the lack of communication of the scale with the rest of the sorter. The scale is implemented in the belts and can therefore be seen as part of the roller track and belts. A software jam was probably the cause why the scale stopped communicating. But overall, there are not that many control related incidents with roller tracks or belts so far (2017).

5.3.2 Electrical

There are also not that many registered incidents with an electrical cause so far. First error concerned a sensor that broke down. Same as the sensors in the sorter, an abrupt failure of a sensor was the cause of the breakdown. The other concerned a frequency controller that was jammed only no registered effects or fixes are mentioned with this error.

5.3.3 Operational

Like with sorter incidents, higher numbers of incidents are related to operational errors. An error that returns here again is the sensor failure. They miss-align by getting hit by something or someone again, which may be due to a parcel that sticks out. Though, that parcel should then not be put on the conveyor which leads us back to operators on the flout that do not work correctly. Same goes for the broken emergency stop and the broken LMS key. These incidents happened because operators did not follow the working instructions. Looking at belt failures, first error that stopped the belt from operating was caused by strips blocking the relays. This is another example of an environment that is not clean and can influence the operation. Other examples are parcels that get clammed between the belt and side guidance. Parcels that are not within the specified dimensions, or do not meet the rules that have been set up, have a higher chance of getting clammed and cause the belts to fray and derail. Last operation errors are the problems with the side guidance. They serve to guide the parcels in the right direction. Employees “throw” these parcels on the belt on the wrong location which causes these side-guides to break.

5.3.4 Mechanical

There are also some mechanical incidents at the roller tracks and belts. Rollers get stuck by bearings that have been worn out. A drive shaft failure is also an example of a part that fails after a number of running hours due to wear and tear. These parts are nevertheless important to monitor due to their function of the conveyor. A belt error or failure has some several causes why it failed. First cause is wear and tear, where the belt has too many holes. Another error is that parcels are not running smoothly over the belt because the finger security is not well adjusted. Parcels can be damaged or get stuck when this isn't set right. Vibrations may be the cause that these settings are changing over time. Monitoring it is not only important for the parcels, but also for the safety of the employees because it is called “finger security” not for nothing. These settings need to be right so that the safety of the employees is guaranteed. Last belt related failure concerns belts that derail and damage sensors and start to fray. When belts age, they may get stiff and lose tension which may cause them to derail.

So far, the root cause analysis on the roller tracks and belts. Some new incidents arose, but also some similar root causes were found between the sorter and the rollers and belts. Next the last root cause analysis on the CWC will be discussed and from that point on, some improvements factors will be determined that can help to improve the availability of the sorter.

5.4 Root cause analysis: CWC

Final piece of equipment looked into is the Check-Weigh-Cube. This piece of equipment is important for retrieving lost revenue by weighing and measuring the parcels. This part uses scanners, cameras and scales to determine the volume and weight, and only some small belts for moving the parcels through the CWC tunnel. Due to the lack of incidents in 2017 so far, the incidents from 2016 are included in this root cause analysis. The fishbone diagram is shown in Figure 29. The incidents are discussed using the same categories as the previous parts.

5.4.1 Control

A common error with the CWC is that results or cameras show on the display that they are blocked. Most of these errors happened due the fact that software got jammed and stopped working correctly. Even though these problems were resolved quite easily by rebooting the system, wrong or incomplete data makes TNT incapable of billing the customer. So even though the physical sorting process continuous, revenue is lost with these incidents. Other control related incident is that the scale loses

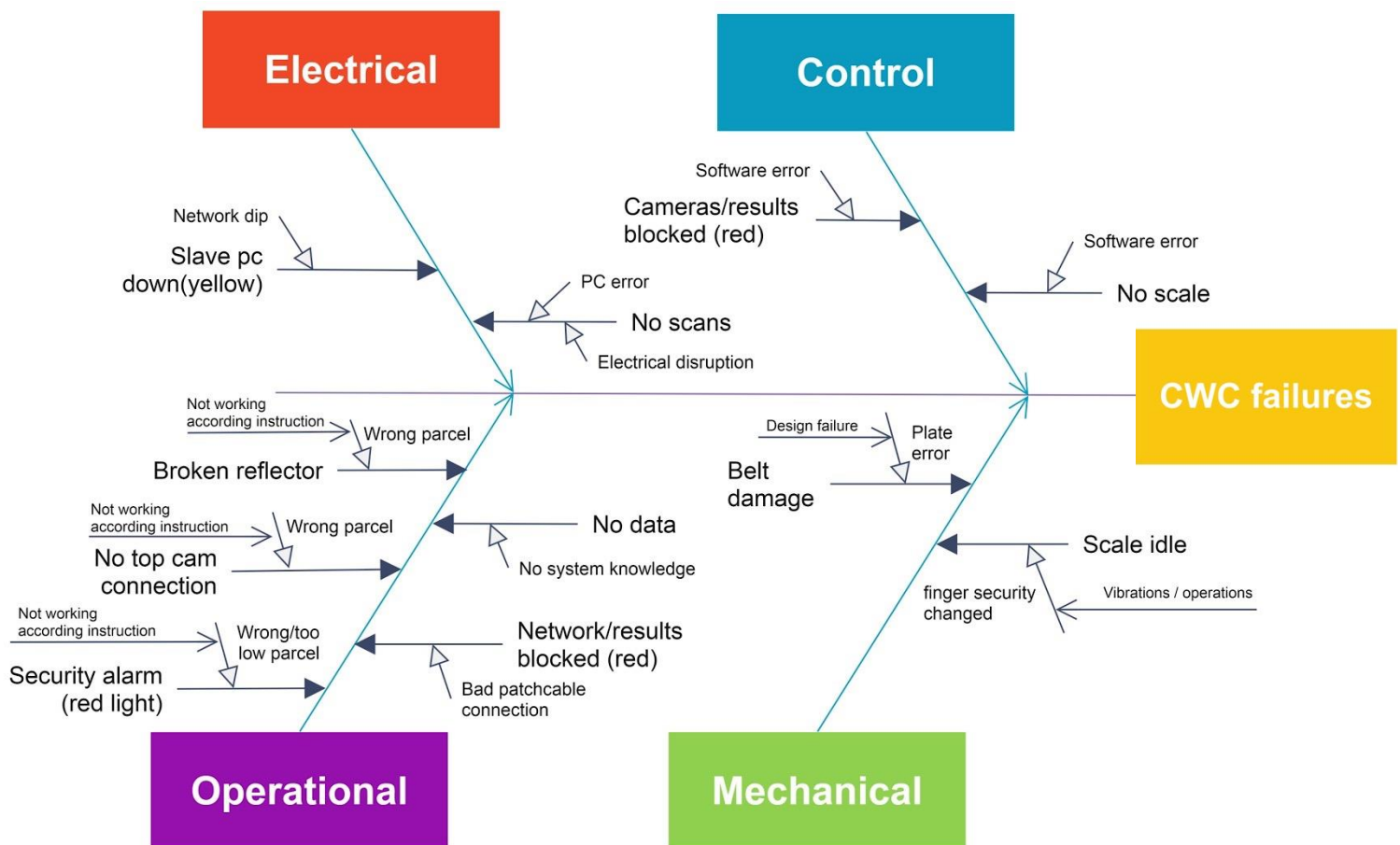


Figure 29: Ishikawa diagram representing incidents related to the Check-Weigh-Cube (Commandeur, 2017)

connection and doesn't send any data anymore. These incidents are also software related, and most of the time fixed with rebooting the system or by remote service from the supplier. So far, the control related incidents.

5.4.2 Electrical

With the CWC, some electrical errors are also responsible for lower performance. The CWC sometimes does not provide any scan data from the parcels. First cause is that the computers were jammed. However, it also happened that due to an electrical disruption the scanners were jammed. Both root causes could be repaired by rebooting the pc's or systems the right way. Another electrical issue are the errors with the slave PC's. These were caused by an electrical or network dip, which put the PC's into a failure mode. Rebooting them solved the problem. Concluding, these incidents do have effect on the CWC performance, but could easily be solved by rebooting.

5.4.3 Operational

Even with the CWC, one can see an increase in operational related incidents. Although there are less human related activities around this piece of equipment, most incidents still have an operational cause. From the fishbone diagram, one can see that a broken reflector and no top cam connection have the same cause. A broken reflector is caused by a hit from a parcel, which indicates that a parcel with wrong dimensions was placed on the sorter. So, wrong types of parcel do not just damage belts and the sorter, they also damage parts from the CWC. The security alarm lights, which light up when a possible danger or error occurs, are also affected by too low parcels. The sensors cannot scan its volume and give an error. When this alarm is taken for granted the employees safety can be in danger when something does go wrong. Working according instructions is therefore again important. Another operation error caused the network and results to be blocked by the fact that patch cables were unplugged or broken. This error could also have a software related cause, and is therefore harder to determine the cause when it occurs. Nevertheless, these cables should be secured and if they are unplugged, the need to be put back in the right way. Some issues are also related to the lack of system knowledge. Data is not visible or the system is set in the wrong modus just because the operator has not enough experience with the system. Training them and increasing their system knowledge helps to prevent such incidents.

5.4.4 Mechanical

Last category is the mechanical incidents of the CWC. There are less mechanical incidents because the CWC doesn't have that many moving parts. One incident concerned clamping of a parcel between two belts. Here, the finger security was not set properly to the right specifications and the belts got stuck. Vibrations or the operational influences could cause the setting to change. Another issue that occurred at multiple CWCs was a plate running against the roller of the weighting scale. The plates had to be grinded off until they now longer hit the roller. Although this was an initial design failure, the solution by adapting the plate is preventing it from happening again.

This concludes the root cause analysis on the selected pieces of equipment. These are responsible for over 60% of all incidents registered by the OES-team within the Benelux. With these root causes determined, improving the causes that have a structural character can decrease the number of incidents and increase the MHS availability. This will be discussed in the next part.

5.5 Selected root-causes

After the visualisation and structuring of the incidents it is time to select the root causes that affect the performance and availability of the three devices the most. As explained, this selection is based on the number of incidents rather than the total repair time due to lacking data registration. However, selecting the root causes for improvements is also based on the potential improvement potential of these causes. From the incident file, all the solutions have been analysed on whether they have been solved remotely, by the OES-team or by the OEM mechanics. Even when a computer error is caused by a network error which is *control* related, these errors are sometimes simply solved by resetting the computer. This broader way of looking towards the incidents and root causes fits the goal of TNT to look for a more general approach that affects the performance of multiple sites. From this analysis, combined with the knowledge gained within the sorting sites, three root causes are causing most incidents, and therefore have the most influence on the MHS availability. These root causes are:

- 1) *Sensor related incidents*
- 2) *Not working according instructions*
- 3) *Lack of system knowledge*

As explained, the effect on other incidents by solving these three root causes is also analysed. Based on that, simple electrical errors that are solved by rebooting the system, could also be solved by increasing the employees' system knowledge. This way of reasoning doesn't mean that the incidents are prevented, but solved quicker without having to wait for a mechanic. This still positively influences the downtime of the HMS thus improves the availability. Regardless if the incident is prevented or quicker repaired, the number of incidents affected by the three root causes are shown in the table below.

Table 7: Number of affected incidents

	# of incidents	# of affected incidents	% affected
Sorter	96	41	42.7%
Roller track/belts	26	11	42.3%
CWC (2016+2017)	69	34	49.3%

The table shows that over 40% of the incidents can either be prevented or improved when improvements for these causes are developed. More detailed information regarding these three root causes is described below.

Sensor related incidents

First root cause that occurs frequently are sensor and reflector related incidents. In all three Ishikawa diagrams these incidents appear whether they have a mechanical, operational or electrical cause. The incident log also shows that these sensor incidents have a structural character because they appear

multiple times. Nevertheless, the impact of just a small malfunctioning sensor can be large. A small sensor can block a chute, send out a signal that the sorter is blocked, etc. Although the incidents are solved relatively easy, the repair time can easily take a minimum of 30 minutes. If the OES-team however has to drive to the locations for such small errors, it can help if these incidents are solved.

Not working according instructions

An obvious root cause is the fact that operators on the ground floor do not work according instructions and are the root cause for many incidents. Zooming into the operational incidents from all three root

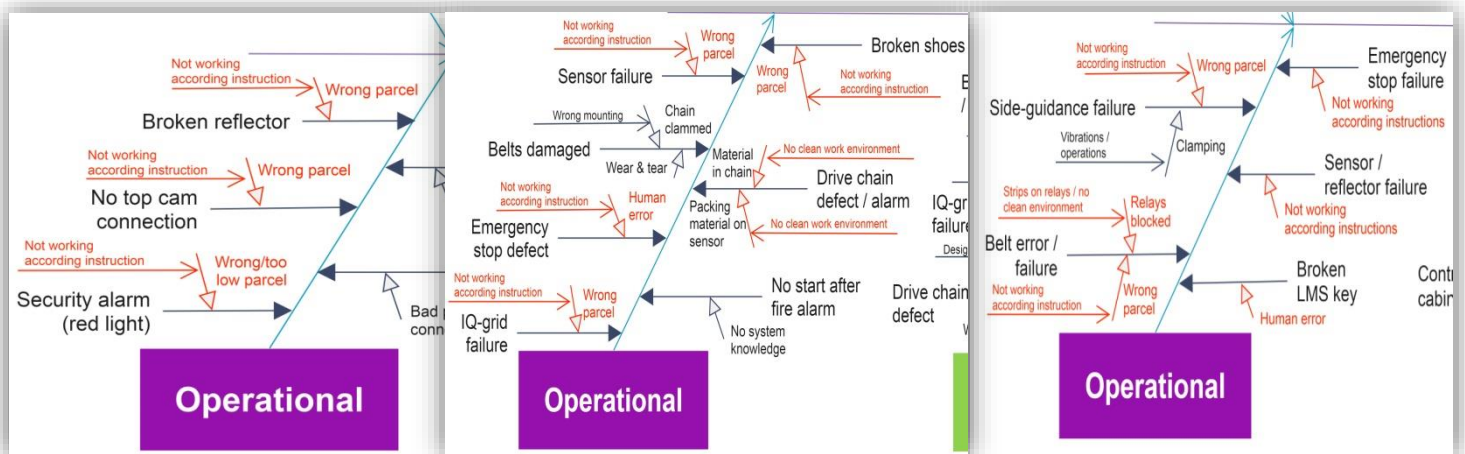


Figure 30: Highlighted incidents from “Not working according instructions” (Commandeur, 2017)

cause analyses, the red highlighted incidents show all incidents with a human influenced root cause. There lies a huge improvement potential in these root causes. The diagrams show that this cause is responsible for all different type of failures, from a simple broken key up till a complete sorter breakdown. So finally, bringing down the number of incidents related to this root cause will have a great impact on the CTQ *MHS availability*. However, changing the way of working and putting more attention to the work ethic of the employees on the floor can lead to an adverse reaction from the staff.

Lack of system knowledge

From the perspective of the root cause, there are only a few incidents related to a lack of system knowledge by the team leaders. However, there are more system related incidents which are solved by rebooting or resetting the device or equipment. A lot of the control and electrical related incidents are solved by rebooting network equipment. As discussed earlier, within the Benelux the OES-team is responsible for maintaining the MHS and they have to drive sometimes more than 90 minutes to simple reset a server or device which only takes a couple of minutes. Improved system knowledge could make sure that TLs can recognize some of these incidents and solve them by their own.

For these three root causes, an improvement plan will be developed in the next phase of the DMAIC-cycle. Choosing these three root causes also means that other root causes like *wear and tear* and *design failures* are not selected for improvement. Looking at *design failures*, one can see that most of these failures can be traced back to location Eindhoven, and that improvements developed for these design failures only have effect on single locations. Besides, incidents related to design failures like in location Eindhoven should be solved together with the OEMs by the fact that this location is quite recently build. Solutions to tackle this problem are already in development. Incidents related to *wear & tear* are more the incidents related to normal operations without any failures that have an external cause. Hence, the number of these incidents is relatively low, and can be monitored by visual inspections. Incidents like broken bearings and drive shafts/belts are occurring incidentally and are in principle suitable for preventive maintenance, but are not causing the most incidents.

5.6 Data verification

The analysis on the root causes has been verified by TNT's senior Service & Maintenance manager. The fact that the data file gave the OES-team room to define a re-occurring incident using other words, made it complicated in some cases to state the root cause. The three fishbone diagrams have been analysed and checked whether there are no mismatching root causes defined for some errors. All 191 (96+26+69) incident have been checked by comparing the data file with the fishbone diagrams. The minor changes have been processed in the research before further analyses were executed.

5.7 Summary root cause analysis

That concludes the *analysis* part of the DMAIC-framework. The goal of this part was to further analyse the defined CTQ *MHS availability*. This CTQ had potential for further analysis where the other cost related CTQs turned out to be a too broad part for this research. From the different equipment related incidents, the two pieces of equipment with the most number of incidents were selected together with the CWC related incidents due its importance. Using the 5-why method and the Ishikawa diagrams, the root causes of the three pieces of equipment are determined. The separation on the four pre-defined categories control, electrical, operational and mechanical served as a base for further analysis. Finally, from those incidents and diagrams, three root causes are selected for improvement based on their impact on availability, and thus their impact on site performance. These three root-causes turned out to be involved in over 40% of the incidents.

6 Development of solutions

This part is about improving the root causes found in the analysis part. This is the fourth step of the DMAIC-framework and has the goal to develop improvements for the determined CTQ in the previous steps. This part will also be looking into a design that can help or support employees in making a well-considered decision on their operations. The incident analysis showed that several incidents have the same root cause, yet a specific incident could have different root causes. That indicates that a certain solution can have several effects. Although this part only looks at improvements aimed for the improvement of *MHS availability*, it does have effect on the other CTQs *breakdown costs* and *maintenance costs*. Improving these CTQs will lead to a better on-time delivery performance and financial performance.

6.1 Lack of system knowledge

After all the analysis, it is time to start with the development of improvements that will decrease the number of incidents. First root cause that will be discussed is the lack of system knowledge. This root cause is a cause that has effect on all different sorts of incidents, but most of all, how to solve or estimate certain incidents. Solving or improving the overall system knowledge of the TL, LH and operators asks for a broader look upon the organisation.

As explained earlier the composition on the work floor exists mostly of operators that sort, transport, label, load, unload and repack the parcels and pallets around the floor. These operators are almost all flexible workers from employment agencies that do not have a strong binding with the company. The technical level of these employees is also not that highly developed, which is in principle also not required for the work-related activities at the depots. It is hard to demand more technical and complicated tasks from them because it differs a lot from their current work. The TL and LH are most of the time contracted by TNT and have a bigger role in managing the operations on the floor. They have a larger affection with the company, and are more eager on having high performance. The fact that they have more responsible and complex tasks makes them suitable for learning new skills.

The increase in automated sensors, wrist scanners, electronic weighing scales and volume scanners is changing the operations on the work floor and require different skills. The balance between human and machine is changing which requires certain knowledge how to use these systems. The systems are built to perform, but as soon as they lose their operational function, the operators on the floor don't know how to handle them. First example of this lack of system knowledge is with the CWC related incidents. Volume, weight and location data is send automatically to the servers without the interference of humans. But when the software or server is jamming, solving these incidents is impossible for TL and LH while most of these incidents are solved by resetting the scales or computers. This is either done by the OES-team or remotely by the OEMs which can easily access the CWC. Although the operators, LH and TL are not certified to repair or fix anything on the CWC, more system knowledge can help identifying the

problem and speed up the procedure to fix it. That would create an extra set of eyes which can help the OES-team with repairing the incidents.

Other examples of lack of system knowledge are the incidents regarding the Cargo computers. A couple or repetitive incidents show that there is no or to less data measured. These incidents were almost always solved by resetting the PC. This relative easy process to reset only costs the OES-team about 30 minutes to reset and reboot, but including travelling time it can add up to about 2 hours. This shows the need for an employee with system knowledge. Although this solution a corrective measure, it is a first safety measure to increase the MHS availability. On the other hand, if these incidents have a structural character, replacing the computer or demanding an improved software application from the OEM is a more preventive solution. Another option is a remotely accessible system that allows OEMs and the OES-team to solve it from another location decreases travelling time. That would remove the essence of having someone on site that can repair the error. But that means that the gap between the technology and employees remains relatively large and the dependence on the system only grows.

Eventually, the automation of the sorting process increases the importance of data and data handling, which requires a different skill set of the employees. However, to get the TL and LH able to take on this responsibility a few changes have to be made to get this procedure to work:

- *Willingness from the TL and LH.*
Some of the employees see it as a too big responsibility and don't want to take that upon them.
- *Training in using and analysing the MHS*
Knowledge how to properly reset computers or scales needs training and instructions. These training programs need to be custom made for the TL and LD and can either be given by the OES-team or by OEMs.
- *Instruction manuals:*
Even after having received the right training programs and gained extra insight, instruction manuals can guide the TL and LD through the process of failure identification or solving the problem.

These changes and improvements are necessary for a better performance and a better cooperation between the MHS and the employees. Together they can form a solid base for increased performance in all depots and hubs.

6.1.1 Willingness to change

The willingness of the employees is the foremost factor that can lead to better performance (Judge & Robbins, 2015). Within TNT, the technological development is increasing with new locations, CWCs at almost all locations and further automation of loading and unloading. Although the financial return on investments of these machines is verified, the introduction of these complicated and expensive machines scared the employees to look or fix simple problems of these machines. The negative thought: "I could break something on a million-euro machine" scared the TL and LH to take care of these machines. Their argument to decline some extra technical tasks was that it didn't belong to their daily

task and it wasn't mentioned in their job description. That shows the resistance and fear of the TL and LD. The process of these complex changes needs to be well managed and supported with the right attitude. To create the willingness to change TNT has to:

1. First important step is to create a sense of urgency why the change is needed. Explain why it is so important that TNT has to change. Show managerial support by explaining and emphasising the importance of the TL and LH and their added value. This support is managerial support is one of the key success factors in getting the employees to embrace the change and get them interested in increasing their knowledge (Shen, 2014). Express the confidence TNT has in the TL and LH and show that TNT is confident to put the responsibility in their hands. Communications is essential here because they feel that they are involved. That makes them less resistance against it. Give them the opportunity to provide input in how they think they can change.
2. When TNT asks more skills and knowledge from their employees, they should reward the fact that the TL and LH take a bigger responsibility on themselves. They are the ones responsible for smooth operations and with higher responsibilities come higher rewards. With giving TL and LH higher rewards, TNT also has the chance to set goals for the TL and LH to increase performance.

It is not self-evident that a small change like giving addition tasks is being implemented without any problems. To overcome such development, a well-designed communication plan is needed that guides the TL and LH from the beginning.

6.1.2 Training in using and analysing the MHS

After having a well-planned and communicated plan that indicates the reasons for change and emphasizes the important role of the TL and LH, it is time to actually increase their system knowledge by training activities. These training programmes do not have the goal to create complete engineers, but to give them a sufficient skill set that enable them to analyse the seriousness of an incidents, and to give them the ability to solve simple errors.

Continuing on the reason why it is so important for TNT that the MHS are running in optimal conditions, is to show them an insight in how the data is used, and how the incidents influence the performance of TNT. Especially when employees have to be trained. Training these employees to do more independent maintenance tasks is also known as *autonomous maintenance*. This maintenance concept is one of the eight pillars in the philosophy of *Total Productive Maintenance* (TPM) and is essential for training employees in preventive tasks (Chen, 2013). If the TL and LH don't care if the parcels are delayed, because they know that extra vans are hired anyway, they don't have a feeling for the consequences of these delays. Creating awareness is therefore a first step before working on the technical skills. This overlaps with the first step mentioned above about creating a sense of urgency.

Second step is to really begin to develop their technical knowledge. The fact that the job description didn't require any technical skills, TNT should start at bottom level with the simplest things. The TL and LH are not expected to change a conveyor belt when it is broken, but they do have to be able to know

when there are too many holes in the belt, it should be replaced. As explained before, several incidents are simply fixed by rebooting or restarting the equipment in the right way. This can always be in consultations with the OES-team and gives them a first step in taking responsibility of the MHS. Therefore, a first training should be about how to start and stop the different devices of the MHS.

Starting equipment

Pallet scales, sorters, small scales and volume scanners all have to start up without any interference. When sensors are blocked, parcels in front of the scanners or weight is on the scales, they cannot settle and set their starting position which leads to an error. Training the TL and LH to know which practical causes can interfere during the start-up process enables them to see and recognize why the device is not working. Using practical examples like packing material on a sensor, someone standing on the pallet scale during start up, or a pressed emergency stop teaches them how this process can be interfered.

Resetting equipment

Before resetting a device or system, the TL and LH need to be able to identify what exactly is not working, and if there is an obvious cause for that. Is there no data measured at all? Or does the display shows a specific error. Following specific steps in the failure identification is very helpful even when the exact error isn't even found. If a TL and LH can exclude simple causes like dust, material blocking a sensor, or a wrong set scale, the OES-mechanic does not have to spend time to first find the cause, but can start repairing the issue right away.

Shutting down equipment

Shutting down equipment after operations or after a failure is also important to train. Just unplugging the power when an error pops up on the display and hoping it is working again afterwards can lead to even bigger incidents. When the power is cut during certain operations, data can get lost and equipment can even get broken due to such sudden events. Also, when a simple incident is detected like a broken sensor or material jamming the sorter, they need to know how to shut down a specific piece of equipment.

How to handle a breakdown and how to safely work with the MHS will create a greater feeling or responsibility towards the equipment. This will contribute to the creation of ownership of the equipment (Pinto, Pimentel, & Cunha, 2016). The TL and LH have to supervise other operators on the work floor, and with more knowledge about failures and what disturbs operations, they will quicker recognize actions that damage equipment. They can act quicker, and intervene quicker as well. Overall, extra knowledge of the HMS will benefit operations and will decrease the number of incidents

6.1.3 Instruction manuals

After having convinced the TL and LH about the added value of their increase system knowledge, and having trained them to handle the equipment, simple instruction manuals can support them with the identification of errors, or repairing simple parts. Although some incidents may happen more often than others, the knowledge of how to deal with one cannot always be up-to-date anymore. Repetition and a simple roadmap how to identify certain incidents can be very helpful. TL and LH can use these roadmaps

as a tool for identification of the error. These roadmaps do need instruction when these are followed during operations. The use of corrective maintenance may be useful at the beginning or end of the operations. When operators use these roadmaps and still cannot find any incidents, then it supports them into calling the OES-team with the thought that they did everything in their power to solve it. Such a roadmap could be interesting for small incidents like the once that involve sensors. Next incident for improvement gives a more extensive elaboration on this solution.

6.2 Sensor related incidents

Improvements regarding the sensor related incidents go a little deeper into the technology related solutions. The Incident analysis and the Ishikawa diagrams showed a relative high number of incidents with a sensor related root cause. This shows the vulnerability of the sensor but also of the sorter. Its dependency on such small parts makes the reliability of these sensors important. From the incidents, one could see that most sensors related incidents came from:

- A broken sensor or reflector
- A blocked sensor or reflector
- A moved sensor or reflector
- A broken or disconnected cable

Developing improvements related to these incidents will never block or resolve all these root causes. For a preventive measure will it be difficult to block simple errors like packing material blocking the sensor. However, the differences in sensor constructions at different sites is also a design failure from central engineering. Differences in sensor performance should have been recognized and used as “best practices” or “lessons learned”. TNT should have chosen the most rigid construction from the start. A more short-term solution will therefore be discussed below.

6.2.1 Sensor Support manual

When the system knowledge of TL and LH is increased, advice was the creation of instruction manuals that can help them guide through the process of failure identification and solving. To design such supporting tool, requirements have to be met that require a safe situation where TL or LH can use this manual without crossing to many set-backs. Furthermore, the action plan for such a supporting manual will be helpful for the development of other supporting manuals too. For now, the supporting manual is focussing on the sensor related incidents, but the steps towards this manual can be used in the future. The decision to develop a corrective support manual is because this is an improvement that will provide some quick wins. Reducing incidents that are frequently present will decrease downtime and boost performance.

The design of a supporting manual needs to either find the problem, or exclude everything else. It is important that when a TL or LH follows the instruction it either gets instruction how he can help, or that he has to contact the OES-team or management. A manual that leaves the reader without knowing what

to do will only raise the number of questions at that person. A manual should help, and not raise more question than at the beginning. Therefore, the design of a supporting manual should have the following structure:

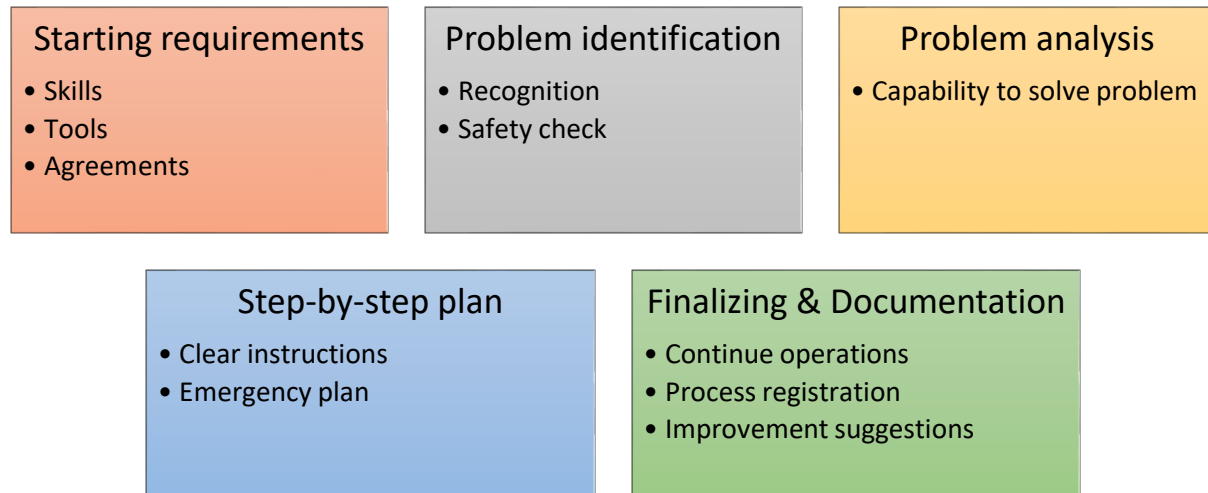


Figure 31: Structure supporting tool (Commandeur, 2017)

Before a supporting manual can be made and implemented, all the requirements that are needed to perform an action described by the manual should be present. Without a clear or incomplete plan, the manual will never serve its goal. When all ingredients are available, the process of problem identification can start. After the situation is safe, the situation can be analysed and a step-by-step plan can be followed if it provides a solution for the found problem. Last step is about finalizing and registration of the process. Feedback on the problem, and possible improvements on the process or manual are valuable. To check if the supporting manual fits the location, it has to be reviewed on the location before implementing it. Small local steps can be added so no mismatch is created between the guidelines and operation.

These steps are followed with the design of the manual for the sensor incidents. To design a clear and understandable manual, the authors should pay attention to the following points.

- Include a (single page) overview of the steps as guidance (flowchart)
- Describe what the function is, and not just what to do
- Avoid technical jargon
- Provide complete solutions
- Use of photos, diagrams and colours for clarification
- Check with TL and LH
- Exclude dead ends

When these steps are used in the design of an instruction manual, it is likely to be used and understood by TL and LH of TNT. The sensor related incidents are excellent candidates for the development of such manual.

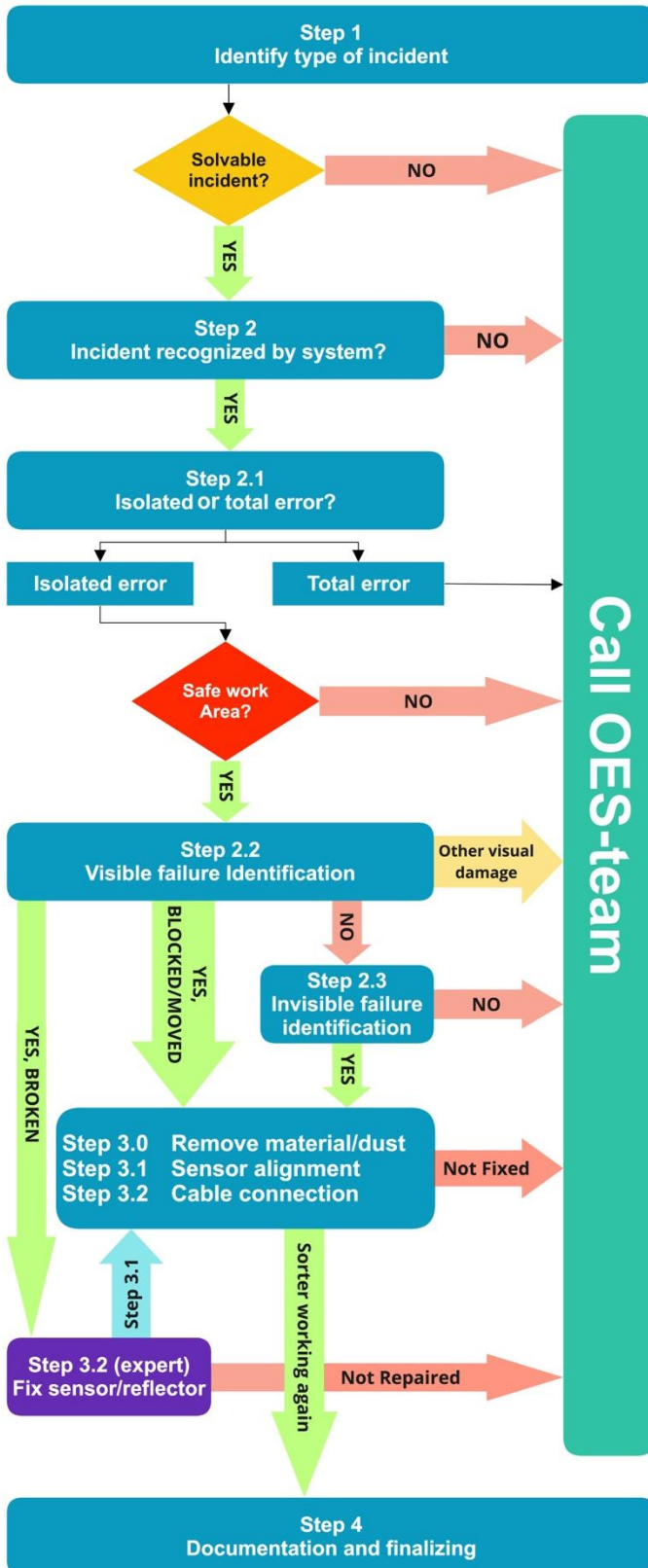


Figure 32: Decision flowchart Sensor incidents (Commandeur, 2017)

Figure 32 shows a single page overview of the supporting manual for sensor related incidents. This chart gives a clear and easy overview on the tasks that need to be executed by the TL and LH. The complete supporting manual can be found in Appendix D: Decision support system for sensor replacement. Step 1 looks at determining the type of incident. When they fall into the pre-defined types of incidents, without a mayor obvious error (complete mechanical crash), they can proceed to step 2. This step is about reading the failure from the computer system, which functions as small control centre. If the failure is recognized by the system, they can proceed to the next step. That's about understanding the error given by the computer, and looking if it is a small isolated error. If it is, the TL or LD can proceed to check the location. First of all, to see if it is safe to execute any type of maintenance without causing danger for him or his colleagues. Without a safe work area, it isn't allowed to clear, repair or do any other maintenance related activities in that area.

In every step, the TL or LH can contact the OES-team if the manual doesn't provide the answer, or they don't know what to do next. This gives them the feeling they can always check if their doing it right. From Step 2.2 in the chart, a simple number of questions leads the reader towards a next step depending on the type of incident. Questions like: "*Sensor blocked by parcel material?*" or "*Reflector out of position?*" are simple question that can be answered with "yes" or "no". If the question does not provide a "yes", they can call the OES-team again for help. A

well explained roadmap with photos from the real scenarios gives the reader a recognizable view on the situation like at the photo below. This photo shows how the sensor and reflector see each other when having a clear view. When having found the failing sensor, the TL and LH can use the manual to fix the error by following the steps. An extra step is added for a complete replacement of the sensor. This is already seen as an advanced technical skill and is only performed by the TL and LH who had extra training and approval from the OES-team. Final step is about documentation and finalizing the repair. For now, the TL and LH have to register the incident in the incident-log that the OES-team is managing, but in the future, they may have to register a more extensive documentation.



Figure 33: Sensor/reflector alignment

This support manual provides the right guidance for dealing with these errors. However, at the end of a shift, the urge of solving these incidents may not be that high. For TL and LD it may be better to finish the sorting process without spending time to fix the sensor/reflector, and leave that for a mechanic during the available time-window. For breakdowns before the peak the urge of repairing is higher. In this case, solving the incident quickly and getting the MHS up and running is important. However, using this framework to find out that the incident cannot be repaired, is a waste of time. Contacting the OES-team has at that time priority, no matter if the failure is eventually fixed by a TL or LD. The decision to switch between fixing the incident and continuing the process in breakdown-modus will depend on the number of parcels that still need to be sorted. This needs to be determined per location, because some are quicker to reach, and some of them have a better contingency plan. Time registration of the incidents is therefore an important

That concludes the design of the supporting manual for repairing sensors. A simple but structured manual can take away relative easy tasks from the OES-team which gives them more time to plan their preventive maintenance activities. The decision for the development of such manual for the sensor is based on the frequency rate of these incidents, but in the future they can be based on the number of downtime combined with the frequency rate. When the incident log is made more complete and is enriched with more data, the decision scheme can be extended with more actions and advices what to do.

6.3 Lack of working according instructions

Last suggested root cause for improvement is the lack of working according instruction by the operators on the floor. A great number of incidents related to wrong parcels placed on the sorter are the cause of incidents. Hence, this uninterested or ignorant attitude from the operators is also slowing down the process even when nothing breaks. Parcels will fit on the sorter, but due to the wrong size it will end up at the reject area where extra employees are needed to manually sort these parcels again. Getting these employees to work according specifications will not only increase the availability of the sorter, but also increase its performance. Solving this incident has therefore a high priority.

The high percentage of flex-workers as operators makes it hard for TNT to control, but more importantly, maintain operational knowledge. The composition of the operators can easily change, which restarts the learning process. The fact that TNT has that many flex-workers is caused by some bad financial results over the past years. However, that does impacts the performance of their depots and hubs.

First improvement that should be made is to improve the clarity of the signs. As seen in Figure 34: Picture of prohibited parcels, besides the prohibit parcels marked with a cross, the minimum and maximum are shown as small boxes with measurements. Employees can have trouble with estimating if the box is within range, but measuring it costs too much time. A simple solution could be hanging 2 dummy boxes with the minimum and maximum size to visualize the approved size. Employees have to only compare their box with the dummy example and then decide if it is too big or not. Although employees that are working there should remember the size after a while, this simple example could be very helpful for new flex-workers. Visualisation of “good” objects is only effective if also a clear plan is designed what to do when the parcels do not fit the description. If the operators do not have a place or idea what to do when the parcel doesn’t fit the description, they cannot do much else than putting it on the conveyor. Clear instructions are therefore also needed for the handling of these parcels when they are not allowed on the sorter.



Figure 34: Picture of prohibited parcels

Instructing and telling operators what to do is also a part that needs improvement. The TL and LH are responsible for instructing new operators and should point them more on the right working methods. If they do not have the ability to watch over the operators during operations, an increase in supervision is needed to accomplish that. Reward some well-performing operators, even when they are from an employment agency, with the task of being “key operator” or “senior operator” and increase their responsibility. Tell them that they become partly responsible for the performance and let them brainstorm on solutions to the lacking performance. Teach them how to speak towards their employees when they don’t follow the instruction by giving them training in communications. These new “senior

operators” don’t need to have the technical knowledge to solve certain incidents, but making them know about the consequences if a failure already gives them the motivation why to have a better performance. Other training programs that could help them with increasing performance are showing them the added value of a clean work environment. Cleaning is already a form of preventive maintenance, and also the root cause of some incidents. Finally, the creation of these “senior operators” and training programs should give the TL, LH and “senior operators” a bigger sense of ownership of the MHS.

This is only possible if TNT reviews its organisational structure, where they hire a part of these operators. It is inefficient to invest in skill training of an employee that can switch from employer without any problems. Showing trust in operators, together with the possibility to grow within the company gives them a better perspective on TNT, and encourages them to work as a permanent employee. Having more control on the work floor is for now more valuable for improving operations. TNT should therefore invest more in their employees, by hiring and training the well-performing ones, and rewarding them if they want to work their permanent. With more own staff on the work floor, knowledge is better maintained which is important working with new systems.

6.4 Data improvements and Impact on CTQs

After the development of these improvements, it is time to discuss the link between these improvements with the CTQs, to see the effect on OTD-performance and financial performance. As mentioned before, availability is referred as *operational availability* and is measured by:

$$\text{operational availability} \left(\frac{\text{hours}}{\text{day}} \right) = \frac{(24 - x) - (\text{downtime during operations})}{(24 - x)}$$

From the analyses, only some registered incidents were measured on “repair time” and “travelling time”. Without accurate data registration and the amount of time spend on repairs by OEMs, the registration of the incidents is incomplete. In new large locations, this registration is at a higher level using data supported systems, and therefore the somewhat older locations really need to improve this part. For the calculation on downtime to measure the MHS site’s performance, TNT should therefore:

- 1 Improve the time registration of the incidents. Logging the start and end time of an incidents together with the question if it effected operation will show if it affects *operational availability*.
- 2 Emphasize complete registration of all incidents.
- 3 Get more insight in the repairs from the OEMs, and how much time they spend to the repairs. Combining this with time registration again is important.
- 4 When it did affect operations, specification in what level it did is important to get insight in the effect of such incident.
- 5 Usage of a software based registration platform. That makes it more accessible and easier for people to manage it. Makes it also possible to share with OEMs.

From a management perspective, the current data registration is not only leading to an unclear vision on the maintenance practices, but also gives no reason to improve the current situation because the impact on OTD and costs is hard to prove. To be able to see maintenance as a necessity and include it in the business strategy, it has to show its value why it should be in. Although the process registration is getting better, the current registration process doesn't offer the possibility to share this with OEMs and other employees. The responsibility of a truth-based registration is completely in the hands of the OES-team. If the TL and LH get more responsibility in maintaining of the MHS, they can be an important chain in this registration. They are the first employees at the location of the incident, and can monitor the time of failure exactly. If they can support the OES-team with the registration, it is likely to be filled in completely.

This centralized registration will also lead to more insight in the practices of OEMs during their periodical maintenance activities which are recorded in the service contracts. If both TNT and OEMs know what and how many maintenance activities they do (corrective and preventive based), they have the possibility to create service contracts that benefit both.

MHS Availability

However these registration improvements would definitely boost the quality of registration of the incidents, some conclusions can be drawn from the analysis and improvements so far. The suggested improvements decrease the number of incidents related to a lack of system knowledge, sensor issues or wrong operations. Although creating technologic knowledge at TL and LH can take some time, the other suggested improvements do not have to take much time to be implemented. To show the possible impact on the number of incidents, the number of failures that can be solved are selected with a safety

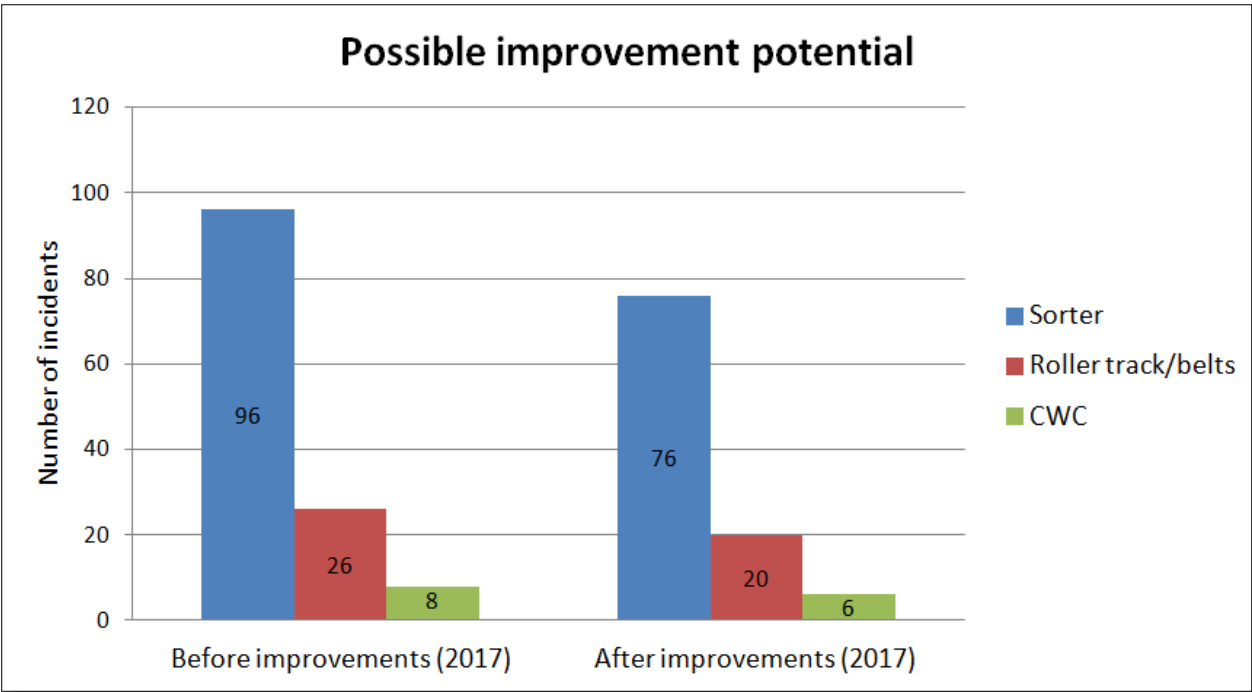


Figure 35: Possible decrease in incidents

margin. A feasible percentage of 50% of the incidents that are affected is selected as a result from the improvements. This assumption is based on the fact that some of these incidents will not disappear, but are solved much quicker by the TL and LH. This percentage should grow with time, but the effect of solving half of the incidents already shows the impact on the improvements. This is not only solving the downtime related to the time to repair, but also decreases the traveling time of the OES-team, and the time needed for finding the failure. The real effect on the amount of downtime is hard to estimate, but will be visible with good data registration. The outcomes are shown in the figure 35.

When 50% of the incidents are resolved, it still shows its significant improvement on the total number of incidents. Compared with the 210 registered incidents over 2017, these improvements can lower the total number of incidents already with 13%. That doesn't even include the reduction of incidents in the other equipment categories that are also affected by the improvements. The fact that these improvements are designed for incidents that are not based on the failure probability of material, gives more certainty of possible gained success. The solutions require commitment from TNT but are relative simple to follow.

Breakdown costs

In the *Analyse* part from this research, it turned out to be hard to quantify the costs of breakdown. The most important cost indicators (x1-x6) were identified for the different processes. A calculation based on information received from interviews and volume data showed the possible impact of a sorter failure on the CWC revenue loss. This number varied between approximate of € [redacted],- and € [redacted],- only for parcels at one location for one shift. For the costs of extra vans an example of a 2,5 hour sorter incident already led to extra costs of around € [redacted],-. These costs were however not traceable to a general number due to a lack of data. Although it is obvious that breakdown costs can and have to be decreased, it can only be concluded that fewer incidents and less downtime will contribute to a better financial performance. In future studies, this is an area that needs extensive research.

Maintenance costs

Last CTQ included the costs of maintenance to solve possible incidents. First improvement mentioned increasing the technologic knowledge of the TL and LH. This improvement will go hand in hand with the development of a communication plan within TNT and an appointed Project leader that will guide this project. This employee has to set up the plan, set up training programmes that include (almost) all TL and LH, and has to make sure that the OES-team will give some technical training programmes. An agreed budget has to be made free to support these initiatives. The cost of such program depends on the size, amount of people and time to complete. OEMs and suppliers need to be asked to give some basic training programs too. However, this program hasn't the intention to retrain the TL and LH to full engineers, only to give them feeling how the MHS system works. Therefore, this program will not have to take years to finish. However, with the continuous automation of the sorting sites, it will benefit the performance in both short and long term.

Training and selecting “senior operators” that have to check and instruct their colleagues on the right way of working will require a mutual plan like above. This has to be coordinated from a central point, to standardize the tasks and working methods as much as possible. The actual change is at a more local level, because they are less involved in the documentation and registering of the incidents etc. Creating these “senior operators” will create new job descriptions which needs to be financial rewarded. However, these salary increases are earned back quite easily if less failures are made on the floor. From the incidents and the lack of knowledge it seems that the current rewarding system is lacking these options, and quantity of employees is chosen above quality. Investing in employees with knowledge is therefore important.

The designed support manual only needs to be implemented at the sites with comparable sensors. Nevertheless, a central location needs to be installed were these manuals can be found, adapted and designed for other components. A central contact point needs to be available when certain manuals lost their use, or needs change. Maybe a platform has to be created were employees can make suggestion for the improvements of these manuals. The manual itself isn’t that expensive, only the trainings and procedures have to be trained and communicated. The control of these manuals can be combined with the suggested incident registration platform.

On-time delivery performance

Finally, will these CTQs impact TNT’s OTD and financial performance. As described in chapter 3.5, the OTD performance depends on a lot of variables which all have their influence. However, the availability of the MHS is the most important factor influencing the sites performance and TNT’s OTD. Improving the MHS availability and thus the sorting sites’ performance, will have a positive effect on the OTD of TNT (figure 36). The results of that should be visible in the future by looking at the financial performance and customer satisfaction.

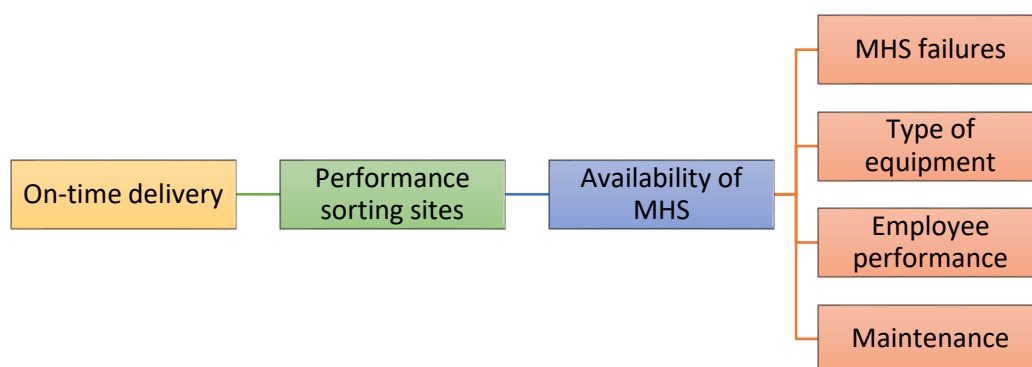


Figure 36: Performance of on-time delivery (narrowed view) (Commandeur, 2017)

6.5 Validation of improvements

Validation of the proposed improvements and the design is needed to decide if these improvements “*will do the right thing*” (van Dam, Nikolic, & Lukszo, 2012). Validation of the suggested improvements is important not just as a single check, but more as a process. In the DMAIC-framework, implementation is often a part in the *Improve* phase, where the suggested or designed improvements are tested and validated if they serve their purpose. As mentioned in the introduction, time constraints limit this research for the implementation of the suggested improvement. However, to make sure that the suggested improvements do have effect, they need to be validated before when they are implemented. Doing so, unnecessary time is saved when project plans are made and models are used within the organisation.

Different validation methods are available for the validation of suggested improvements and models. Van Dam, Nikolic & Lukszo suggest several validation models that can be used to validate a design:

1. *Historic replay*
2. *Expert consultation*
3. *Validation by literature comparison*
4. *Validation by model replication*

Because the suggested improvements consist of recommendations on changing working methods and structures, and of the design of a model, validating these improvements requires different validating methods. *Historic replay* is suitable for models that can be compared to real-world situation. This method isn't suitable because the model or recommendations cannot include parameters from reality that can be used in a simulation. *Validation by model replication* is also not applicable by the fact that result cannot yet be compared by the fact that it is not implemented. For the recommendations related to changing working methods and training the TL and LH, *validation by literature comparison* is applicable. If the suggested improvements have been proved to work in other theories or cases, it increases the validity of the recommendations. For the validation of the design, *expert consultation* is a suitable validation method. The design is made to solve certain sensor related incidents which occur in a specific operational environment. That requires an expert's opinion to see if the design serves its purpose.

6.5.1 Validation by literature comparison

The suggested improvements that are validated using literature are the improvements related to increasing system knowledge, and improving operators to work according instructions. These two improvements are validated using literature that already has shown the added value of these improvements.

The root cause analysis showed a lot of incidents that can be solved by increasing the system knowledge of the staff, and in particular the TL and LH. Three points of the first improvement suggestion were explained more in depth; *Willingness to change, Training, Instruction manuals*. These three points of attention will generate more system knowledge, but with the goal to give the TL and LH the ability to

solve and identify minor incidents. As mentioned above, is this called *autonomous maintenance* and is one of the eight pillars of the maintenance philosophy of TPM.

First point to validate is that *willingness to change* is a necessity for the implementation of a new way of working. Within TNT, this problem exists at operator level. Operators are not willing to include technical tasks because it is not defined in their contract. An article by P. Kotter and L.A. Schlesinger (Kotter & Schlesinger, n.d.) they discuss the added value to overcome this resistance. Creating a sense of urgency can be seen as *unfreezing* the status quo in the three-step model by Kurt Lewin (Judge & Robbins, 2015). Training the TL and LH are the *movement* towards a desired end-state and creating instruction manuals can help with the consolidation of the made changes.

Increasing system knowledge and sense of ownership contributes to the main goal of reducing downtime and increasing performance. In an article of Pinto, Pimentel & Cunha (2016) a study is conducted towards the sense of ownership amongst operators on different processes after the implementation of TPM related tools. This research especially focussed on the implementation of the TPM pillar *autonomous maintenance*, which is also recommended to implement at the Benelux locations within TNT. The results of this research showed that the performance and sense of ownership had grown. Also, the detection and anticipation grew, which decreased the number of incidents and breakdowns. Another case study by Workineh & Iyengar (2014) showed positive result after implementing TPM into their company. Their different levels of system knowledge included simple things like understanding the importance of cleaning, discovering abnormalities in equipment and operators and understanding causal factors behind defects. After the implementation of autonomous maintenance, they managed to decrease the amount of breakdown time with 46% while also decreasing the maintenance costs with 64%. Another case study by Tsang and Chan (2000) is about the implementation of TPM in a factory that exist mostly of low level employees, that have no technical skill and empathy with the equipment they use. Although cultural differences influence the implementation of TPM, the setting and attitude from the operators in this case reflects the situation at TNT. This article also showed that the implementation of TPM strategies requires a well thought out plan. The methods used in this article also contain visualisation of working instructions. Emphasizing the use of visual aspects is important for reminding employees to the new working methods, and to make it easier to understand as well. Clear and well visualized limitations will therefore contribute to a better performance.

6.5.2 Expert consultation

The designed supporting manual is validated using expert consultation. This type of validation is also known as *face validation* and discusses if the model looks reasonable and will do what it supposed to do. The model has to be validated before it is going to be used to avoid serious mistakes. The model is not ready to be tested in reality, because its requirements are not fulfilled yet. For the validation of the model, two sessions have been organized to discuss the steps of the model. For now, the sessions are organised with the senior Service & Maintenance engineer of TNT global.

- Senior Service & Maintenance engineer

The Service & Maintenance engineer is responsible for the current maintenance and service related processes within TNT global. This includes global service contracts with some of the OEMs, but also for the registration of the incidents data within the Benelux. He has lots of experience in maintenance and the development of business processes in several industries.

First session

The developed manual is designed to capture the sensor related incidents that affect the performance of the sorter. The first design was made on the assumption that all these incidents could be solved by TL and LH of TNT. The design followed the 5 defined steps in 6.2.1 Sensor Support manual, and created a manual that included instruction to solve all related incidents. During the first session, the next points were discussed:

1. *Set of requirements*
2. *Position of OES-team in process*
3. *Capabilities of operators*
4. *Technical settings*

The usage and design of such manual goes hand-in-hand with requirements that need to be fulfilled before the manual can be used. First remark on the requirements was that the TL and LH not only need technical training, but a complete communication plan has to be developed to support those training sessions. Next to that, the lay-out and registration of spare-parts need to be revised if TL and LH are also executing small repairs. The OES-team is responsible for the spare-parts on location, which is not accessible for TL and LH at the moment. New rules and regulations have to be made on the storage, registration and tasks between TL, LH and the OES-team. Think of a new location for some small spare-parts that is accessible for TL and LH.

Second remark considered the position of the OES-team in this process. Although the TL and LH are only allowed to follow the flowchart and support manual when they had sufficient training, the OES-team is still end-responsible. The OES-team stills need to get updated on the incidents and be able to give their advice on certain incidents. Next to that, the OES-team also knows at the hubs and depots within the Benelux who is capable for performing these repairs best. The decision for training the right TL and LH should be made together with the OES-team

Third remark from the first session concerned the capabilities of the operator. First design already included more complicated solutions and failure analyses. Advice was given that, although received training, the technical level of the TL and LH is not high enough to perform tasks like replacing complete cables and checking connections at controllers (PLCs). The model was adjusted and simplified after these remarks.

Last remark concerned the technical setting from the sensors. This technical task is also excluded from the manual by the fact that sensor adjustment is also too complicated for the TL and LH. Again, the design needed to be simplified to function effectively.

Second session

After the remarks and recommendations on the model, a second sessions was planned to review the changes that have been made, and to give further feedback on the design. During this second session, the following points were discussed:

1. *Use of colour coding and visualisation for clarification*
2. *Changing order of two steps*
3. *Adding an extra step for even simpler incidents*

Although the flowchart is a clear and structured guide for the TL and LH to follow the steps, the manual itself needed some attention. The use of colours in the report and visualisation of the sensor alignment makes it easier for the TL and LH to read the manual. Next to some photos from the sensors at the locations, a visual representation of the alignment is added to emphasize how the sensor should standing.

Two steps are changed in the manual to even simplify the manual even more. Although this leads to the possibility that the author has to take a step back in the process, it puts the easiest tasks first in the process. The final step before finalizing has been changed to an *Expert level* step, and this task can only be performed by TL and LH who are certified by the OES-team.

Last remark included an advice to even split the easiest task into two tasks. On behave of this advice an extra step is added to solve the simplest failures by removing only some paper or packing material.

Session wrap-up

These two sessions are very valuable for the designed model, and validate the choices made in the model. This validation gave meaningful insights in the development of such a supporting tool, and helps including influential factors that are easily overlooked. The supporting manual and flowchart comprehends the incidents and solutions as complete as possible, to provide a tool that has no or few problems during implementation. However, the implementation of the model goes hand in hand with the implementation of the TPM based solution and training sessions.

6.5.3 Future validation and threats.

Although literature provides some excellent examples of the success of TPM and the model is verified using expert consultation, that doesn't provide guarantees for a successful implementation at TNT. Further validation is needed that examine TNT's training programmes and purchasing strategy with the recommended maintenance strategy. The advice direction may not fit TNT's current long-term focus, were TPM is a too large investment. The failure analysis points towards improvements that are most effective at this moment, and emphasizes the improvement potential the strategy could have. However, the current culture within the depots and hubs should also be ready for the implementation of TPM

related improvements. So, validating the match between TNT's depots and hubs with TPM is necessary to ensure its success.

Validation of the model is now executed by expert consultation. Before implementing the support tool and corresponding actions, the model should be validated by local experts at the hubs and depots too. These experts have even better knowledge on the content, and can give their advice on that area. These outcomes can lead to design changes at different locations, but the design allows such customization. Validation of the tool does require a structured and well communicated approach to prevent resistance from the OES-team, managers, TL and LH.

Furthermore, is the design based on a failure analysis of the Benelux, but for global implementation further analysis is needed for validation. Due to a different set-up of service contracts from third parties and different working methods, sensor related incidents may not be a frequent cause of a decrease in performance and availability within locations outside the Benelux. Therefore, implementing and using this supporting tool may not be as effective as in the Benelux.

For future validation, and to really see if the recommendations and the supporting tool *"will do the right thing"*, the results and effects have to be made visible in some way. Getting more insight in TNT's local site performance, especially in the area of performance and maintenance management, is crucial for decision making regarding maintenance strategies. The current data registration makes it (almost) impossible to predict possible effects of maintenance decisions, except on the number of incidents that can be reduced. For validating the effects, TNT should:

- Review their current data collection system
- Use a "platform" based system that allows multi-directional communication
- Further specify breakdown costs and maintenance costs to site level
- Extract maintenance information from OEMs

Taking these aspects into account will create data that can be used for deeper analysis on availability and costs.

6.6 Summary Development of Solutions

Previous chapter elaborated the suggested improvements and how they affect TNT's on-time delivery performance. The improvements are based on the failure analysis, and focussed on the most obvious and most effective solutions to eliminate certain root causes. The suggested improvement areas were:

- *Lack of system knowledge*
- *Sensor related incidents*
- *Lack of working according instructions*

Solutions for these frequently occurring incidents are most easily solved by changing the way of working and investing in the knowledge and responsibility of the employees on the floor. Increasing the

knowledge of the TL and LH required a solid plan to overcome the resistance to change and develop a sense of urgency amongst them. Technical training sessions and instruction manuals are then needed to give the TL and LH the skills and tools to solve simple incidents.

A design of such manual is made to solve sensor related incidents with a clear structure that is easy to understand. The framework used for this manual gives the TNT the possibility to make other manuals as well. Hence, to overcome an overflow of manuals, well-argued considerations have to be made for which breakdowns a manual is designed.

Almost all improvements for solving the related root causes are not affected by the dynamic environment like changing weights and increasing volume. A lack of system knowledge has little to do with fluctuating volume during a week. Sensor related incidents are most of the time caused by packages or employees that have hit the sensor. Although in theory more packages should lead to more sensor incidents, this causality is impossible to prove. The lack of working according to instructions is a combination of too little serious supervision, flexible employees and unclear instructions.

However, the improvements developed and designed to eliminate these root causes are all related to the maintenance strategy of Total Productive Maintenance (Pinto et al., 2016). Looking back on these improvements, it is not that strange that TPM is most suitable for TNT. The provided recommendations and design are all focussing on *autonomous maintenance*, which is not only useful with the current incidents, but are also helpful for decreasing the dependency of a single maintenance plan. The lack of controlling these incidents and the capacity to quickly solve them gives individual sites the ability to fix simple incidents when needed.

That concludes the *Improve* part of the DMAIC-framework, where recommended improvements and strategy is explained. Next chapter will discuss how this TNT can manage and control these improvements, and what they should do to keep improving their MHS.

7 Managing improvements in the future

This chapter will elaborate how TNT can control their breakdowns in the future and retain their OTD by insights from this research. Normally in the DMAIC-framework, the *Control* phase is used for introducing a system that monitors the implemented improvements. However, the improvements are not implemented yet and therefore don't provide feedback. Yet, this phase can still contribute on how TNT should continue with their maintenance analyses for future improvements.

7.1 Central control centre

TNT's strategy with the construction of new sites is focussing more on standardization of the operations and monitoring performance of the MHS. To prevent the already constructed sites of drifting off too much of this strategy, TNT should focus more on a computerized maintenance management system (CMMS) that can analyse these sites. A CMMS can be used to manage information, operation, preventive maintenance and an inventory (Huo, Zhang, Wang, & Yan, 2005). This will increase the control and visibility of smaller sites. After the implementation of autonomous based solution as recommended, other failures will be getting more attention. With a well organizes registration of downtime, costs, impact etc. TNT's maintenance department is able to show the importance of an up-to-date maintenance strategy for the overall performance. Advantages of such a system are:

- Central point of collecting all data of incidents and repairs
- Benchmarking of sites
- Better view on abnormalities
- Easier recognizing of structural errors
- Possibility for easy expansion due to increasing mechanization

Such a computerized system does require full support within the organisation, from operators to site managers up to senior management. This support is needed to create support amongst the whole organisation. That will contribute to the fact that maintenance is seen as an important entity within the company.

7.2 Supplier involvement

Supplier involvement is another positive outcome of a centralized and well-communicated control centre. The OES-team and OEMs are currently working parallel on maintaining the MHS, with some collaboration with some incidents. Using a platform that is not only accessible for TNT but also for suppliers gives them both the possibility to share information amongst each other. This will create new insights on the maintenance tasks and gives the OEMs a more realistic view on the breakdowns. The developed solution where focussing on the (non)capabilities of TNT, but with better communication, solutions regarding technical design changes or equipment updates become more feasible. If a OEMs

sees that a part of piece of equipment has a high failure rate, which is normally fixed by TNT, it can design a more permanent solution that eliminates the root cause of the failure.

A more controlled and accessible framework also allows TL and LH to provide feedback and points of improvement that can be designed better. Employees that have to work with the equipment are valuable for providing feedback. Although some improvement may not be possible to implement at that location, the lessons learn can be taken into account with a new design.

7.3 Long-term Improvements

Besides the advantages of having a centralized failure centre, this research also gives the opportunity to keep improving TNT's maintenance on the long-term. One of TNT's question was how to identify their constraints, and this research helped looking at the opportunities to do so. This step-by-step approach helped doing that. So, when the first and most frequent root causes are eliminated, other failures and incidents will play a bigger role and become more interesting to improve. In this research, analysis tools like Pareto, Root Cause Analysis, 5-whys and the Ishikawa diagrams gave insight in the most frequent and worst incidents that affected *MHS Availability, Breakdown costs and Maintenance costs*. These analysis tools can be used again to determine the next incidents that have the most effect on performance at that specific moment. For example, when having implemented the recommendations on autonomous maintenance, the focus could shift towards to decreasing the longer and more technical incidents. For this example, it may be better to develop some technical design that strengthen the MHS.

Using well registered data on downtime for future analysis provides much more opportunities for process improvements. With this data, one can see exactly which incidents require more attention by better knowing their impact. Also, if the focus of improvement is on finding the incidents that have the largest financial impact, the development of improvements could shift from parcels to another freight type if financial data is clear regarding the downtime. This research is therefore helpful to continue improving the MHS by using the new collected data to find the most frequent and hardest bottlenecks.

The current situation and way of working within TNT offers a lot of room for improvement, where the provided recommendations are a first step in the right direction. This research was also initiated by TNT to work as an eye-opener and to explore the lacking information and processes regarding this subject. This research and its findings really helped to visualize the problem, which TNT can use to further specify and explore.

This concludes the *Control* phase of this thesis. Monitoring the outcomes of the implementation of the improvements wasn't the case, yet elaborating the advantages of doing so gives TNT the opportunity to adapt its structure. TNT can use this DMAIC-framework and analysis tools to analyse their performance in the future, and can easily implement extra tools if more data is available. Next part will present the final conclusions and recommendations for TNT.

8 Conclusions and Findings

This is the final chapter of this thesis report. This chapter discusses the findings and recommendations of this research and elaborates these findings by following the sub-questions developed previously. Following these sub-questions and the findings will answer the main question:

“How can the constraints of TNT’s Material Handling Systems in a dynamic environment be identified, and how does TNT preserve its on-time delivery performance at lower costs?”

Before being able to answer this question, some elaboration was needed on the terms *dynamic* and *Material Handling Systems*. In this case, *dynamic* refers to the different operational environments of the sorting sites of TNT. The fact that all these sorting sites are linked together and influence each other makes the whole network of sorting sites a dynamic environment. Zooming in on these sites, one notice that these sites have to be able to handle all sizes of freight, and the average input of freight fluctuates during a day. Combining that with the high occupation rate of the equipment in a week makes it hard to determine the effect over time and makes the decision for a maintenance strategy very complicated and complex. The term Material Handling System encompasses equipment that is used for processing, sorting, weighing and measuring of freight within a location. The level of automation and the age of equipment varies between locations which makes these locations not comparable with each other.

The research outcome of this main question is answered using the sub-question for guidance. After the findings and recommendations are discussed, the research limitations are discussed. The final part gives recommendations for further research.

8.1 Research findings and Discussion

SQ1. Which research framework can be used to identify the constraints, and is suitable for the development of improvements?

To be able to identify the constraints of the dynamic environment and Material Handling Systems, first the right research framework had to be selected to evaluate this problem. This research approach should match the objectives of TNT so that these can be researched properly. The research framework should also contain the possibility to use different analysis approaches, depending on the data and scope of the problem. Four research frameworks were analysed to see if they could provide the right options. The general 8-step decision framework of Baker et al. (2001) already needed a pre-defined process for improvement which was not clear in the beginning phase of this thesis. The prescriptive design approach by Dym & Little (2008) was focussing too much on the development of a design as a complete solution. Due to the unknown result this framework was also not that appropriate. The design-focussed business problem-solving methodology by van Aken et al.(2007) was too focussed on implementation of the solution and didn’t provide enough possibility for a well elaborated problem

identification. The last framework was the DMAIC-framework of the Six Sigma methodology (Breyfogle, 2003). This framework gave room for structured problem identification, and doesn't require implementation for it to work. It also provided the possibility to develop suitable solutions like recommendations and a design in one of the phases. Although other frameworks would have worked for the identification of the problem, The DMAIC-framework suited best.

SQ2. How can the operational environment of TNT be described?

To be able to understand TNT's operation and the use of equipment during this operation, background information was needed to get a better understanding of the problem. Understanding the steps and processes within a depot or hub are essential in seeing and understanding possible problems that can occur. Sites visits and internal documentation helped to understand the crucial points within the process. These site-visits also showed the diversity in equipment and size between certain locations. Understanding the link of time-critical issues between locations and within locations made it hard to look for a common goal. Furthermore, the research was looking at location within the Benelux, excluding the largest locations which have own mechanics on-site. Although these locations do not fall into the scope, lessons learned or more data of equipment could help with the development of certain improvements. And when improvements or strategy is implemented, they should be included as well to see if it may increase their performance too.

SQ3. What does the literature say about different types of maintenance/operation?

Before arguing and discussing possible solutions, background knowledge on different types of maintenance types was necessary. The three main categories are according to Horner et al. (1997), corrective, preventive and predictive(condition-based) based. These three are well known categories in literature. Furthermore, a recent predictive maintenance approach was elaborated due its interesting possibilities (Tiedo Tinga, 2013). This approach uses an approach that links usage and loads to determine the maintenance interval. The fact that TNT has a lot of data available regarding these loads made it a very interesting option for possible improvements. Also, literature regarding the trade-offs between corrective maintenance and preventive maintenance helped understanding TNT's problem and the optimum area for maintenance costs. Other maintenance theories are available that use computerized data from vibration sensors and technical failure rates of material to determine when maintenance should be executed. With the background information of TNT's operation known, the author was slightly biased, and therefore are these high-tech and precise strategies not elaborated. Hence, these could be important in future analysis and should be included when a new research is executed regarding maintenance.

Furthermore, the maintenance activities of TNT were researched. Interviews with engineers and managers gave insight in the distribution of the amount of maintenance between TNT's mechanics and the mechanics of OEMs. Insights gained in the service contracts of the OEMs showed potential for

improvements. However, these are not taken into account in this research, because this research first focussed to find the root causes before looking into contracts. Nevertheless, with the root causes known, revising service contracts should be a potential improvement possibility.

SQ4. What factors should be analysed for improving TNT's site performance?

This question looked at the TNT's performance and how it is influenced. TNT's two main performance indicators were *on-time delivery*, and *financial performance*. Before making a decision about which factors to improve, these performance indicators are broken down, to understand the link and conflict between them. From that point on, three important Critical to Quality factors (CTQs) are selected. Due to the explorative character of this thesis, other possible CTQs are ignored to prevent the thesis of getting too big. These CTQs are further specified and adapted to the current situation at TNT. *MHS availability* is specified as the operational availability of the MHS. Although data quality was lacking, this is the right way of determining the performance of the MHS. Nevertheless, looking into the operational profile of TNT provided useful insights in the urgency for a high availability rate. *Breakdown costs* and *Maintenance costs* are selected as CTQ by the fact that they need to be compared with each other for the "optimum total costs". These two CTQ influence TNT's financial performance are not well defined yet within TNT and need further quantification. These financial CTQs are also needed to support the decision to invest in developed solutions.

SQ5. How can these factors be analysed to develop useful solutions?

After the definition of the CTQs, this phase looked into to the collection of data that is needed to analyse the CTQs. Using "Soft" operations research, it allowed the author to use a less mathematical way of analysing important factors which are hard to quantify. Data regarding *MHS availability* included an incident registration file that has been filled in by the mechanics of TNT, which visit smaller locations within the Benelux. The data quality of this incident file was very poor, and couldn't provide the right data to perform deeper analysis. Incident registration by OEMs was also unavailable, which made the current incident file the only tangible data to investigate. The fact that this research was focussing on the Benelux made it impossible to perform measurements experiments, and that would only deliver data of a short period which is not representative. Therefore, it was better to use "soft" approaches to narrowing down and structuring the problem.

To provide useful information, the data from the incident file is extended by looking at the root causes of these incidents. Using fishbone and Pareto charts based on the number of incidents, the most frequent failing parts of equipment are selected for improvement. Fishbone and Pareto are used in literature more often to determine the systems bottlenecks. However, it needs to be considered that using these techniques on data regarding downtime and level of impact may provide a different distribution.

To define breakdown costs to a level that can be generalized and used at all locations, a thorough research was necessary. Several costs indicators were identified, but the two most influential ones were further elaborated. Missed revenue from weighing and measuring the dimensions of the parcels appeared to be one of them. However, trying to specify these missed revenues to the desired level required an analysis of the whole revenue model of TNT. Combining sensitivity analyses and expert validated assumptions, a gross estimation could be made that shows the order of magnitude of missed revenue due to a breakdown. Although the magnitude of order is a realistic representation, the numbers shouldn't be used for further research. Extended research is needed for further specification. Same goes for the definition of costs for hiring extra vans. At the moment, they are solely registered as ad-hoc costs but are impossible to specify to the desired level. A single example is not sufficient to draw conclusions on, and more research in this area is needed to get better insight in this cost indicator.

Maintenance costs are defined by identifying the costs factors that can play a role. Maintenance costs vary from hiring more technicians, training sessions, technical solutions and service contracts. This research priority is focussing on decreasing the number of incidents and increasing their maintenance capabilities, but not on reducing maintenance costs. To examine this CTQ further, it would require more insights in the service contracts of OEMs. However, re-evaluation these contracts based on costs would not necessary increase performance of the MHS and is therefore excluded in this research.

The extended incident file provided a clear overview on the root causes of the failures. The fact that this research is based on the elimination of root causes that appear most frequently, the root causes that did are chosen for improvement. These root causes appeared in multiple locations and were not solely bonded to one location. That made it possible that developed improvements have effect on all or most sites. These developed improvements will positively affect the on-time delivery performance, and will lower the costs to improve the financial performance.

SQ6. What maintenance approach matches the improvement needs of TNT's operations?

After the selection of the root causes that need improvement, it was time to look at the nature of these root causes. In this particular case, most failures were caused by human errors. The separation by Control, Electrical, Operational and Mechanical failures already showed a high percentage of operational related incidents, and the fishbone diagrams even emphasised this even more. Because these root causes didn't point towards reasons that they are influenced by the dynamic environment of a sorting site, the developed solutions didn't focus on these factors. The solutions for the selected problems therefore focussed more on problem solving by training sessions, supporting tools and changing the way of working. The causal link between the selected root causes and solutions was verified which led to improvements focussed on *autonomous maintenance* with preventive measures as central point of attention. These improvement methods have clear similarities with the maintenance approach of TPM. The essential managerial support, ownership of equipment, training etc. are all parts of this philosophy and reflect the improvement needs for TNT and is therefore the right approach. However, with the implementation of a CMMS, more data is gathered, and more predictive approaches may be helpful in the future.

SQ7. What effect will these improvements have on the dynamic environment of TNT?

The development of improvements and eventually implementations of them, will retain or increase TNT's on-time delivery performance and lower costs. The OTD is retained by the increase in site performance and higher MHS availability. Maintenance costs will increase as well although these costs will be compensated by the decrease in breakdown costs. Referring back to the description of a dynamic environment, one has to analyse if these improvements affect the fluctuating demand and input of freight. These dynamics are not really affected besides the fact that in case of a breakdown the delayed freight can be processed sooner. These improvements do decrease the negative effects of having different sorters and equipment at different locations because less specialized maintenance is needed to solve these incidents. Overall, equipment is better maintained and makes locations less depended on specializes parts and maintenance.

Main question:

“How can the constraints of TNT's Material Handling Systems in a dynamic environment be identified, and how does TNT preserve its on-time delivery performance at lower costs?”

The large number and diverse locations, together with TNT's operational process makes it hard to find their constraints. The scarcity and dispersion of data makes it difficult to centralize the information needed to make well-argued decisions. Information regarding TNT's performance (financial, on-time delivery) made it clear which factors should be analysed. Using qualitative approaches to find the root causes and structuring and narrowing down the problem, the constraints are made more tangible. With more tangible information on these constraints and the effect they have on TNT's performance, improvements and recommendations could be developed for these incidents. Most problems can be solved by improving the employees' technical knowledge, or to use supporting tools to solve incidents. These solutions led to more *autonomous maintenance* that will increase the MHS availability by having less breakdowns and quicker repairs. That will decrease the breakdown costs and retains TNT's on-time delivery.

This concludes the research findings and discussion part. These findings show how a different environment needs a well-structured framework for the development of a maintenance strategy. The research delivered improvement recommendations and a supporting tool for solving a simple but frequent occurring failure. Research shows that implementing these improvements will increase performance and fewer breakdowns and downtime. Next part will discuss the limitation of this research.

8.2 Limitations

This part will discuss the limitations of this research. First, limitations regarding data collections are discussed, followed by limitations on the used theories.

When researching the performance of a company or system, having the right data is crucial for the development of useful improvements. The results are based on a data file filled in by TNT, but excludes repair data by OEMs what can cause a skewed view on the number of incidents. Furthermore, the data file was lacking details on the impact on operations, time of failure, exact downtime and costs or repairs. Nevertheless, the suggested improvements are still valid because trends and obvious improvement areas could still be derived. However, having exact data of breakdowns would further strengthen the decision to invest and improve TNT's maintenance.

TNT's financial revenue model, and all its variables that determine the costs of a parcel, made it impossible to calculate exact breakdown costs using average earnings per parcel. To show the monetary impact of breakdowns and delays, an average number for lost revenue was needed. Even without an average number the data to calculate some specific cases was not available, which caused that estimations based on expert opinion are used to calculate the impact.

Last data related limitation concerned the position of the author within the organization. Before a strategy for multiple locations could be developed, thorough information about operations on floor level was needed for the analyses. The complicated organisations structure within TNT made it hard to gather data from the right locations and persons.

The developed improvements point towards the maintenance approach of Total Productive Maintenance with special attention towards autonomous maintenance. Although some characteristics of TPM match the needs of TNT, a total implementation of TPM may conflict with other corporate strategies. This part therefore needs extra attention because implementation of improvements was out of the scope of this research.

This research focussed on only three pieces of equipment for the development of improvements. Hence, the same research on the number of incidents and root causes can be conducted on the other pieces of equipment as well. If the analyses on these pieces show similarities with the root causes of the already analysed parts, it can strengthen the urgency for the selected maintenance strategy.

8.3 Future research

The explorative character of this research made it impossible to include some areas that needed further elaboration. That could either be due to time restriction or due to the complexity of the tasks. These are interesting areas to further analyse.

- Firstly, TNT should build on this research by further validating the suggested improvements. This research provides enough support for the implementation of these improvements and offers a great improvement possibility. To create even more support, the same failure analysis tools can

be used to find more incidents at other pieces of equipment that are also solved using these suggested improvements.

- A second recommendation for further research is that TNT looks deeper into making breakdowns financial visible. Today, only estimations are available on the costs of a breakdown, but the ability to assign costs to pieces of equipment when they break down will give TNT a much better view prioritizing maintenance. Think of average missed revenue per kilo, separated by type of freight. And
- A third interesting field for further research is to specifically look at the incidents that can be solved with use and load based maintenance. For now, the frequent and most obvious incidents are not ready for such a maintenance system. But identifying which parts and pieces of equipment are directly affected by the type and number of parcels can lead towards a plan of more mechanization and linking this data.
- Comparing TPM with corporate strategy of TNT. Although TPM and some of its pillars are effective in solving certain incidents, this strategy still has to fit within the corporate strategy of TNT. This research will be purely based on strategic level has less to do with operations.

8.4 Reflection

As a final chapter of this report, a reflection on the performed research and on my personal experience is given. The first part discusses the used research methods and results. The second part goes deeper into the challenges of the author during this period.

At the beginning, the research objective was open for interpretation which made it hard to develop a specific research. The problem at TNT was quite broad, which made it hard to scope it to a specific goal. From the literature found, using data to derive to a solution is a common way of looking at the problem. The initial goal was to match data of breakdowns with operational data to see when and what exactly caused the problems at TNT, only the lack of data soon changed this initial goal. Using the DMAIC-framework as thread for this report helped structuring this report. This decision was also based on the Six Sigma background of the DMAIC, to quantify and process data. Other approaches would have worked too, but this is approach also worked. Gathering data turned out to be the hardest part of this research. The data needed was pretty specific and sometimes confidential, which often led to delays in the process. An example is the calculation of the breakdown costs, where some general numbers were not available and led to a dead end. That made it hard to look at the problem from a mathematical point of view.

The root cause, Pareto and 5-why method that were used, were capable approaches to analyse the incidents. These analyses were useful, although data from OEMs was not included. The validation of these analysis could be better, by having multiple assessments with other employees. However, due to

some mayor incidents within TNT, all the manpower and attention was needed elsewhere. The lack of data regarding incidents and manual capacity within the sorting centres made it hard to discuss the impact on the process in different phases of the operation. Nevertheless, the results of breakdown costs, gave a right indication of the magnitude of order of these costs. However, getting the complete accurate financial breakdown data requires a study on its own.

The suggested improvements really emphasize the issues in the locations. Nevertheless, in a big company like TNT it is hard to get to the current state of such programs/trainings. The sensor support tool is however a really practical tool that can be used. It does still needs to be tested and validated on floor-level.

Personal reflection

The choice to conduct this research at a company was pretty clear. TNT was a great opportunity to see a large cooperation from the insight. Nevertheless, it was hard to set up a research that was so broad. First issue was picking the right approach for structuring this research. However, from that point on, it helped quite a bit. This subject is conducted at the Head Office of TNT, but still involved a lot of floor level incidents which made it hard to gather data. Getting to the right person was all about networking, and in a global organisation that's hard. Furthermore, it was hard to balance the interests from the university with the company's interests. This conflict was known, but still made it difficult.

Because this research had to provide recommendations on strategic level, but still based on floor-level details, it was hard to narrow down the focus and still include the important parts. That made it hard to focus on the right thing. The lack of data and information was also sometimes frustrating. Some simple things were simply not registered. However, the largest setback was the loss of all my data due to a virus attack. Safety policies didn't allow personal back-ups, and most personal back-ups were also infected. This was a major setback and not conducive for this research and the authors motivation. Retrieving lost data and reproducing calculations caused several weeks delay, and had quite an impact on further research. Hence, to conduct this research at a global company was still a great opportunity where the author learned to understand the dynamics of a large company.

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Appendix A: Research approaches

Prescriptive approach by Dym & Little

Dym & Little proposes a 5-step framework, with a final model or design as a result. These 5-steps function as a guide, to help the designer figuring out where to think of when making a design (Dym & Little, 2008). These 5 steps are:

1. Problem definition

In this step the objectives are clarified, and user requirements are established. This is a pre-processing stage, which is done before the conceptual design. The needs of the client with the refined objectives, constraints and functions serve as input for the conceptual design.

2. Conceptual Design

As input, the objectives and requirements are used from the previous step. The goal of this step is to establish design specifications and to generate design alternatives.

3. Preliminary Design

In this phase, the conceptual designs established in the previous step are modelled or analysed. The goal is to select a design from these developed alternatives, and test and evaluate the selected design.

4. Detailed Design

After selecting a design, it needs to be refined and optimized. This can include local regulations, component specifications etc. The outputs of this phase are proposed model specifications and a model that is ready for a design review by the “client”.

5. Final Design

This last step is about communicating and documentation of the final design. Feedback from the client and users is given, and the final design is justified according to its specifications.

Taking a deeper look into these steps, one will notice that this approach is made for a more technical design. Clarifying objectives and translation into the appropriate form is essential elements of a design. The framework by Dym & Little is also used as overarching framework within the design process, which encompasses the design and product realization process (Ozge Ozaltin, Besterfield-Sacre, Okudan Kremer, & Shuman, 2015). So even though this approach is used for product designs, its generic function makes it also useful to use it for the development of recommendations.

General 8-step Decision-Making

Most theoretical frameworks use a somewhat similar methodology. Good decision making, and

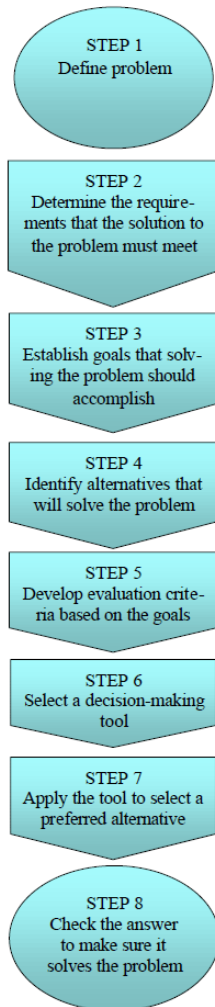


Figure A1: 8-step decision making (Baker et al., 2001)

choosing the right design are important for making the right choices. This is best reached when everyone involved uses a clearly defined and acknowledged decision-making process (Baker et al., 2001). This general method states that a transparent process will provide structure to approach complex problems, rationality in decision making, consistency in the process, objectivity, documented criteria and values and sound and reviewable decisions.

This general method can be used for simple and complex decision-making problems. As in many other methods, the problem definition is a first step where the involved stakeholders are reviewed next to the description of the initial and desired conditions (see Figure A1). A root cause analysis, that digs deeper into the real problem, is a first step in this process. Step 2 and 3 are important in establishing goals and requirements that the design has to meet. These requirements are the parts that the solution must need. This general model is also roughly followed in a study by Ierace & Cavalieri (2009), where they define the goals, criteria and alternatives to satisfy the needs of the problem.

With the development of different solutions, one will have multiple options that can lead to the desired goal and requirements. These can be built on qualitative research with interviews, expert interviews etc. (Baker et al., 2001). Quantitative analysis for the development is also possible, which are based on data collections. This can be already existing data, or generated data by data measurements.

Criteria for the design will lead towards a decision for an Analytic Hierarchy Process (AHP), Cost Benefit Analysis or custom-made tool. In the study by Ierace & Cavalieri (2009), they use the AHP process to make a grounded decision to decide which categories to take into account when operating in a specific maintenance system. Their goal is to know which decision categories may have a major impact on the maintenance strategy. Their literature study upfront showed that this AHP-

based model is the best way to compare these categories, but they still use this structure as guidance.

A sensitivity analysis can improve the quality of the selection process, which justifies the choice of that model (Baker et al., 2001). A study by Maletič et al. (2014) also uses the AHP for decision making, but they extend the 8-steps shown in figure A1, to a 11-step framework. They include a sensitivity analysis into their process to see if their outcome changes when the weightings on their criteria change. The application of this customized framework shows the versatility of this approach.

Design-focussed business problem-solving

Another design approach is the design-focussed research introduced by van Aken et al. (2007). This

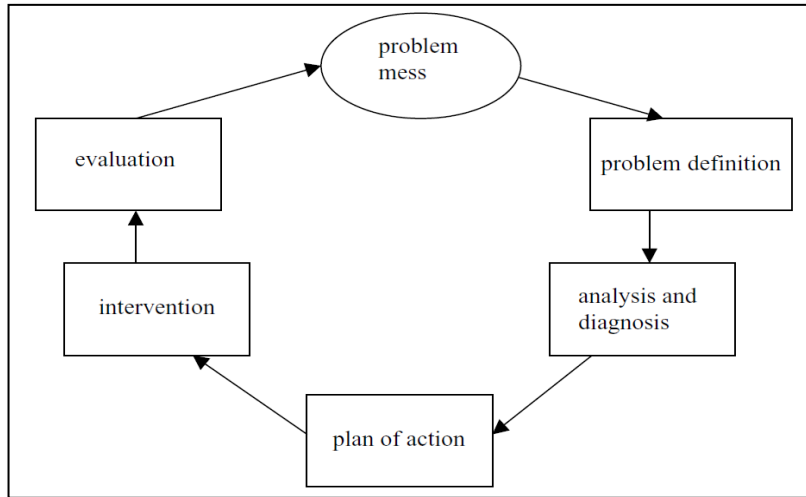


Figure A2: Regulative cycle (van Aken et al., 2007)

the design is using state-of-the-art knowledge found in literature rather than using informed common sense and one's own experience. Still, this theory has to be contextualized to be able to use it for the specific case. To be able to develop a result for this business problem, they use the regulative cycle which is often cited in literature (see Figure A2). Following these steps, a plan of action will be designed that implement the result of the analysis. This solution is found in literature, but needs to be custom made for the business problem. This approach is useful for the design and implementation for several business-related problems.

This business problem-solving is theory-based, which means that

DMAIC-framework

An interesting framework is the DMAIC-framework which is derived from the Six Sigma methodology. This Six Sigma method is developed by Motorola to increase the level of quality, and eventually increase revenue of the company. Implementation of Six Sigma at Motorola led to immense growth and sales, and it didn't take long to spread Six Sigma worldwide (Breyfogle, 2003).

To increase the quality of a company's product or service, the DMAIC-cycle is used as guiding steps. DMAIC stands for *Define, Measure, Analyse, Improve* and *Control* (Figure A3). This framework is also known as the "breakthrough strategy" which is focussing on the improvement of the process rather than on the defects in the output (Tang et al., 2006). When focussing on the variability of the process, the

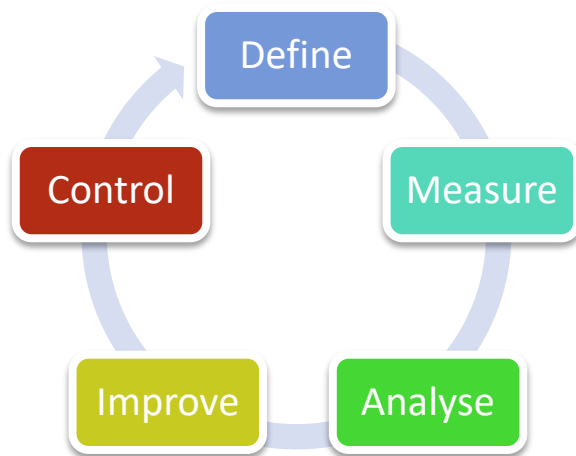


Figure A3: DMAIC-framework (Breyfogle)

output of the system will eventually benefit from it as well. The framework can be seen as a circular process instead of a linear process. The process also iterates between the steps if necessary, to deliver results that match the expectations.

The first step within this framework is the process definition or the “Define” phase. In this phase, the needs and requirements of the customers and stakeholders involved have to be found (Breyfogle, 2003). The process in need for improvement has to be defined, together with the problems of this process. Two key elements in this process are the Cost of Poor Quality (COPQ), and Critical to Quality (CTQ). Identifying the COPQ will give an estimation of

the costs lost due to low-quality, by not performing work correctly the first time or meeting customers’ expectations. The other key element in this process is the CTQ. These are factors that have influence on the quality of the product or service (and may influence the COPQ), and reflect the critical characteristics of the customer focus (Tang et al., 2006).

Measuring is next in the DMAIC-framework. This step is introduced to confirm the problem by measuring the existing system (Milosavljevic & Rall, 2005). In this step, the search for the first root causes begins, by focussing on the problem. This will extend the problem bases on measurements of the process (Tang et al., 2006). Gathering information on efficiency of the process by conduction a failure analysis or measuring performance are ways to conduct this.

After measuring, analysing the gaps and failures is next. Problems that have been identified in the previous step are now turned into statistical problems. Identifying the important factors out of root causes is one step in this phase. Next, hypotheses are developed.

Next step is to *Improve* the system by using project management tools (Milosavljevic & Rall, 2005). Techniques like “Design of Experiments” or “Poka Yoke” are also ways to improve the analysed systems. This step is about developing ideas to remove the root causes found in previous steps. And these ideas have to be workable and realistic to be able to implement them (Tang et al., 2006).

Last step in this framework is *Control*. In this phase, a control system is introduced that can monitor the process continuously to facilitate consistency in quality of the product and service. To have project success, this control system needs to set standard measurements for performance and needs to correct problems as required (Milosavljevic & Rall, 2005).

Appendix B: Failure calculations

These calculations are not publicly available

Appendix C: Incident log

	A	B	C	D	E	F	G	H	I
1									
2	Weel	DATUM	YEAR	WIE	SERVICE TICK	WAAKDIENT	DEPOT	s/n of itemnr	DEVICE soort
519	1	03/01/2017	2017	Edwin			QAR	Cargo pc	Cargo pc
520	1	03/01/2017	2017	Edwin/Kristof	INC3673582	x	SP8	Sorter	sorter
521	1	04/01/2017	2017	Edwin/Kristof	INC3676071	x	EIN	Sorter	sorter
522	1	04/01/2017	2017	Kristof/Stefan		x	LGE	AKL	AKL
523	1	05/01/2017	2017	Kristof			BZQ	Sorter	sorter
524	1	06/01/2017	2017	stefan	INC3684454	X	SP8	DWS	DWS
525	2	10/01/2017	2017	Kristof			BZQ	Cargochecker	
526	2	10/01/2017	2017	Kristof			QAR	Cargochecker	
527	2	10/01/2017	2017	Kristof	INC3689970	x	BRU	Vitronic	CWC tunnel
528	2	11/01/2017	2017	Kristof			EIN	Sorter	sorter
529	2	11/01/2017	2017	Kristof			EIN	Sorter	sorter
530	2	11/01/2017	2017	Kristof	INC3692261	x	EIN	Sorter	sorter
531	2	12/01/2017	2017	Edwin			EIN	Sorter	sorter
532	2	09/01/2017	2017	Edwin			GTH/AMS	Rollerbaan	banden/rollerbaan
533	2	12/01/2017	2017	Edwin			EIN	Sorter	sorter
534	2	12/01/2017	2017	Kristof			LGE	AKL	AKL
535	2	12/01/2017	2017	Kristof			LGE	Sorter	sorter
536	2	13/01/2017	2017	Kristof/Edwin			ARH	AKL 1 en 2	AKL

	J	K	M	Q
1			WHY?	
2	Probleem category ▾	PROBLEEM ▾	OORZAAK ▾	OPLOSSING
519	Control	Geen data van deze morgen in BCI rapportage.		Cargo PC opnieuw opgestart.
520	Operations	Veel data zonder gewicht op de Vitronic	er hing een strip met stickers aan de band	strip verwijderd
521	Operations	Er worden geen barcodes gelezen	Verklemming geweest in PM proces, waardoor camera en invoersensor verschoven was.	Camera's, ledverlichting en invoer sensor afgesteld.
522	Control	PST van toestel APA312-119 werkt niet	? Gevraagd aan Vitronic om grondig te onderzoeken gezien dit regelmatig terug	
523	Mechanical	Volgens Patrick werkt wissel 59 niet	?	Geen probleem gevonden aan wissel
524	Control	scanner komt niet meer op beginpositie	onbekend	persoon telefonisch begeleid om het toestel terug goed te krijgen
525	Control	Weinig data	?	Cargochecker software opnieuw opgestart
526	Control	Weinig data	?	Cargochecker software opnieuw opgestart
527	Control	Result staat in het geel en de rode lamp blijft aan	?	
528	Mechanical	bij item 020.230 draaien enkele wieltes niet mee	?	Vanriet ter plaatsen geweest en hersteld
529	Operations	Band van item 015.020 is vastgelopen	Er is een ketting van de bordjes die boven de band hangen tussen de band en de vingerbeveiliging gekomen	Vanriet ter plaatsen geweest en hersteld
530	Mechanical	Bij item 020.190 draaien enkele wieltes niet	?	Vanriet ter plaatsen geweest en hersteld
531	Control	Geen gewicht in BCI rapportage	Sensor niet goed afgesteld	Sensor 10P1 afgesteld op de Vitronic.
532	Operations	Een noodstopknop verdwenen	?	Noodstopknop vervangen
533	Mechanical	Rotation disk defect op unit 001.110 en 010.040		Rotationdisk 001.110 B5 en 010.040 E8 vervangen.
534	Electrical	Cradle defect	pen afgebroken	Cradle vervangen
535	Control	Zendingen blijven in de chute liggen	Niet glad / stijl genoeg	chute met wax ingevreven
536	Operations	Stof als storing en dubbele voorwerpen ziet machine	Scanner akl kop vervuild	Scanner kop goed gereingd, zelf aanslaglaag verwijderd.

Appendix D: Decision support system for sensor replacement

Sensor Support Manual for Team leaders and Leading hands

This manual helps identifying simple sensor related incidents, and guides the Team leaders (TL) and Leading hands (LH) with how to fix these incidents. This manual will help resolving relative easy sensor related failures which lead to bad performance of the sorter. This manual is to just solve these fixes by repair, cleaning, replacement or simple checks and not to solve potential errors that have a more technical character. This will lower the work pressure on the OES-mechanics, which gives them the possibility to do more preventive maintenance. When the cause is not sensor related, the team leaders or leading hands should immediately contact the OES-mechanics for further steps.



Before starting with this process the Team leader or Leading hands should meet the following requirements:

- TL and LH should have sufficient **training** and **explanation** on how to detect and clean/repair sensors and reflectors.
- Spare-parts needed for eventual repair need to be **available** for TL and LH. Arrangements regarding spare-parts should already be made with the maintenance engineers. Think of sensors, reflectors and cables.

Before starting the first step, the TL should always follow the steps and instructions. **If and only if these are met**, the TL are required to continue this procedure. If these are not met, or if the TL are not sure, they follow the procedure by calling the OES-team.

Step 1

Checking what type of failure is present. Sensor related problems are:

- | | |
|--|----------------|
| 1. Parcels go to the reject/overflow area. | → Go to Step 2 |
| 2. Chutes are not used/too full. | → Go to Step 2 |
| 3. Sorter stops working. | → Go to Step 2 |

When there is a different incident present and the TL cannot identify the cause they should not be looking further and follow the existing procedure by

- Call the OES-team.
- Start Contingency mode

Step 2

When one of these incidents occur, it is essential to look further into the cause. All sensors are connected to the sorter system, and checking this system gives insight if there is an error reported by the system.

- System gives notification of an error → Go to Step 2.1

If the system does not give a notification of a present error the TL should not be looking further and follow the excising procedure by:

- Call the OES-team.
- Start Contingency mode.

Step 2.1

When the system gives notification of an error, it means that the error is monitored by the system. That means that it can be traced to a location. The TL should follow the next steps:

- Read the error and trace back the location → Go to Step 2.2
- If the complete system gives an error → Call OES-team

Step 2.2

When the location has been identified, the TL goes to the location where the incident should be. First thing to do is:

- Check if the situation is safe. As for himself and as for other employees. If the situation is not safe. → Notify OES-team and management

Although the incident may be small, an electrical error could cause a dangerous situation. Therefore checking if the incident isn't causing potential dangerous situations is a priority.

When safe, the TL should follow the next steps that may cause the sensor to block operations of the complete sorter of operating. These steps are aiming to identify visible damage or errors. When one of these questions can be answers with YES, then follow the next step. Otherwise continue with the next question.

1. Sensor blocked by packing material? → Go to Step 3.0
2. Sensor blocked by something else? → Go to Step 3.0
3. Sensor/reflector out of position? → Go to Step 3.1
4. Reflector broken (partly/completely)? → Go to Step 3.3
5. Sensor broken (partly/completely)? → Go to Step 3.3
6. Damage/loose sensor cable? → Go to Step 3.2
7. LED on sensor deviating? (no green AND/OR orange LED) → Go to Step 2.3
8. No visible damage that sensor is broken? → Go to Step 2.3
9. Other visible damage (non sensor related)? → Call OES-team

Step 2.3

If there is no visible damage to the sensor, there can still be sensor related problems. The sensor has 2 LEDs to show if it is working or not.

- The **GREEN** LED is indicating if the sensor has power or not. So when there is no green light, the sensor is off.
- The **ORANGE** LED is indicating if it receives a signal from the reflector which means that the sensor is not blocked by a parcel or sticker.



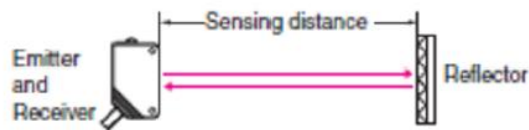
If the sensor has no **ORANGE** light, it is probably out of position and needs to be adjusted to the right position. → Go to Step 3.1

If the sensor has no **GREEN** light, the LED is either broken or the power is off. To check if that is the case: → Go to Step 3.2

If the sensor shows **BOTH** lights, but the system is still not working: → Call OES-team

Step 3.0

Before adjusting or replacing the sensor, the easiest fixes are to remove packing material, paper, a sticker or dust from the sensor. The sensor and reflector should have a clear view towards each other like on the photo below. The sensors used are so-called retro reflective sensors, which mean that they transmit and receive light which is reflected at the other end by the reflector which is shown on the photo below.



The red circles on the next photo show the sensor and reflector without any material around it. If there is any material around the sensor, remove it **CAREFULLY** to prevent damage to the sensor or reflector.



The sensor could also be filthy or dusty and therefore doesn't work. If so, use **only** the selected cleaning material for the sensors. Other cleaning materials may damage the sensor. The cleaning materials can be found at the same discussed location of the spare parts.

When having removed the material or cleaned the sensor, check whether the sensor is showing a **GREEN** and **ORANGE** light again. If so, → Go to Step 4
 If there is only a **GREEN** light, → Go to Step 3.1
 When it **NO** light, check cable: → Go to Step 3.2

Step 3.1

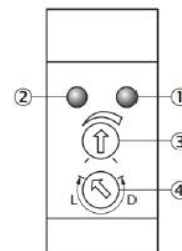
This step explains how to align and adjust the sensor to the right position. Most if the time the sensor or reflector is moved, and repositioning it is enough to fix the incident and continue operations. After these steps, the system can be switched back on. Next, the angle of the reflector



should be parallel with the conveyor to make sure it will reflect the light of the sensor. If the reflector is shifted, make sure it is parallel and at the right height above the conveyor. Use the sensor as reference point.

Adjusting the sensor is a bit more difficult. Following these steps should get the sensor in the right position.

1. Slide the sensor in front of the hole in the side guidance and make sure the emitter and receiver are both in front of the hole. Part circled in orange → See picture
2. Make sure they are also parallel with the conveyor and aim at the reflector.
3. On top of the sensor are 2 adjustment wheels visible. Do **NOT** change any of these wheels when positioning the sensor. When they are changed accidentally: → Call OES-team



4. When adjusted right, the sensor should be working and showing again a **GREEN** and **ORANGE** light like in the previous step.
 When only **GREEN** light: → Call OES-team
 When it NO light, check cable: → Go to Step 3.2
 When **GREEN** + **ORANGE** Light continue to step 5 below.
5. Restart/reset the system and look if the sorter is working normally.
 If the system works again → Go to Step 4
 If the sorter still not (completely) works: → Call OES-team

Step 3.2

That concludes the steps of positioning the sensor and reflector. The related problems could also be caused by a disconnected or damaged cable. Following these steps will exclude (as far as possible) a cable error. When the sensor didn't show a **GREEN** light, the sensor has no power which could be caused by the cable.

1. Check for visible damage on the cable. When it does have severe visible damage:
 → Call OES-team

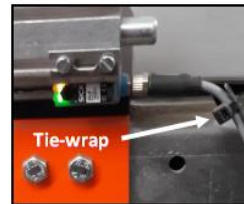
Do NOT replace the cable. This needs to be done by the OES-team.

2. Check if the cable is connected. On side has a locknut on the cable like on the photo. Make sure to check whether the cable is well mounted to the sensor. The cable can be connected by pushing the cable on the connector and turning the locknut clockwise until it is tightened.
 Does the sensor show a **GREEN** and **ORANGE** light again?
 → Go to step 4



3. Check the other side of the cable (as far as possible) for damage or disconnection. If it runs into a cable tray, stop following it. Connect it if you can trace it.
 Is the cable undamaged and connected but still not LED lights?
 → Call OES-team

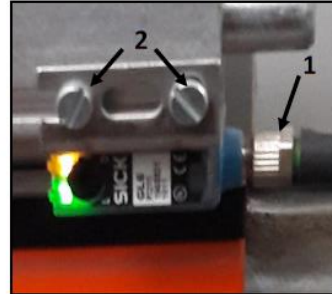
When the cable is connected and the system works again, make sure to check if the cable is attached to the frame properly with tie-wraps like on the photo. Proper guidance of the cable is important for the prevention of the cable getting stuck or pulling at the sensor. Finished?
 → Go to Step 4



Step 3.3 (Expert level)

This step is all about replacing a broken sensor. In the previous steps, the TL determined that the sensor was broken. This step can only be executed by certified TL and LD. These have more training and are approved by the OES-team. First the replacement of the sensor:

1. Take picture of current condition of the sensor/reflector for incident data.
2. Make sure the area is **SAFE** to work. Do not repair any sensors next to moving belts for own safety.
3. The cable has a security nut which can be loosened by turning it counter clockwise. This nut is shown as 1 in the photo. After it is loose, the cable can be pulled off the sensor.
4. Remove sensor by dismounting the sensor from its mounting frame by unscrewing the 2 screws marked by 2 at the photo. Now the sensor is removed and free from the system. Save the screws for later.
5. Remove the small L-shaped profile from the sensor, and save this profile with the screws. These are needed for mounting the new sensor.
6. Replace sensor by an **IDENTICAL** sensor by checking the serial number at the white sticker on the sensor. The sensor can be found at the spare parts rack which is available at every location. When these are not available at the location: → Call OES-team
7. First mount the L-profile back on the sensor. This should fit because the sensor should be **IDENTICAL**. Afterwards mount the sensor back on the mounting frame by putting the screws back indicated by number 2 on the photo. Do **NOT** tighten the screws because the sensor has to be adjusted.
8. Click the cable back on the sensor and lock it by turning the locknut clockwise.
9. Follow the Steps of 3.1 to adjust the sensor to the right position.



Changing the reflector is a somewhat easier job. There are no electrical components, and are therefore less vulnerable for failure. Changing them only requires loosening 2 screws. They can be found at the front side.

1. Unscrew the reflector and place a new one on the mounting frame. Make sure that the reflector reaches above the conveyor.
2. If the reflector is not available: → Call OES-team
3. Follow the Steps of 3.1 to adjust the sensor to the right position.

Step 4

This final step is documentation and finalizing the repair procedure when operations are continuing. When the defect has been fixed the system should work like before.

1. When working back to normal, record incident in the incidents log, and contact OES-team to restock the spare parts. They may need to order more parts.

Documentation of the whole procedure is important for future problems, as for keeping spare-parts on to a sufficient level. That's it. You fixed the problem.

GREAT JOB!

Appendix E: Summary interviews

This is a summary of the interview with business improvements managers Ted Vledder and Hugo Langelaan. This summary is based on historical information. The original transcript unfortunately got lost during this thesis.

Ted: It is wise to start at the beginning, and name all elements that are affected during the import process due to a dysfunctional sorter. What happens if a sorter fails, and what is the impact when it does? This will be repeated for the export process to name as many elements that cause extra costs.

Jim: I was told that in the morning process, when the packages are transported to the customers, they are not checked using a CWC, and revenue is not lost because freight already had a check.

Hugo: True, you never measure at the morning process. If the sorter fails in the morning process, you need extra man hours if to process freight by hand. And you need to hire extra vans, to lower spread the volume on more and shorter routes. Worst case scenario: you will have a bad delivery service because vans arrive late. Only that depends on the freight that enters the depot last, and where these packages have to go to. If TNT's lucky, they only have 1 or 2 vans, if you're unlucky, you need more.

Jim: It is for me important to know the magnitude of order regarding the costs of downtime. The costs are now relatively unknown.

Ted: It is very difficult to determine the exact costs of a breakdown. When a sorter breaks down in the morning, negative status codes are send to other depots and customers service so that they can inform the customers about the breakdown. These processes are not only active in one depot but in multiple locations and are impossible to translate to costs. Besides in the worst case, when parcels are delivered late, the customer can switch to a competitor. Nevertheless, it is important to mention these processes and hidden costs.

Jim: Agree. Even if these costs are not quantifiable, mentioning them presents is already important. Regarding the missed CWC revenue in the evening process, what are the gains of using them?

Hugo: In previous research, we have calculated that with every kilogram weight measured, we gain an extra of € . So that can really add up. However, it only counts in the original country. It is not validated in other countries. So, there are some possibilities for multiple checks for weighing the parcel. As example, if you have an unmeasured trailer from Eindhoven to Arnhem (with a CWC performance of 85%), still 85% of the parcels will receive a check. Only if the trailer drives to Brussels, a new check isn't allowed by legislation and all revenue is lost.

Jim: Are there no clear numbers or information available regarding the costs of customers that leave TNT for having bad performance?

Ted: If you look from the import process, you do not have any insight in what is happening across the border due to a delayed shipment at the incoming depot. You never hear something about that,

exception made with large customers for instance. Besides the fact that costs are made within operations to solve these delays, other process regarding Customer Service are also busy with these delays. These costs should eventually also be linked to a sorter breakdown.

Hugo: Have you seen this simple excel too? Using a simplified excel tool, you can play with the capacity of the location and with the incoming volume. This can indicate how many extra hours are needed to process the buffer using manual sorting. However, the real capacity, number of employees, manual capacity etc. are needed to determine the extra labour costs.

Jim: Looks nice and helpful to play with. I will look into it.

Ted: In case of location Eindhoven where customers are dealing with too many delays, extra transportation costs could also arise. If they want their products to be delivered on time, trucks with too less freight avoid Eindhoven and drive with half-full loads directly to Arnhem or Brussels. That increases the transportation costs.

Another costs factor to consider during the export process is that trucks have a dedicated time-slot, and on that time, they start driving no matter if they are half full or not. The volume that comes afterwards, needs to be put in a new truck which have to be hired again. Sometimes a truck that has freight that needs to be delivered next day by road, can also choose to transport them via Liege, if this freight is moved by air instead of road. These costs are significantly higher.