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Master thesis

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Designing a process performance measurement system for zero-defects logistics: A case study at the Dutch Flower Auction

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Abstract

This report details the design process of a process performance measurement system for zero-defects logistics, with a focus on process quality. The system is the result of a combination of theoretical sources and best practices found in various industries. The final design is applied on the distribution process of cut flowers at Royal FloraHolland in Naaldwijk. Calculations return the expectation that implementing the system leads to increased process quality and a decrease in financial impact of poor quality.

Preface

The report before you is my master thesis, written to partially fulfill the requirements of the master program Transport, Infrastructure and Logistics. With the finalization of this report, I finish my five years of education at the University of Technology in Delft, something I have been working towards since my bachelor studies of applied sciences.

The road towards this point has been long, longer than I anticipated, and far from smooth. Along the road, I have learned a great deal, about subjects pertaining Transport, Infrastructure and Logistics, as well as about myself. The start and finish of the road have been especially rocky and challenging, pushing me to the limits of what I could handle besides the academic demands. Looking back, I cannot be anything but proud of myself and thankful for the people that supported me throughout the entire process.

To be able to cap my master studies with this project, was something I had not foreseen. I expected my fascination for ports and waterways to lead me to a research subject more related to that area of expertise. However, a Lean project for a subject in the Engineering specialization had me introduced into the complex world of auctioning off flowers and plants, and I was hooked immediately. Ever since the introduction into Logistics Engineering during my bachelor, where the teacher told me about the automated, organized chaos that was the flower auction at Aalsmeer, I wanted to go and see it myself. Circumstances prevented me, so it never came to fruition until said Lean project. The first time I entered the auction building, I think I literally bounced all over the place, as I was so excited to finally be there.

Any thesis research is complex, as it requires all academic research skills a student is taught throughout their studies, but I chose a particularly hard method. I wanted to do my research at a company, to maintain the link to practitioners, and, after the initial project, was determined to do it for Royal FloraHolland Naaldwijk. I formulated the problem and convinced the resident Master Black Belt to let me do the project. Gathering and accessing the data was no problem, I knew exactly who to contact for whatever information I needed. It was the academic aspect of the research I struggled with. As I had formulated the problem from a practical viewpoint, finding a theoretical relevant gap was an arduous process. Eventually, I managed, which kick-started my graduation project in December 2019.

Now, eight months later, I am proud to have concluded the project and present you with the results of my efforts. This result could not have been realized without the support of a couple of specific people around me. Therefore, I want to thank my company supervisor Abbe Zwaal for giving me the chance to do this project, having the patience to keep up with it and listening to my frustrations throughout it. I also want to thank dr. ir. Jaap Vleugel for coaching me on the academic side of things, for making sure I kept my edge and for his understanding through the rocky personal periods. I thank dr. ir. Wouter Beelaerts van Blokland for using his extensive Lean Six Sigma knowledge to ask the right questions and offer useful suggestions during our sessions. Furthermore, I want to thank the chair of my graduation committee, prof. ir. Rudy Negenborn, for his patience, his feedback and his flexibility.

Last, but not least, I want to thank my family and every one of my friends that has put up with my crazy schedule, tardy communication and overall weirdness during this process.

Please enjoy reading,
Anne van Langevelde

The most effective way to do it, is to do it.
- Amelia Earhart

Executive summary

The cut flower distribution process is the process in which flowers that have been sold, are divided over carts for buyers. Before distribution starts, the products arrive, are sorted and checked, and transferred to temporary storage. Flowers will leave storage after the auction moment and enter the distribution process directly. After distribution, the carts are consolidated to trains per one or two buyer and towed towards the box of those buyers. Most buyers either have a permanent physical location in the building, or are assigned a temporary one for that specific day.

In the course of this study, the following research questions are answered through various methods, leading up to the answering of the main research question.

How can the quality performance of a distribution process for cut flowers be measured and controlled to incorporate zero-defect logistics?

1. What is zero-defects logistics?
2. What is state-of-the-art in performance measurement models?
3. What are best practises for quality performance measurement in different industries?
4. How would the optimal quality performance measurement and control system be configured?
5. What is the current situation concerning process control at Royal FloraHolland?
6. How does Royal FloraHolland perform in terms of process quality?
7. Which mistakes influence process quality?
8. How should the designed system be adapted for Royal FloraHolland?
9. How would the system affect the process and performance in current and future state?

Zero-defects logistics has its roots in Lean Six Sigma and is used as an aspect of Total Quality Management. Commonly used by applying statistical process control and integrating a quality related philosophy throughout the whole company. The state-of-the-art in performance measurement varies on the industry it is applied to and the point of view process engineers have while designing the system. A recently developed, generic model, the Goals, Performance and Indicators model (GPI model), is found to be applicable to the cut flower distribution process, as it provides a model which only requires the correct selection of process performance indicators. To give direction and guidance to the selection of the right performance indicators, the best practises from other industries can be combined and used as framework for performance indicators applicable to the case.

Following the theoretical input, the optimal quality performance measurement and control system is designed, presented as a preliminary framework. As there was no definite proof of one perfect method, the framework combines the viewpoints of two sources into one hierarchically linked model, with (key) performance indicators linked to the different levels. The circle of influence differs between the levels, so the type of indicator and the frequency of reporting is adapted to fit. This results in three key performance indicator categories that provide all necessary input for the business unit managers on the strategic and tactical level; first time right (FTR), sigma quality level (SQL) and cost of poor quality (COPQ).

The FTR category is split in two KPIs, one reporting on the number of days the FTR target is reached, the other on the average FTR level. Sigma quality level is based on the FTR level, calculating the average sigma level, with the ambition to eventually achieve 6 SQL. Similar to the FTR KPI, the COPQ is split, recognizing the difference between internal COPQ and external COPQ. Internal COPQ is the cost of poor quality that remains within the limits of the process, the external cost of poor quality is the monetary result of mistakes ending up with the customer. Splitting the PI to reflect the internal and external cost, is important since it separates impact on the customer from internal impact. Only focusing on output (customer service level) skewers the impression of quality performance, as it creates the illusion that internal mistake correction does not cost anything.

To generate the information in the KPIs, PIs are formulated and linked to overlying KPI categories. The PIs are sourced and reported by the business sub-units, on the operational level, where the employees can actively influence the elements of indicators themselves. As the theoretical framework is applied on a practical case, the company and business process are described, as well as the current performance on quality performance. This information answers the next few sub-questions.

The auction location in Naaldwijk is the second largest of Royal FloraHolland. It processes both cut flowers and potted plants, through a system that is mainly executed by humans, supported by software. The cut flower process is handled by three departments, Logistics Services for Suppliers (LSS), Logistics Operations (LO) and Logistics Services for Customers (LSC). The current performance monitoring system is based on the overhead Operational Excellence (OpEx) strategy, dividing the KPIs into People, Safety, Quality, Delivery and Cost (PSQDC) categories. The OpEx strategy also includes a regular maturity scan, which determines the manner in which the documentation, control and monitoring of the process is done by the three departments. Of the three departments, LO scored highest at level two, after its own internal appraisal.

Regardless of the order of PSQDC, the leading KPIs are focused on the output of the process and productivity. Some KPIs on process quality are reported, but are not stressed in the evaluation of performance. All three departments have KPIs reporting on an element of quality in the process steps they execute, but not all departments reach target. LSS and LO did not reach their respective targets in 2019, while LSC did. However, the definition and calculation of all KPIs is rather ambiguous and selective. These vague descriptions result in omitting mistakes and the use of wrong units, which decreases the eventual worth of the KPI when relating it to the actual process performance.

With use of information provided by the team that recovers and restores mistakes, the quality performance with regards to mistakes has been quantified to monetary output. The cost is divided into direct and indirect cost, where the direct cost is based on the compensated cost to the customer, and indirect cost is based on the cost the Search and Correction team makes while searching for the cause and fixing the mistakes. All three departments contribute to the overall cost for RFH Naaldwijk, both through direct and indirect cost, where LO has the largest share. This is mainly due to LO being the department which is responsible for most human handling of the products in their packaging units.

To further specify what influences process quality in the LO department, the next sub-question aims to determine which mistakes have impact on it. That information is used to adapt the initial design to Royal FloraHolland. The final design is a hierarchical system, with daily and weekly feedback loops between the business unit levels. It includes key performance indicators categorized into first time right, sigma quality level and cost of poor quality, specifying the process indicators to the actual mistakes that were found to have the biggest influence on process quality. These PIs are normalized to defects per million opportunities, for the purpose of being able to monitor and control through an np-chart and cancel out the influence of varying transaction totals per day. The output in the shape of (K)PIs should provide insight on every level on the quality performance of the process, as well as give a narrow scope for possible process improvements when the (K)PI reports abnormalities. The system is visualized in the figure below:

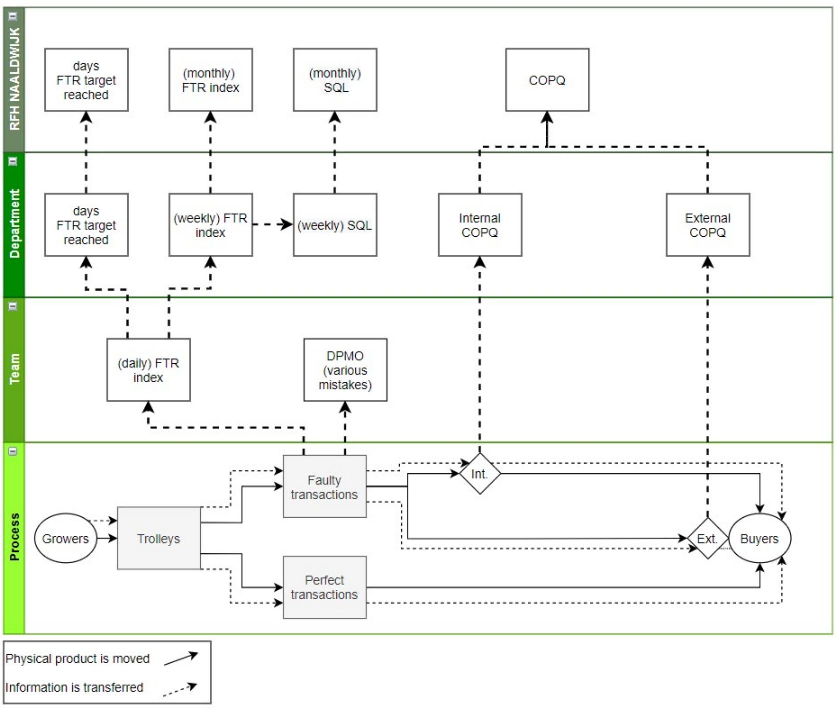


Figure 1: Swimlane visualization of final design

The next step is to determine how the application of the system would affect the process and performance in the current and future state. To simulate the expected future state, the number of transactions is decreased with 4%, as it is expected that the shift from auction to direct services continues. However, the number of transactions could also increase due to the implementation of the new logistics concept, which is reflected in a variant with +5% transactions. Furthermore, the situation after applying the framework, with more focus on reaching targets, and the situation with long term implementation of the system are simulated for all three variants : baseline, -4% and +5% transactions.

The differences in input are not reflected in the KPIs for FTR and SQL, as these are calculated based on historical percentage of mistakes made, which were not changed between the different input scenarios. As applying a focus on reaching the target, or implementing the framework does result in a different percentage of mistakes made, FTR and SQL were affected by them. The COPQ is calculated with use of the number of mistakes, instead of the percentage, all variants and scenarios resulted in a difference in internal and external COPQ.

Overall, by implementing the framework and focusing on reaching target, the percentage of perfect transactions increases, both in value and in frequency the target is reached or transcended, leading to a higher sigma quality level. Consequently the cost of poor quality decreases, both caused by internally and externally found mistakes. The highest expected decrease in overall cost of poor quality, is 39,3%, which would be due to a combination of less transactions (-4%) and effectively implementing the framework.

In conclusion, the answer to the main research question:

How can the quality performance of a distribution process for cut flowers be measured and controlled to incorporate zero-defect logistics?

The quality performance of a distribution process for cut flowers can be measured and controlled with the incorporation of zero-defect logistics, by applying a hierarchical KPI and PI framework, with indicators that are specified on the circle of influence of the business levels. The KPIs report on weekly first time right, sigma quality level and cost of poor quality, while the PIs report on daily first time right and mistake specific defects per million opportunities. These indicators are generic enough to be applied on every aspect of the process, with some minor adaptions to fit the other departments, ensuring a uniform method of monitoring and control of process quality. To ensure the uniformity and continuity in the quality performance measurement system, a person or team is appointed as Process Quality Control, whom are responsible for monitoring the quality and reporting anomalies.

However, certain assumptions and averages have been used, leading to a generalized expected outcome. By specifying the cost of poor quality and running a pilot, LO would acquire more realistic and thus more reliable outcomes. Additionally, as the process covers more than one department and the framework functions optimally when all departments employ a uniform quality performance measurement system, it is recommended to appoint the Process Quality Control to be in charge of the entire cut flower process quality performance.

Management samenvatting

De verdeling van snijbloemen is het proces dat plaatsvindt na de verkoop van de producten door middel van een veilingsysteem. Voordat de verdeling start, arriveren de producten, worden ze gesorteerd op productsoort en gecontroleerd op volledigheid, waarna ze naar een tijdelijke opslaglocatie gaan in een koelcel. Deze verlaten ze na geveild te zijn, waarna de karren met snijbloemen bij het verdeelproces aankomen. Hier worden fusten met snijbloemen van de kwekerskarren verdeeld op die voor kopers. Na het verdeelproces worden de karren verzameld en met slepen naar de klanten gebracht. De meeste kopers hebben een vaste fysieke locatie in het gebouw, of krijgen een tijdelijke locatie toegewezen.

Voor dit onderzoek zijn de volgende onderzoeksvragen beantwoord met behulp van een aantal onderzoeksmethoden, in aanloop naar het beantwoorden van de centrale onderzoeksvraag.

Hoe kan de kwaliteitsprestatie van het verdeelproces voor snijbloemen worden gemeten en bestuurd met inachtneming van zero-defect logistiek?

1. Wat is zero-defect logistiek?
2. Wat is state-of-the-art in prestatie meet modellen?
3. Wat zijn best practises voor kwaliteitsprestaties meten in verschillende industrieën?
4. Hoe is het optimale kwaliteitsprestatie meet en controle systeem opgebouwd?
5. Wat is de huidige situatie rondom proces controle by Royal FloraHolland?
6. Hoe presteert Royal FloraHolland op het gebied van proces kwaliteit?
7. Welke fouten hebben invloed op de proces kwaliteit?
8. Hoe wordt het ontworpen systeem aangepast op het proces van Royal FloraHolland?
9. Welk effect heeft het systeem op het proces en de prestatie in de huidige en toekomstige staat?

Het doel nul defecten in een logistiek proces te bereiken, komt voor een deel uit de Lean Six Sigma filosofie en wordt gebruikt als onderdeel van Total Quality Management. Het wordt vaak gebruikt door statistische proces controle toe te passen en een kwaliteits gerelateerde filosofie door het gehele bedrijf te integreren.

De state-of-the-art in prestatiemeting varieert afhankelijk van de industrie waarin het wordt toegepast en het standpunt dat procesingenieurs hebben bij het ontwerpen van het systeem. Een recent ontwikkeld, generiek model, het Goals, Performance and Indicators model (GPI-model), blijkt van toepassing te kunnen zijn op het snijbloemendistributieproces, omdat het een model oplevert dat enkel nog de juiste selectie van procesprestatie-indicatoren vereist. Om richting en begeleiding te geven aan de selectie van de juiste prestatie-indicatoren, kunnen de best practices uit andere industrieën worden gecombineerd en worden gebruikt als kader voor prestatie-indicatoren die op de casus van toepassing zijn.

Op basis van de theoretische input wordt het optimale kwaliteitsprestatiemeet- en controlesysteem ontworpen, gepresenteerd als een voorlopig raamwerk. Omdat er geen definitief bewijs was voor één perfecte methode, combineert het concept de standpunten van twee bronnen in één hiërarchisch gekoppeld model, met (key) prestatie-indicatoren gekoppeld aan de verschillende niveaus. De cirkel van invloed verschilt tussen de niveaus, dus het type indicator en de frequentie van rapporteren wordt hierop aangepast. Dit resulteert in drie (key) performance indicator categorieën die alle benodigde input leveren voor de business unit managers op strategisch en tactisch niveau; first time right (FTR), sigma kwaliteitsniveau (SQL) en kosten van slechte kwaliteit (COPQ).

De FTR-categorie is opgesplitst in twee KPI's, de ene rapporteert over het aantal dagen dat de FTR-doelstelling is bereikt, de andere over het gemiddelde FTR-niveau. Sigma kwaliteitsniveau is gebaseerd op het FTR niveau, het berekent het gemiddelde sigma niveau van het proces, met de ambitie om uiteindelijk 6 SQL te behalen. Net als bij de FTR KPI is de COPQ gesplitst, waarbij verschil wordt gemaakt tussen interne COPQ en externe COPQ. Interne COPQ zijn de kosten van slechte kwaliteit die binnen de grenzen van het proces blijft, de externe kosten van slechte kwaliteit is het financiële gevolg van fouten die bij de klant terechtkomen. Het splitsen van de PI om de interne en externe kosten weer te geven, is belangrijk omdat het de impact op de klant scheidt van de interne impact. Alleen focussen op output (klantvriendelijkheid) wekt de indruk van hoge kwaliteitsprestatie, omdat het de illusie wekt dat interne foutcorrectie niets kost.

Om de informatie voor de KPI's te genereren, worden prestatie indicatoren (PI's) geformuleerd en gekoppeld aan bovenliggende KPI-categorieën. De PI's zijn afkomstig van en worden gerapporteerd door de teams, op operationeel niveau, waar de medewerkers zelf actief invloed kunnen uitoefenen op de elementen die de resultaten van indicatoren aanjagen. Als het theoretische kader wordt toegepast op de case study, worden het bedrijf en het bedrijfsproces beschreven, evenals de huidige prestaties op het gebied van kwaliteitsprestaties. Deze informatie geeft antwoord op de volgende subvragen.

De veilinglocatie in Naaldwijk is de op één na grootste van Royal FloraHolland. Er worden zowel snijbloemen als potplanten verwerkt, via een proces dat voornamelijk door mensen wordt uitgevoerd, ondersteund door software. Het snijbloemenproces wordt uitgevoerd door drie afdelingen, Logistieke Dienstverlening Aanvoerders (LDA), Logistieke Operatie (LO) en Logistieke Dienstverlening Klanten (LDK). Het huidige prestatiemonitoringsysteem is gebaseerd op de overkoepelende Operational Excellence (OpEx)-strategie, waarbij de KPI's zijn onderverdeeld in de categorieën People, Safety, Quality, Delivery en Cost (PSQDC). De OpEx-strategie omvat ook een periodieke maturity scan, die intern meet op welke manier de documentatie, aansturing en monitoring van het proces door de drie afdelingen wordt gedaan. Van de drie afdelingen scoort LO het hoogste: niveau twee, na een eigen interne beoordeling.

Ongeacht de volgorde van PSQDC, zijn de belangrijkste KPI's gericht op de output van het proces en productiviteit. De KPI's over de proceskwaliteit worden wel gerapporteerd, maar niet benadrukt bij de evaluatie van de prestaties. Alle drie de afdelingen hebben KPI's die rapporteren over een element van kwaliteit in de processtappen die ze uitvoeren, maar niet alle afdelingen halen het doel. LDA en LO bereikten hun respectieve doelstellingen in 2019 niet, terwijl LDK dat wel deed. De definitie en berekening van de KPI's is echter dubbelzinnig en selectief. Deze vage omschrijvingen resulteren in het weglaten van fouten en het gebruik van verkeerde eenheden, wat de uiteindelijke waarde van de KPI vermindert wanneer deze wordt gerelateerd aan de daadwerkelijke procesprestaties.

Met behulp van informatie van het team dat fouten vindt en herstelt, zijn de kwaliteitsprestaties met betrekking tot fouten gekwantificeerd tot financiële output. De kosten zijn verdeeld in directe en indirecte kosten, waarbij de directe kosten zijn gebaseerd op de gecompenseerde kosten voor de klant, en de indirecte kosten zijn gebaseerd op de kosten die het Zoeken en Correctie team maakt bij het zoeken naar de oorzaak en het herstellen van de fouten. Alle drie de afdelingen dragen bij aan de totale kosten voor RFH Naaldwijk, zowel via directe als indirecte kosten, waar LO het grootste aandeel heeft. Dit komt voornamelijk doordat LO de afdeling is die verantwoordelijk is voor de meeste menselijke handelingen met de producten.

Om nader te specificeren wat de proceskwaliteit in de LO-afdeling beïnvloedt, is de volgende deelvraag bedoeld om te bepalen welke fouten daarop van invloed zijn. Die informatie wordt gebruikt om het initiële ontwerp aan te passen aan Royal FloraHolland. Het uiteindelijke ontwerp is een hiërarchisch systeem, met dagelijkse en wekelijkse feedbackloops tussen de niveaus van de business unit. Het bevat belangrijke prestatie-indicatoren gecategoriseerd in first time right, sigma-kwaliteitsniveau en kosten van slechte kwaliteit, waarbij de procesindicatoren worden gespecificeerd voor de daadwerkelijke fouten waarvan werd vastgesteld dat ze de grootste invloed hebben op de proceskwaliteit. Deze PI's zijn genormaliseerd naar defecten per miljoen opportunities, met als doel om via een np-chart te kunnen monitoren en controleren en de invloed van wisselende transactietotalen per dag teniet te doen. De output in de vorm van (K)PI's moet op elk niveau inzicht geven in de kwaliteitsprestaties van het proces, evenals een beperkte ruimte bieden voor mogelijke procesverbeteringen wanneer de (K)PI afwijkingen meldt. Het systeem is gevisualiseerd in de figuur op de volgende pagina.

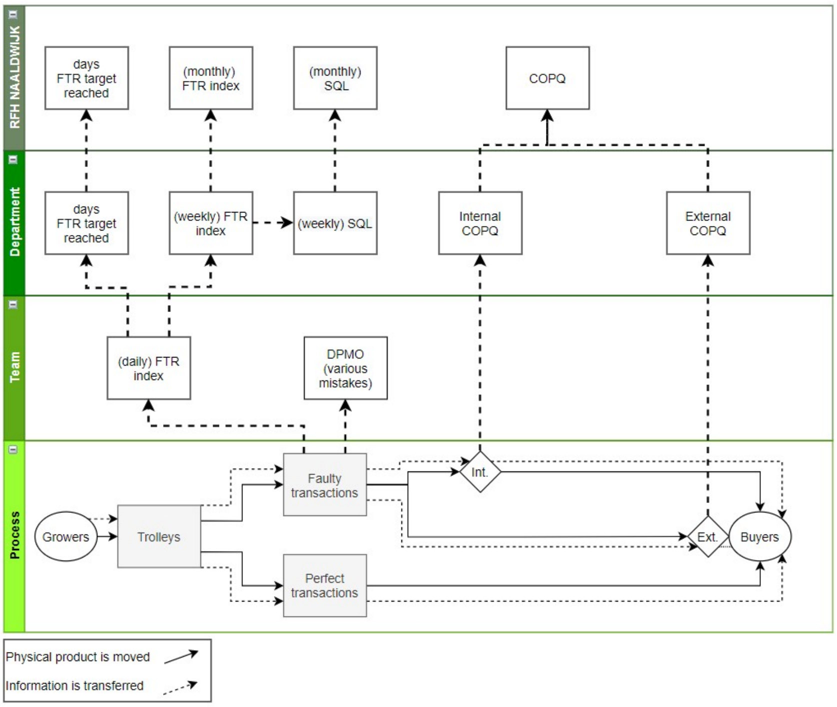


Figure 2: Swimlane visualisatie van definitieve ontwerp

De volgende stap is het bepalen hoe de toepassing van het systeem het proces en de prestaties in de huidige en toekomstige staat zou beïnvloeden. Om de verwachte toekomstige situatie te simuleren, wordt het aantal transacties verlaagd met 4%, aangezien verwacht wordt dat de verschuiving van veiling naar directe dienstverlening doorzet. Het aantal transacties zou echter ook kunnen toenemen door de implementatie van het nieuwe logistieke concept, wat tot uiting komt in een variant met +5% transacties. Verder worden de situatie met toepassing van het ontwerp, met meer focus op het behalen van doelen, en de situatie met lange termijn implementatie van het systeem gesimuleerd voor alle drie de varianten: basis hoeveelheden, -4% en +5% transacties.

De verschillen in input worden niet weerspiegeld in de KPI's voor FTR en SQL, aangezien deze worden berekend op basis van historisch percentage gemaakte fouten, die niet zijn gewijzigd tussen de verschillende invoerscenario's. Echter, doordat het richten op het bereiken van het doel door implementeren van het ontwerp leidt tot een ander percentage gemaakte fouten, worden FTR en SQL hierdoor wel beïnvloed. De COPQ wordt berekend aan de hand van het aantal fouten, in plaats van het percentage, en in alle varianten en scenario's resulteerden dat in een verandering in interne en externe COPQ.

Door het ontworpen systeem te implementeren en te focussen op het bereiken van de gestelde doelen, neemt het percentage perfecte transacties toe, zowel in waarde als in frequentie dat het doel wordt bereikt of overschreden, wat leidt tot een hoger sigma-kwaliteitsniveau. Hierdoor dalen de kosten als gevolg van slechte kwaliteit, zowel veroorzaakt door intern als extern geconstateerde fouten. De hoogst verwachte daling van de totale kosten van slechte kwaliteit is 39,3%, wat komt door een verwachte combinatie van minder transacties (-4%) en een effectieve implementatie van het ontworpen systeem.

Concluderend, het antwoord op de centrale onderzoeksvraag is:

Hoe kan de kwaliteitsprestatie van het verdeelproces voor snijbloemen worden gemeten en bestuurd met inachtneming van zero-defect logistiek?

De kwaliteitsprestaties van een distributieproces voor snijbloemen kunnen worden gemeten en gecontroleerd met de integratie van foutloze logistiek, door toepassing van een hiërarchisch KPI- en PI-systeem, met indicatoren die zijn gespecificeerd op de cirkel van invloed van de bedrijfsniveaus. De KPI's rapporteren wekelijks over first time right, sigma kwaliteitsniveau en kosten van slechte kwaliteit, terwijl de PI's rapporteren over dagelijkse first time right en specifieke defecten per miljoen opportunities. Deze indicatoren zijn algemeen genoeg om op elk deel van het proces te worden toegepast, met enkele kleine aanpassingen voor de andere afdelingen, waardoor één methode van monitoring en controle van de proceskwaliteit wordt gegarandeerd. Om de uniformiteit en continuïteit in het kwaliteitsprestatiemeetsysteem te waarborgen, wordt een persoon of team aangesteld als Proceskwaliteitscontrole, die verantwoordelijk is voor het bewaken van de kwaliteit en het melden van afwijkingen.

Er zijn echter bepaalde aannames en gemiddelden gebruikt, wat heeft geleid tot een algemeen verwacht resultaat. Door de kosten van slechte kwaliteit te specificeren en een pilot uit te voeren, zou LO realistischere en dus betrouwbaardere resultaten opleveren. Bovendien, aangezien het proces meer dan één afdeling bestrijkt en de aansturing optimaal functioneert wanneer alle afdelingen een uniform kwaliteitsprestatiemeetsysteem hanteren, wordt aanbevolen om de Process Quality Control de leiding te geven over de gehele snijbloem prestatie van de proceskwaliteit.

Contents

1 Introduction

This chapter outlines the general context of the research. It will start with the floriculture industry on a macro level and gradually focus on the business level of Royal FloraHolland. The future developments for the company are described after the company is, followed by a brief problem statement.

1.1 Dutch floriculture industry

There has been limited recent research on the operations of the (Dutch) flower and potted plant auction. Most available academic research on flower auctions pertains the technical aspects of the auction mechanism and its effect on prices, the effect of a global auction marketplace on supply and demand, or the digitization of the auction process [48, 72, 73, 122, 126]. Studies on fruit and vegetable auctions provide more insight in logistics co-operations on a smaller scale, but are generally focused on Asian organisations and supply chains overall [15, 20, 22, 84].

Economist Michael Porter analyzed the Dutch Flower Cluster in 2011 to determine the reasons for its success in the floricultural trade and the strategies that are meant to keep the Dutch as largest flower cluster. He recognized the following actors: Growers, suppliers, auctions, logistics and distribution, and research organizations. Besides internal actors of the cluster, Porter mentions the competition it has from countries like Colombia, Ecuador, Kenya and China. Especially the rise of internet has contributed to the growing stake these countries have in the global floricultural network. Increased wealth and access to technology, research and developments also play a role in the growth of these previously 'underdeveloped' countries [81].

Some aspects have changed since Porter's analysis, including the increasing use of the Internet for auctions, the number of direct transactions between growers and buyers, and the demand for transparency and sustainability throughout the supply chain [21, 38]. A major research effort by DINALOG and Wageningen Universiteit (DAVINC^{3}I) adds information on the developments in logistics concerning the global floricultural supply chain networks [38]. One result is a paper by Keizer et al., in which they state that the main challenge for the floricultural supply chain networks is to successfully combine strong dynamics and uncertainty with fresh product quality and volume. The developing trends in the global market increasingly force high flexibility and responsiveness on planning and executing the logistics services [34].

The University of Technology in Delft has had several master and PhD students that studied some elements or the whole of the florichain. Chen proposes a model to optimize multi modal transport in the final leg between auction house and buyer [26], Beemster designs a new logistics concept that combines the virtual marketplace with a physical transportation hub, a design that has been part of the groundwork of current developments at Royal FloraHolland [19], and Binneveld sought to re-design the distribution process of products after auction and before delivery in Aalsmeer [21]. A recent PhD study by Lin, applies a quality based control model for cut roses in the supply chain that focuses on the wholesaler and florists [66].

1.2 Royal FloraHolland

Royal FloraHolland (RFH) is a cooperation of growers of cut flowers and potted plants in the Netherlands. Since merging with Veiling Bedrijf Aalsmeer (VBA) in 2008, it is the biggest auction organisation in the Netherlands. While it also states to be the largest flower auction in the world [93]. Its yearly revenue of € 4.800.000.000 is partially acquired through import from countries such as Kenia and Colombia, and exporting sold products to Germany, the United Kingdom, France, Italy and Belgium [94].

According to the yearly report of 2019, 2.458 customers bought products through RFH, from 3.894 cooperation members. 5.406 logistics service providers (LSPs) have either provided inbound or outbound transport for cut flowers, potted plants and logistics means that are used in the auction building. Of the total revenue, close to € 2.000.000.000 is the result of the auctioning process. The remaining share is due to direct services that RFH provides for its members and customers. A total of 12.300.000.000 products has been traded through RFH, either directly or with auction, of which 5.800.000 products were cut flowers that have been auctioned in 2019. The entire company had 2.543 employees in 2019, costing a total of € 166.000.000 in salaries. The general cost for 2019 amounted up to € 112.000.000 [94].

Currently the four locations operate fairly independent, with pilots and small steps towards a more integrated network. The foundations of a supply network with various hubs are transparency, communications and standard procedures [43]. The operational excellence strategy that RFH applies to achieve this, has been developed internally, by the Transformation and Continuous Improvement department. This T&CI department is responsible for concern-wide application of Lean Six Sigma techniques that support continuous improvement. Operational Excellence is based on various improvement and bench-marking tools that T&CI has gathered, combined with expertise and brainstorming sessions with different management levels of RFH. The levels and elements of the OpEx strategy serve as a benchmark and basis for the new standard, increasing the transparency and standard procedures over all locations similarly. Naaldwijk, as second largest location, will be the first to be linked to Aalsmeer in various manners. Already Connect services have been introduced, shuttling products between the locations, and several departments are joined on the tactical level [96].

1.3 Future developments

As Royal FloraHolland has evolved through the collective efforts of growers looking for a way to level optimal prices, its operations are primarily focused on facilitating growers and secondly on offering services to buyers. Changes in the global flori-chain force the internal process to adjust accordingly, which is an ongoing process that increases in frequency of introducing new aspects [34]. This is reflected on the way operations in Naaldwijk have developed, with service level agreements of delivering produce within 180 minutes after auctioning them off, but also in the location and routing of the process. New developments and future goals are formulated with that starting point in mind, but are motivated by the global changes and the know-how in the entire floriculture industry [95].

Since 2017 RFH has joined forces with various digital market platforms to develop a digital service for her customers, with Floriday as a result. This platform offers growers, buyers and LSPs a means to connect digitally, view produce, join in the auction process, buy directly, and organize the transport and delivery [41].

The transport part of this fulfilment strategy, will be supported by the newly minted corporation Floriway. This joint venture with RFH and several large transport companies, will specialize in transportation of the cut flowers and potted plants from growers to buyers [29]. By joining with existing enterprises, RFH has simplified the research and development process and managed a quick first step in the evolution towards fulfilment [96].

1.4 Problem statement

Developments in the global floriculture industry predict a change towards focus on quality, efficiency and responsiveness of service [56]. Process quality is defined as the right amount of products on the right cart at the right order on the right time. Efficiency is related to actions and time surrounding the process steps to achieve process quality. Responsiveness is adaptability to either direct transaction or via auction, moment of auction and transition towards fulfilment [7].

To improve market position and maintain its importance for growers and buyers, RFH increased its focus towards (digital) logistics service fulfilment, in order to unburden growers and deliver customized service to buyers, ultimately functioning as a Cross Chain Collaboration Center (4C) for the global floriculture industry [21, 38, 94, 96].

The future logistics concept will comprise the ability to offer full services to the grower and buyer, by coordinating and organising transport from the garden or greenhouses to a storage facility (if necessary) and finally the buyers' locations. After storage, products will be picked, consolidated and delivered to the buyer. In effect, this will mean a shift from a predominantly push process to a pull process, changing the flow and initiative in the entire logistics chain [96].

For the new logistics concept to be successful, as well as to improve the transparency of operations in Naaldwijk, its process quality performance will have to be monitored and controlled closely, with a system that will adapt to the new logistics concept. This report presents a performance management method applicable to perishable product logistics, with a test on the distribution process in Naaldwijk.

1.5 Report structure

The report follows the research structure of the DMADE phases, with every chapter centered around answering the sub-questions that are stated in section 2.2. The first sub-questions are answered in chapter 3, where the theories concerning the subject are reviewed. This is used as input for the preliminary concept, which is described in chapter 4. Then the current state of performance management at RFH in Naaldwijk is discussed in chapter 5 to specify the framework. The design is applied to the case in chapter 6, with the results and impact of the framework presented in chapter 7. Chapter 8 will conclude the research and discuss its limitations, as well as recommendations for future research and application.

2 Research design

The problem statement highlights the necessity for a process performance management system that concentrates on the process quality aspects of a cut flowers distribution process, more specifically the monitoring and control of these aspects. This chapter elaborates on the research process that lead to the final framework.

2.1 Structure

One of the most effective methods to improve process quality and performance is Lean Six Sigma (LSS) [36, 65].

Womack and Jones claim that change will only stay as long as the change agent is present, unless the change is settled and solidified in the organizational system [130]. Incorporating the new design in the existing continuous improvement effort, is therefore key to success. The importance of culture in organisations and their effect on the adaptation of changes is especially felt when the change affects multiple departments and teams, as a quality and process related change often does [37].

Elements of LSS are therefore used to structure this research and design. Secondly, as it coincides with the preferred method of improvement at RFH itself, the use of tools from the LSS philosophy will increase the applicability of the system within existing company structures [113].

When it pertains the design of a (new) process or system, it is recommended to follow the Design For Six Sigma phases, known as Define, Measure, Analyze, Design and Evaluate (DMADE) [10, 64]. The goal of DMADE is to incorporate the Six Sigma ambitions of the process as early as possible in the design, to ensure unity in the eventual output [100].

The Define phase results in the definition of the gap, the scope within which the solution is designed, and when the design is considered done. The Measure phase pertains gathering the customer requirements and acquiring information on the current state of affairs, in order to locate the specific context and operational objectives the design needs to meet. Analysis of the requirements, the current state, the objectives and the context to formulate the concept design, is done in the next phase: Analyze. The design concept is then developed into a detailed design in the Design phase. The final phase, Evaluate, contains the verification of the design through implementation in the process, or with use of calculations and simulation, followed by a pilot run [64, 65, 75, 88].

2.2 Research questions

The problem statement combined with the research structure of Lean Six Sigma leads to the following main research question:

How can the quality performance of a distribution process for cut flowers be measured and controlled to incorporate zero-defect logistics?

Supporting the main question are the sub-questions listed below:

1. What is zero-defects logistics?
2. What is state-of-the-art in performance measurement models?
3. What are best practises for quality performance measurement in different industries?
4. How would the optimal quality performance measurement and control system be configured?
5. What is the current situation concerning process control at Royal FloraHolland?
6. How does Royal FloraHolland perform in terms of process quality?
7. Which factors influence process quality?
8. How should the designed system be adapted for Royal FloraHolland?
9. How would the system affect the process and performance in current and future state?

The DMADE phases are incorporated in the research questions, with questions 1, 2, 3 and 4 in the Define phase, question 5 in Measure, questions 6 and 7 are in the Analyze phase, question 8 is the Design phase, followed by question 9 in the Evaluate phase.

2.3 Gap and objectives

Fitting a performance measurement model on (parts of) the floricultural supply chain network has not been explored, neither is the operationalization of the proposed best practice list with performance indicators. Both present an opportunity to combine product quality, efficiency and responsiveness in a holistic performance measurement system. This twofold approach benefits the academic body of knowledge and logistical practice in the floricultural supply chain. The gap is visualized in Figure 20, included in Appendix B.1.

The theoretical objective is to provide insight in the application of a performance model on a shifting floriculture distribution process. The practical objective is to design a quality process performance measurement system and provide recommendations for monitoring and control. The actual implementation is out of scope for this research.

The societal relevance of this research is limited to the direct stakeholders of the distribution process, as the quality performance become more structured and transparent, with less mistakes in the long term expectations. The commissioner will be able to monitor and actively control the process quality. The final design provides the commissioner with means to pro-actively locate areas where problems occur and mitigate the effects before the customer experiences them.

2.4 Methodology

Initially, the methods used to execute this research focus on the theoretical development of a performance measurement model for cut flower distribution operations, based on a structured literature review and a design process with use of the results of the theoretical study. After that, the theoretical model is translated to a practical model to reflect performance of the process in the case study. This model is then adapted according to the expected variants, which are calculated to determine the possible results of its implementation.

2.4.1 Literature review

Performance measurement has been the subject of numerous studies, which provides this research with a broad base of literary sources as well as practitioners' papers, blogs and conference proceedings. These sources are reviewed with the aim to extract the general agreed upon definition of zero-defects logistics and state-of-the-art with regards to performance measurement, both in theory and in practice. Furthermore, the review uncovers the best practises currently in use in different industries that have some similarities with the distribution of cut flowers, or are renowned for process quality control.

2.4.2 Design

The framework of theories leads to functional requirements and objectives for the process performance indicators (PIs), as well as performance measurement models that function as basis for the initial design concept. Elements that are used from these base models, are selected based on the requirements that are the result of the literature review. The resulting conceptual model is verified with data from the case study, after which it is finalized and calculated for its impact on the process. The final design is delivered with an expectation of impact and recommendations for management during transition.

2.4.3 Case study and scope

The benefits of conducting a case study to try and gain insight of a process and its characteristics, is the depth which it gives the information. By focusing on one (or more) cases and delving as deep as time permits, the researcher is able to qualitatively compare, analyze and interpret the results for that specific process [127]. This research focuses on the logistics process in the auction building in Naaldwijk. The logistics departments in Naaldwijk are a part of the case study, as far as their employees are involved in the process of the selected process steps.

According to Verschuren and Doorewaard, results of a case study will be more readily accepted when the researcher has been visible and close to the object of study [127]. To acquire thorough knowledge of the system and the process, as well as create precursory acceptance, meetings are conducted with managers and employees are questioned during gemba walks and training sessions. A gemba walk is a method used in both Lean Six Sigma and Total Quality Management, in which a person gets familiarized with the process and environment of the work floor, while physically walking in the midst of the activities [88]. Training on the job is also used as method to acquaint oneself with the ins and outs of the process execution.

The information required for testing the model with scenarios is acquired from the process, current systems and observations when necessary.

2.5 Data acquisition

To be able to quantify the performance of the cut flower process on process quality, the data generated by the control steps in the process is of vital importance. The data provides information about the mistakes found by the employees and customers. It provides insight in the types of mistakes, the origin and the effect, as well as the time it takes to solve the mistakes.

The global pandemic that disrupted the economy in 2020, has influenced the configuration and performance of the operation, in such a way that the results are not representative for regular operations performance. This research therefore uses available data from the year 2019. However, due to outdated software, not every check point in the process can provide inclusive data over a longer period of time. To negate this, the reports on KPIs of these departments are retrieved to provide the average performance over 2019. Secondly, certain check points do not register mistakes or rectifications as detailed as necessary, which forced the researcher to assume percentages based on historic data and generalizations. These assumptions are mentioned and substantiated when they come to pass.

Most of the quantitative data is acquired from the Searching and Correction team (S&C), directly from their customer complaint database. The data was filtered on cut flowers and the process steps that have a check or a control function. In addition to the data from S&C, the performance of inbound control, the financial transactions and the average cost of a searcher are accessed.

3 Literature review

This chapter discusses the information retrieved from literature and practitioners' sources that is used as input for the theoretical framework. The first three sub-questions are answered in this chapter, with sub-question 1 (What is zero-defects logistics?) in paragraph 3.1, sub-question 2 (What is state-of-the-art in performance measurement?) in the next paragraph and the third sub-question (What are best practices in different industries?) in the final paragraph before the chapter summary.

3.1 Quality management

Various industries have different definitions of quality and how to manage it, as product quality is supposedly different from process or service quality [71]. Garvin defines it as "innate excellence" of which performance is an important factor [42]. Anderson et al. use the definitions as used by the NIST, where process management is used to assess quality [6]. This section reviews three methods of quality management that are thought to be different, but have similar aims: mainly to minimize waste and increase quality through improvements, limiting resources, and improving customer satisfaction and financial results, supposedly reaching zero-defects in their processes [8].

3.1.1 Total Quality Management

The term Total Quality Management (TQM) is most likely a combination of the Japanese originated strategy and American methods, resulting in the philosophy that quality should be managed on all levels, for all process steps, with the customer requirements as guidance [71]. TQM consists of seven quality control tools and seven management tools which can be applied according to the business specific goals, processes and issues [8].

As an essential feature of modern business strategies, TQM has contributed considerably to company successes. With a proven positive statistical correlation between TQM and logistics performance on operational, quality and technology [24]. However, TQM is considered to be an umbrella term, meaningless unless an organization attaches measurable targets and concise methods to its TQM strategy, which methods like Lean Six Sigma provide [8, 79]. Tools frequently used in TQM, such as the PDCA cycle, correspond with the tools used in a Six Sigma DMAIC framework, for example Pareto charts, cause and effect diagrams and applying statistical process control (SPC) [32].

Tari concludes that TQM is a network of components that, interdependently, work towards the highest quality achievable. These components were found to be critical factors, practices, techniques and tools, but there is not a set model of combinations that should be used [118]. Reed et al. support this and add that adopting the core concept of quality management is more important than rigidly following a roadmap or blindly applying tools like SPC [90].

Quality in supply chain management is used to contribute to supply chain and product resilience, leading to a more effective, robust and flexible process, ironically aligning with agile philosophy [7]. Kannan and Tan performed an empirical study that resulted in the conclusion that commitment to quality and an understanding of supply chain dynamics have the greatest effect on business performance [53]. This is underlined by the international study executed by Sila and Ebrahimpour [109].

However, Hackman and Wageman claim that only if continuous improvement comes to apply to the TQM philosophy itself as well, will it be able to sustain its effectiveness [44]. A successful implementation of TQM is largely dependent on the correct selection of techniques and tools, as well as the full adoption of the philosophy and improvement in the various components [118].

3.1.2 Lean Six Sigma

The Toyota Production System is generally accepted as the basis for lean thinking, as Womack and Jones introduced and since then promoted in various books, workshops and consultancy successes [130]. Lean Thinking directs its executors to identify value and waste in a single process, through value stream mapping of the current state and desired state. The future state is then used to identify gaps and implement lean techniques to minimize or overcome that gap. Examples of frequently used lean techniques are parallel working, single minute exchange of dies and 5S [59, 75]. Any lean tool is fairly effective on its own, however, greater power and effect lie in the right combination of techniques and integrating them holistically in the organization [80].

While the philosophy has been mostly revered in high volume, high standardized production processes, it can be applied to job-shop companies as well. However, its success is not as great as for larger mass production facilities. Mainly since the inherent variation of products, batch sizes and customer demands, limits the standardization possibilities in the process. Secondly, as a smaller player in the supply chain, the job-shop companies do not have the clout to motivate their suppliers to conform to their internal process and flow [80].

Where Lean has a qualitative analysis outlook and a focus on activities, Six Sigma uses quantification of outputs to highlight and target variation and waste in a process [105]. A common misconception that Six Sigma is only applicable on production processes is disproved by various studies, although using it in a service process does require concise definition of units to measure and quality conditions [10, 11, 18]. Similar to TQM and Lean Thinking, Six Sigma is not only a strategy or a method, it is a philosophy and should be adopted as such into the organizational culture [79, 80].

To ensure that the optimizations reach their goals, Six Sigma uses data analysis tools to measure performance of the improvements. These tools are visualized in a control chart, that offers a clear indication of performance at a glance [59]. Together with the regular checks during the improvement cycle, this gives pointers to adjust the project management and stay on course [67].

Integrating Lean and Six Sigma provides the holistic focus on customer demand and value for said customer, while maintaining a scientific approach to quality[16]. The latter enables an organization to monitor and control through SPC, using it to keep the process on target and thus reducing waste that is a result of faulty process steps[16, 59]. Pepper and Spedding propose a model for the integration of Lean and Six Sigma. This framework uses Lean techniques to identify improvement hot spots, while applying Six Sigma methods to target the issues and drive it towards the desired improved state [80].

Identifying the right performance metrics is essential to any improvement effort, being TQM, Lean or Six Sigma. Aligning them with the business objectives, gives improvement projects the justification and context [10, 36].

Another important aspect that bolsters the success and the wide applicability of the LSS method, according to Pyzdek and Keller, is the use of specifically trained, full-time dedicated Six Sigma employees [88]. The presence of these dedicated Six Sigma employees (a Master Black Belt, Black Belts and Green Belts), ensures that the Six Sigma goals are known throughout the organization and that they are supported [67].

3.1.3 Zero-defect Logistics

Part of the zero-defect philosophy originates from Six Sigma goals. That philosophy aims for a quality level of 3.4 defects per million opportunities (DPMO), which coincides with a short term sigma quality level (SQL) 6 sigma and a long term SQL of 4,5. The latter reflects the 1,5 sigma shift that is assumed to occur in a process over time [12, 32, 107].

The goal of zero-defects is more than the elimination of defects, it defines zero-defect elements as its goal, meaning the philosophy is to eliminate anything that does not bring value to the product [86]. The way to reach this goal is primarily by eliminating and improving the origins of defects, and preventing the issues from transforming into a defect that reaches the customer [68]. Misinterpreting the goal of zero-defects, could lead to decreased motivation in the workforce, as zero-defect philosophy is an aspect of quality, not the pinnacle of it [117]. Successfully applying zero-defects logistics (ZDL) requires a thorough focus on detecting the nature of the defects, the reason and frequency at which they occur, the impact on the customer and possibilities to measure and prevent the occurrence [87].

Benefits of zero-defects philosophy for service organizations are, amongst others, a reduced amount of customer complaints, a reduced cycle time, higher customer satisfaction and a higher efficiency in the process. For a logistics company, areas to employ ZDL are, potentially, but not limited to, wrong or late shipments, wrong contents of orders and mistaken addresses [61, 137].

To quantify six sigma performance and thus ZDL performance, there are indicators of cost of poor quality (COPQ), the earlier mentioned DPMO and process capability index (ability to meet specifications of service) amongst others [10, 59]. De Leeuw et al. introduce the 'Perfect Order Index' in their case study of Lean Six Sigma implementation, which measures the percentage of orders that are on time, complete, error and damage free. This study states that the implementation of LSS will potentially benefit logistics services organizations by improving service quality [36].

With the emergence of technology, the goal of zero defects has become increasingly popular, both in manufacturing and in logistics, since camera technology and RFID tags considerably increase the chance of reaching zero-defects in a process or product [76].

One of the ways to improve inspections is through automation and technology. By using automation to ensure 100% inspections for entry and exit checkpoints, it would eliminate the need for other checkpoints entirely, as well as result in low external failure, especially in combination with poka-yoke [16, 57].

Various studies have reported the improved DPMO after implementing total quality management and applying Lean Six Sigma tools to both manufacturing and service processes [1, 3, 13, 14, 30, 47, 50, 58, 106]. The acquired increase in SQL has been collected, with the average increase calculated as well, visualized in Table 1.

Table 1: Sigma Quality Level increase after improvement projects

Source	Before	After	Increase
Antony and Kumar (2007) [13]	2,43	3,94	1,51
Antony et al. (2011) [14]	2,5	4,0	1,5
Kalra and Kopargaonkar (2016) [58]	4,34	4,65	0,31
Hakim et al. (2016) [47]	0,2	1,0	0,8
Purnama et al. (2018) [1]	3,61	3,86	0,25
Shafira and Mansur (2018) [106]	3,98	4,09	0,11
Shafira and Mansur (2018) [106]	3,05	3,80	0,75
Alshammari et al. (2018) [3]	1,40	2,37	0,97
Costa et al. (2019) [30]	4,22	4,44	0,22
Iriani and Mulyani (2020) [50]	3,71	5,93	2,22
			0,86

3.2 Process performance measurement

Every company that delivers a kind of product to a customer, either related to physical distribution, production or a non-physical service, has to manage its process in some sort of manner [74, 128]. Managing the entire process is most effective if the performance can be measured, in order to quantify and benchmark its process indicators. This is especially important for the transport and distribution of perishable products, like flowers and potted plants [49]. Process Performance Measurement Systems (PPMS) is a method to do so, as it focuses on the process throughout the company, from start to finish [63].

3.2.1 Performance Measurement Models

Neely discusses the rise of performance measurement systems in 1999, finding there have not been made major changes since the start of larger enterprises [77]. Following this, they propose an encompassing PPMS to guide managers in their quest for process control, while enabling the use of tried concepts like the balanced scorecard [54, 78]. Since then, PPMS has been the subject of numerous studies conducted both in literature and academia, as well in practise with case studies varying from health care, agri-food, automotive to reversed logistics [23, 25, 60, 103, 104, 123].

In a paper published in 1999, Neely noticed an increase in popularity surrounding process performance measurement. They have identified seven main reasons for performance measurement to have become a much more frequently used tool. "The changing nature of work, increasing competition, specific improvement initiatives, national and international quality awards, changing organizational roles, changing external demands, and the power of information technology." [77]

Following the initial research into PPMS, Neely published a paper that presents a framework for designing a performance measurement system. This paper identifies a gap between well-known frameworks, such as the balanced scorecard by Kaplan and Norton, and the actual business process [55]. They developed a process for performance measurement system design, enabling managers to translate the theoretical performance measures are to an applicable and manageable system [78].

Research by Prajago et al. shows that good information management practices have positive implications for process management and integration. It has potential in terms of affecting internal performance measures and outcomes. They imply that managers should look to ways and tools to share and manage information across internal functions. Introducing and managing Internal Process Management has a positive effect on Internal Operation Performance Measurement [85].

Simeunovic et al. found that most of the existing PPMS approaches do not link the process performance with strategic goals and the achievement of those goals, even if it is widely recognized as important to do so. To provide the connection between process performance and achievement of goals, they propose the use of a new kind of model: the GPI model. It is an acronym, referencing to Goals, Processes and Indicators that are combined to monitor the performance on strategic goals. It is considered an improvement on existing PPMS, as the traditional performance measurement systems do not focus on the implementation of the system nor the business application [110, 111]. The model is visualized in Figure 21, included in Appendix B.2.

Finally, as Neely states in his 1999 paper, which is underlined by several authors in theirs: the design of a PPMS is not all, it needs to be managed and evolve alongside the development of the company [74, 77, 85, 111]. Managing process performance while improving it, is right up the Lean thinking alley. As Womack and Jones discuss in their book, continuous improvement is not possible without monitoring the performance of the process, since one needs to know the process to improve it [130].

3.2.2 Key performance indicators

Key performance indicators (KPIs) are metrics that measure performance in critical areas for the business process or departments, where performance indicators (PIs) focus on other areas [69, 89]. Internal efficiency that is reflected in KPIs that contribute to the strategy, provide insights and focus points for control and improvement. Especially effective KPIs are those that measure cross-departmental performance [112, 129]. Within a logistics network, KPIs aimed at delivery, service level agreements (SLAs) and cost are vital to prevent penalties from customers. Successful KPIs require reliable and accurate data, as well as integration in the ecosystem, network or company [114, 119]. Lohman et al. present a performance metrics definition template to specify exactly what information/data is to be measured, at which interval and with what goal [69].

KPIs are only useful when they are connected to the strategy, thus playing an important role in strategic decision-making. Furthermore, the measuring of processes purely for the fact that it can be measured provides an overkill of data, not extra control of said process. Similarly, measuring that what the neighbors measure, without verifying the need and use of the KPI within the company for its strategy, will add no value, nor will it provide control [70].

Especially organizations with functional silos that lack integration face a decentralization of reporting and sometimes even of strategies and goals, creating a disconnect between departments, which essentially counters the effectiveness of the business process [120]. Most frequently used KPIs are visualized in Figure 3 in a top seven of the entire list in Appendix B.3.

KPI name/description	Krauth et al. 2005	Aramyan et al. 2006	Rodriguez et al. 2009	Glavan, 2011	van Dooijeweert, 2014	Iuga et al. 2015	Kucukaltan et al. 2016	Simeunovic et al. 2016	Haliye, 2019		Torman, n.d.	AuditShipment, n.d.	Datapine, n.d	
Cost (operations)	X	X		X			X	X	X				X	7
Cost (service)	X			X	X			X	X			X	X	7
Delivery (on-time)	X			X			X	X			X	X		6
Cost (overhead)	X	X		X					X				X	5
Product (damaged or failed)		X			X	X		X				X		5
Time (lead-time)				X		X		X					X	4
Customer (satisfaction)		X			X	X								3

Figure 3: Short-list of frequently used KPIs in literature

3.2.3 Push-pull

Cohen and Pike found that push and pull is either categorized as an attribute in the controlling mechanisms on factory floor, or as a policy for inventory management and production planning. They propose a framework of assessing whether decisions in a process are based on push or pull, using it to prove that a strictly pull and strictly push method are in fact both hybrid approaches [28].

Subsequently, in a comparison of a pull system to the traditional push system, Spearman and Zazanis found that pull systems have less congestion, easier to control and that the benefits are in large related to the policy surrounding work-in-progress. In addition to these conclusions, the authors found that a hybrid system outperforms both strictly pull and strictly push systems, while being more general in applicability [115].

The need for a hybrid approach to decision-making, combining push and pull aspects, is underlined by Hagel and Brown.
The implication of the transition from push to pull is mostly found in the broad spectrum of products and services that can be offered with specialization. The interaction with humans in the system, both customers and employees will shift, as both will have a more active participation [45].

3.3 Best practises

The sections below provide insight in the type of performance measurement and indicators used in several types of logistics industries, in particular the automotive industry and postal services. This serves as an example and inspiration for the requirements that are necessary for a performance measurement system and its indicators when applying it to the distribution of cut flowers.

3.3.1 Automotive industry

As far as quality performance measurement goes, one cannot discount the automotive industry, especially when considering Lean techniques, since the philosophy was developed by Toyota [130]. Traditionally, most performance measurement systems in the automotive industry are centered around production, with a relatively recent focus that includes logistics and supply chain performance [2, 4, 31, 39, 51]. In order to quantify leanness, some studies have introduced the use of lean metrics to compare the lean performance of one industry or company to another [40, 116, 131, 135].

With the eight dimensions of quality as Garvin defined them, Curkovic et al. concluded that quality of the product and service influences the overall company performance. They recommend a focus on those elements of excellence that affect product (perceived) quality and customer satisfaction directly [31, 42]. In an extensive comparative study, Iuga et al. used several iterations to define 18 KPIs that are most relevant to the shop floor of an automotive organization. Seven of these KPIs are directly or indirectly related to service and product quality [51].

As mentioned before, logistics performance in the automotive industry has become increasingly important to maintain a competitive edge [39]. An initial study by Amran and Yose designed a model of logistics performance measurement to enable automotive component companies to improve performance in order to compete. They used five perspectives: business strategy, capacity and planning, efficiency and productivity of logistics, information technology and supply chain collaboration for their Logistics Scorecard. With a scale determination per KPI, they are quantified in maturity as well as priority. The quantified results are charted in a radar chart, providing an internal and external benchmark tool [4].

Dörnhöfer et al. continue the logistics performance measurement development by stating the need for a lean holistic monitoring tool. Their model considers the complete logistics chain, while staying adaptable to innovations on both scientific and practitioners' side [39]. The generic performance measurement system framework consists of five design steps:

1. Analysis of objectives
2. Analysis of reference processes in selected company
3. Determination of relevant performance dimensions and the strategic key performance indicators
4. Detailed breakdown of evaluation aspects along the logistics process
5. Definition of performance indicators for the selected evaluation aspects

The authors recommend using a standardized KPI definition table, to ensure alignment with interpretation and application of metrics among all parties involved. The resulting performance measurement system provides a comprehensive view of how KPIs relate to each other and the highest level KPI. The KPIs are categorized in *Efficiency*, *Perfection* and *Lean Logistics*, providing a direct context for them in company strategy [39].

A similar design, with a different approach, was proposed and implemented at an automotive production plan by Facchini et al. The researchers developed a KPI tree for lean production systems based on an adopted performance pyramid. The operational indicators are non-financial, as finances are not directly involved by the business process. The KPIs in the proposed model are related to a lean production system, making it applicable to any process that practices lean methods. A unique feature of the model is the difference between improvement and monitoring KPIs, where improvement KPIs allocate improvement opportunities, and monitoring KPIs represent a system that can be improved [9].

3.3.2 Postal/package services

As the Netherlands' largest postal service, PostNL serves as a leading company in delivering letters and packages to Dutch citizens. In order to accomplish this, the distribution process requires close monitoring and control, as well as forecasting. Customer satisfaction is based on the performance of PostNL on the aspects of shipping cost, damage on parcels, throughput time and accessibility of services [125]. Developments in digitization towards the use of Internet of Things have offered PostNL the opportunity to keep track of its operations in detailed real-time intervals. This has contributed substantially to the strategy of process optimization that PostNL has adopted [82].

Similar to PostNL, UPS uses real-time data to optimize its logistics networks, by using it to provide effective information for decision-making. Part of the success of this approach, is the re-use of information to improve other aspects of the company and network. This is in contrast to most companies, which tend to focus on a single data set and apply it in the isolation of the business unit it originates [101]. According to Stuart McAvoy, global director of supply chain optimization and sustainability at UPS, inventory demand forecasting is one of the most important KPIs to track within a warehouse management environment. KPIs that align with known bottlenecks can justify investing in solutions or improvements by reflecting the cost or inefficiency that is a result of the bottleneck. However, using KPIs for successful warehouse management means more than focusing on one in particular, its success lies in balancing the functions and KPIs [121].

AuditShipment, an online platform that offers parcel shipment assistance and a digital performance dashboard, claims there are seven metrics that help steer towards a more effective last-mile strategy, to improve customer satisfaction and loyalty to e-tailers.The most important one, the company states, is the performance on on-time delivery [17]. This coincides with what PostNL and UPS consider top KPIs, which shows how the companies attune to customer demands in order to focus their quality performance [83, 101].

On-time delivery is the result of the internal process, which DHL controls by focusing on two main performance drivers: Productivity and Cost. These are supported by static and stable indicators, subdivided to provide information about the cohesion of the processes in the categories master KPIs, scorecard KPIs and detailed KPIs [46].

3.3.3 Various industries

Logistics companies have difficulties with deciding on key indicators and recognizing interrelationships between the PIs [46]. Kucukaltan et al. present a model to evaluate logistics PIs from the logistics point of view. The most prevalent PIs in logistics are ranked, the most important PI appears to be the educated employee, followed closely by managerial skills, then a gap with costs and an even larger gap to the next one: profitability. The authors argue that these four should be the main focus for managers in the industry [62]. Mapping the performance on three axes (efficiency, changeability and effectiveness), provides a coherent visual indication of the performance of a logistics company [5]. All logistics KPI targets should be set with a benchmark, followed by a frequent benchmark and update if necessary to stay relevant to market developments [33].

For a clothing production plant, Rodriguez et al. propose a performance measurement design model, with four phases, roughly composed of the design and analysis of a PMS, data treatment, identification of relationships and the presentation of results. They present 42 KPIs that are defined to fit a PMS, of which eleven are found to be especially important. The authors have formulated a method to link certain PIs to higher prioritized KPIs, so managers can control the process. Control is exerted by correcting those elements that are under-performing in the relative PIs that contribute to the KPI [92].

Van der Vorst adapted a list of logistic KPIs for food-chain networks on three hierarchical levels (Supply-Chain network, organization and business process). The KPIs work cohesively through the levels, affecting one and another with their performance and results [124].

3.4 Synopsis

Zero-defects logistics is an aspect of TQM, one that is strongly based on the six sigma performance of a process. It can be included in the quality management system by including statistical process control tools, but more importantly by integrating the philosophy in all forms of management and control.

Secondly the section on performance measurement describes several theories that provide some framework or other to measure a company's performance. The GPI model proposed by Simeunovic et al. offers a performance measurement system that is nearly ready to use on a company, with the selection of PIs as a variable step.

However, selecting company specific PIs is a major challenge for the design and later use of the performance measurement system, which is not entirely covered by the research conducted by Simeunovic et al., as is described in their recommendations for future research [111]. To guide the selection, the best practises in other industries are used to base quality KPIs on to be compared to the case study.

Finally, the best practises for performance measurement in different industries, combined with a combination of performance measurement models, provide base for the development of the performance measurement system for cut-flower distribution. The studies of Dörnhöfer and Facchini counter Simeunovic and her co-authors' findings, concerning the link of performance measurement to strategy [9, 39, 111]. This difference in views presumably stems from the selection of sources and a different definition of performance measurement systems. For the purpose of this research, the two views will be combined into one performance measurement framework. Performance indicators used in logistics, production, argri-food distribution, automotive and package delivery have been listed in a table (Figure 3), highlighting the most frequent mentioned KPIs.

The GPI model, with its management level hierarchy and the frequently used KPIs for process quality, are the theoretical basis for the performance measurement system that will be applied in the case study.

A functional PMS requires a balanced number of performance metrics at several levels in the process: these should be indicators of the output of relevant chain business processes and chain management structures (lead time, responsiveness, delivery reliability, product quality, et cetera) as well as the use of chain resources (process yield, utilization, employee satisfaction and sustainability for future developments). It also requires dynamic metrics that recognize and respond to changes in requirements, inputs, resources and performance over time. Relevance for the focus on process management lies in the challenge of having an efficient value chain, while maintaining flexibility throughout the process. To ensure orientation on the business process, an organization should organize responsibilities horizontally [129].

4 Framework design

This chapter details the design and adaptation of a performance measurement model for cut flower distribution, based on the theoretical results found in the previous chapter. To complete the Define phase and answer subquestion 4 (How would the optimal quality performance measurement and control system be configured?), the objectives and requirements function as the definition of what the design should meet in order for it to fill the research gap.

4.1 Design objectives

Several sources state that the choice of KPIs is essential, but not always easy [39, 46, 111]. Especially in deciding on which level the indicator reflects the process for the manager to successfully control it. A (K)PI should report on the process performance that can be influenced by that level, to ensure the usefulness and applicability of control measures [70]. Secondly, any (K)PI that is used for monitoring and control purposes, should be defined with vital aspects of the metric stated plainly, to minimize confusion about the purpose, responsible parties and sources of the indicator [124].

Furthermore, the hierarchy and underlying relations of (critical) process steps should be mapped, as well as linked to the performance indicators that can be used to control them, as several authors recommend. This includes the elimination of financial (K)PIs on an operational level, using those for information on the cost of bottlenecks instead [9, 39, 62, 120].

Approaching a logistics process with process monitoring and control has considerable benefits, such as a shift towards a process-oriented organization which values its primary process performance over secondary processes and results [85, 129].

Additionally, when extracting methods used by the automotive industry to ensure early notice of mistakes, several Lean Production tools arise to tackle issues at the source. This can be done by using the employee that executes the actions as its own quality inspector, giving them the possibility to stop the process if an element does not pass inspection, and by designing the process in such a manner that the human acting in the process cannot make a mistake (poka-yoke) [59].

4.2 Design requirements

To achieve the objectives stated in the previous paragraph, there are certain requirements that should be met by the quality performance measurement system. The requirements are categorized into functional and non-functional requirements. Functional requirements are elements that are necessary to reach the objectives, by describing a specific function or behavior. A non-functional requirement details the way the system should perform [69]. The requirements applied to this design have been sourced from the reviewed literature and are listed below.

For the final design to both fill the found research gap in the academic body of knowledge and function as a solution for the practical problem, it should fulfill these design requirements. In DMADE terms, adhering to these requirements provides the definition of 'done' for this research and design process.

Functional requirements
The following aspects are mandatory for the framework to function as described in the theories:

- FR 1: (K)PIs must be specified to tactical, operational and process level, omitting financial (K)PIs in the latter [39, 46, 70]
- FR 2: (K)PIs must report on (critical) process steps [9, 39, 62]
- FR 3: (K)PIs must be linked hierarchically [39, 85, 92, 124]
- FR 4: (K)PIs must report on perfect orders, DPMO, COPQ/cost of bottlenecks, on-time delivery and sigma levels [10, 39, 75]

These objectives relate to both the specification and definition of the (K)PIs, as well as the positioning and reporting of the information acquired through the calculations.

Non-functional requirements
Alongside the mandatory functional elements, the framework should contain the features listed below:

NFR 1: A daily feedback loop for process KPIs [39, 91]

NFR 2: A weekly update for operational KPIs [39, 91]

NFR 3: A description of (K)PIs specifies exactly what information/data is to be measured, at which interval and with what goal [69, 124]

NFR 4: Employee is made to feel responsible for quality [59, 102]

In addition to these requirements, the generic applicability of the framework, in order to be used for other industries, and the practical applicability of data generation methods to ensure accessibility for practitioners should be taken into account.

4.3 First draft

The initial draft for the framework is the result of applying the objectives, functional and non-functional requirements to the GPI model proposed by Simeunovic et al. [111]. The scope of this research is the operationalization of the theoretical model, so the abstract and external elements such as stakeholder requirements, generalized business goals, organizational structure and process architecture are excluded from the preliminary design basis.

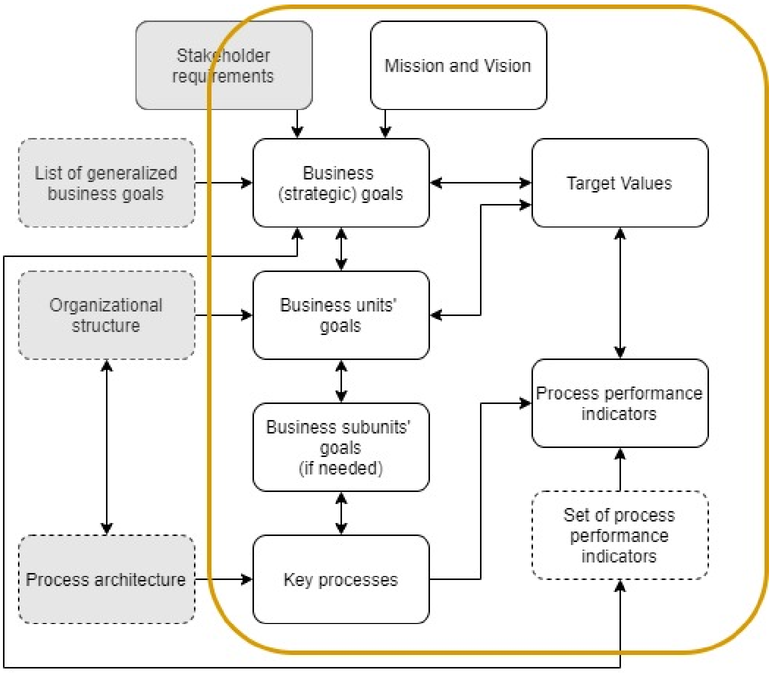
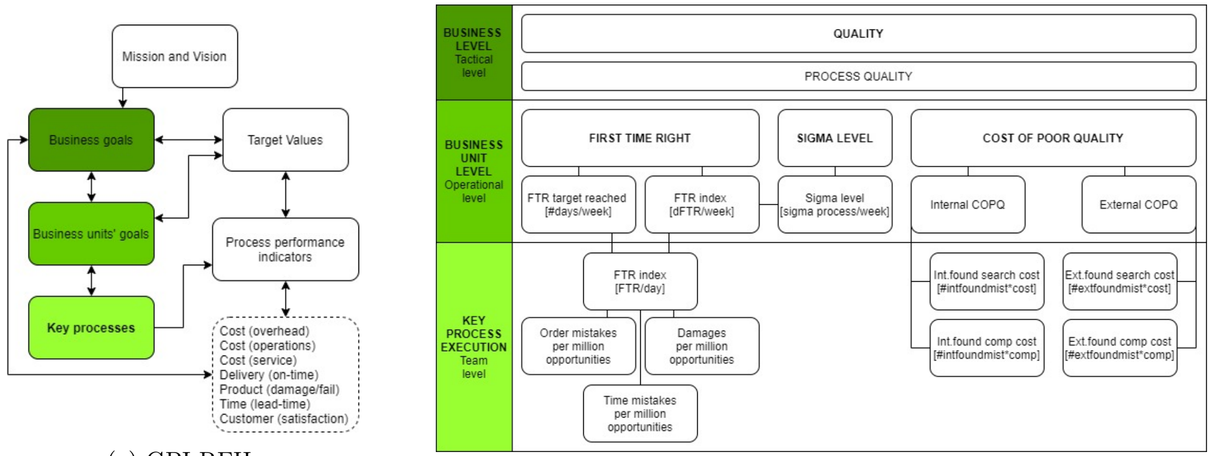


Figure 4: Operationalization of the GPI model

The right side of the model contains the elements that can be operationalized and fit to a company structure, its goals and its target values. The set of process performance indicators as positioned in the right lower corner, is the set of frequently used KPIs extracted from the reviewed texts in the previous chapter. The following sub-paragraphs contain the specific description of the parts of the model that have been adjusted to match the design requirements.

4.3.1 Key Performance Indicators

Initially the short-listed KPIs in Figure 3 were included in the GPI model, visible in Figure 5a (Appendix C). However, these KPIs remain generalised, without hierarchy, definition or calculation appointed to them. The generic PMS framework by Dörnhöfer et al. is combined with the elements of the GPI model to achieve the hierarchical requirements (Figure 5b) [39]. The process quality related indicators that are mentioned in the functional requirements, to do with first time right, cost of poor quality and sigma levels have been introduced as key performance indicators to be reported at business unit level, to its higher level (operational to tactical level). The tactical level then cross-references the reported performance to its strategic goals to function as input for the control decisions on long term aspects. As this pertains the level that does not have direct influence on the process, these (K)PIs will be updated weekly on business unit level.



(a) GPI-RFH

(b) Detailed (K)PIs

Figure 5: The combined GPI-RFH with Dörnhöfer levels

The KPIs are categorized in First Time Right (FTR, based on DPMO), Sigma Quality Level (SQL) and Cost of Poor Quality (COPQ). In order to attain the values reported to the tactical level, the business unit must acquire information about the elements that make up the calculation. These values are reported daily from the key process to the leadership of the business unit. A daily reporting frequency is preferred, as these pertain critical KPIs and they are reported on the level that can take quick actions to alter the process if necessary.

First Time Right

Achieving perfect quality performance, or realizing zero-defects, is the fundamental goal of all quality related performance measurement systems and philosophies. A key feature for this performance, is the percentage of perfect orders, also known as first time right (FTR) percentage [35, 91] Therefore a KPI pertaining this percentage is essential for a quality performance measurement system that monitors and controls a service process. For FTR there are two KPIs, one reporting on the amount of days in the week the FTR target was reached and the other presenting the average FTR index for that week. Both KPIs have a realistic target, which should be reviewed periodically in order for the value to stay relevant to the process developments. The periodical review ensures the process maintains quality, while looking to continuously improve and eventually achieve the zero-defects ideal.

The KPI that functions as input for FTR calculations is:

- FTR index : The daily percentage of orders that are executed without mistakes or delays.

This KPI is reported daily and visualized by a bar or line chart, with a smiley or colour for the employees to see the status of the performance.

To monitor and control the quality of the key process, the PIs are:

- Order mistakes (PMO) : The number of order mistakes that are made per million opportunities;
- Damages (PMO) : The number of damages that occur per million opportunities;
- Time mistakes (PMO) : The number of orders that are delivered too late per million opportunities.

Individually, the PIs report on separate results of the process, functioning as input to calculate the key performance: first time right. Hence the differentiation between KPI and PI. The PIs used to monitor and control the quality of critical process steps should be visualized in a control chart [88]. The control chart will be updated daily and communicated to the employees working in the process.

The values are normalized into DPMO to counteract the variance of order input, and allow for fixed upper and lower control limits based on process variance for the duration of a period (of weeks or a year) [59]. Conform the shortlisted KPIs and Lean Six Sigma theory, on-time delivery is included in the FTR PIs as a mistake or defect. After all, not delivering an order on the agreed time or in the appointed time slot can be considered as a mistake in service industry [136].

Sigma Quality Level

The category SQL has only one KPI, which reflects the sigma level for the week. The target for this KPI is one that is set for a longer period of time, it should be reviewed every year to account for the sigma shift in the process. The SQL KPI shows how well the process performs in light of the ultimate six sigma goal: SQL 6,0. Similar to the control chart used for DPMO, the SQL gives insight in the variance in the process, quantifying how much the process is *in control* [88].
The KPI for the sigma quality level:

- Sigma level of process : The number of standard deviations between the mean and the variance of the process.

The SQL is calculated with use of the first-time-right index per week. The inverse of the normal distribution of the FTR index added to 1,5, results in the SQL. The 1,5 is used to offset the sigma shift that happens between long and short term performance.

Cost of Poor Quality

As there is a cost as a result of internal activities as well as external activities to fix mistakes, the COPQ category is split into two PIs. These PIs serve as monitoring PIs, informing the business unit of the impact of the quality management system and the process bottlenecks on the company's bottom line. This information should be used to check the results of adjustments and mitigating actions on the other PIs and improvements in the process. The KPIs COPQ are the following:

- Internal COPQ : The cost of mistakes that are found internally, both in labour cost and in possible compensation cost;
- External COPQ : The cost of mistakes that the customer reports, both in labour cost and in eventual compensation cost.

The PIs serve to calculate a value used for monitoring purposes and will thus be reported and calculated on a weekly basis. The input for the PIs is based on daily operations, but the result will not be used to manage the process per day, as the cost depends on factors that lie outside of the direct circle of influence of the daily operating crew and the business units as well.

4.3.2 Operational application

The concept framework is a generic one, applicable to any type of distribution process. To specify it to the cut flower distribution, the steps that Dörnhöfer et al. propose are shortened for clarity, combined with the requirements and applied to fit the specifics of the case study [9, 39] :

1. Analysis of business objectives;
2. Description of reference processes;
3. Determination of relevant (K)PIs;
4. Detailed breakdown of critical process steps and PIs.

This facilitates the inclusion of different hierarchical levels (FR 1+3) and enables the practitioner to select relevant (K)PIs (FR 2) through a guided method, which is a frequent problem in logistics [46].

Analyzing the business objectives gives the practitioner insight in the context of the system and processes, in addition to the reference base for step three. Without a process to link the objectives to, they will remain an abstract concept, without operational meaning and thus no value for process control. Therefore, step two aims to describe the reference process(es) and their relevant aspects. Certain elements of the reference process(es) provide information about performance in relation to the business objectives in step one. These elements can be formulated in (K)PIs with evaluation points and dimensions, which is step three. The final step in order to finish the framework, is detailing the relevant aspects process steps and their PIs, so the (K)PIs are interpreted and reported similarly throughout different units. The detailed (K)PIs will be defined following a shortened table as presented by Van der Vorst et al. in their paper about agri-food supply chain networks [124].

After applying the adapted GPI through these steps and verifying whether the configuration fits the current organisational structure, the next phase is to implement the newly designed performance measurement system. This is not included in this research and therefore will not be added in the application method.

4.4 Conclusion

Based on theoretical sources that have been combined to fit the distribution of cut flowers, the preliminary framework is designed. This framework incorporates the need for hierarchically linked KPI and PIs, that are synchronised to the managerial levels in a company (FR 3). Similarly, the framework facilitates prioritisation of indicators that are critical to the process and regulates the feedback loop accordingly (FR 2)). The framework recognizes three levels in the company: tactical, operational and process level. The (K)PIs are specified to fit the operational and process level circle of influence, with the operational level reporting its (K)PIs to the tactical level for strategic control of business targets (FR 1+NFR 3).

The three categories are first-time-right, sigma quality level and cost of poor quality (FR 4). These (K)PIs are meant to be reported weekly to the strategical and tactical level (NFR 2). Underlying PIs are generated by the business process and reported to the operational level, with the results clearly visible for the employees (NFR 1+4). Both KPIs and PIs are defined to fit the circle of influence of the level that reports them, in order for the process to be monitored on changeable aspects.

The aspects mentioned, fulfill the indicated functional and non-functional requirements that are deduced from the state-of-the-art in performance measurement and best practices in other industries. Adhering to these requirements as the framework is applied to the case and fulfilling them after verification, defines the design as done.

The preliminary design can be applied on the whole distribution process for cut flowers, ensuring the uniformity in monitoring and control throughout the entire business process as well as between different teams and departments.

5 Case study

This chapter presents the current state of the business process of RFH Naaldwijk as it is measured and observed, as well as provide the analysis that has been done on those measurements and observations. Consequently this chapter will answer the sub-question on the current situation concerning process control is and how RFH Naaldwijk performs. The information in this chapter is acquired through multiple gemba walks, informal interviews, working along side several employees and extensive data analysis. It contains the results of the Measure phase described in paragraph 2.1.

5.1 Royal FloraHolland Naaldwijk

Royal FloraHolland Naaldwijk is the second largest location of the organization, with a total surface of 740.000 square meters and a yearly performance of 2.600.000 transactions [95, 97]. The top products in these transactions for cut flowers are roses, chrysanthemum, tulips, gerberas and lilies. In the product group potted plants, the orchids, arranged cacti, kalanchoës, anthuriums and potted roses are sold most [94].

The auction building is located in the Westland, one of the largest areas with greenhouse horticulture in the Netherlands [95]. The building in which the auction and logistics processes take place, is configured with many different halls, and linked buildings with docks and storage. The widespread and inefficient configuration hinders efficient logistics considerably, as transportation of products and auction trolleys has to be done over many kilometres [21].

Regardless of the physical size of the auction terrain, there is a chronic lack of space. Many stakeholders, both from RFH or from buyers' sides, vie for the available spaces on premium locations. As the distribution process of auctioned flowers and plants is the primary process, it has priority in space optimization, but supporting processes encounter more issues when trying to optimize spatially [95].

RFH Naaldwijk has auctioned off a total of 1.528.162 trolleys (including smaller rolling containers: CC), of which 950.934 where for cut flowers and 577.228 for potted plants. After auction these trolleys resulted in 9.086.084 logistics transactions for the distribution department. To facilitate and execute these transactions, RFH Naaldwijk employed 438,7 FTEs in 2019. The employees that have a task in the logistics process caused a total of 56.260 registered mistakes. More than half of these mistakes was caught internally (58,78%), the others where reported by customers. To compensate mistakes to the customers, RFH Naaldwijk paid out € 960.764,-, which was then internally directed to the departments that are responsible for the causes. The general cost in Naaldwijk was € 1.923.000,-, 1,72% of the total general cost for RFH. Direct labor cost per auction trolley amounted up to € 3,50, while the labor cost per transaction was € 1,58. The amount of labor cost for RFH Naaldwijk was € 27.421.000,-, 16,52% of the total labor cost for RFH, of which € 806.152 was paid to the Search and Correction department [98, 132, 133, 134].

A total of 33.713 mistakes have been registered in Naaldwijk for the cut flower process, 18.766 of these are related actual steps in the process, 14.947 mistakes are caused either by an unknown source, the grower or the customer. The former amount is in scope, so that number is taken into account for further calculations. When a trolley contains the wrong quantity of packaging units, but it is not caught by inbound control, it will be registered as a counting mistake for inbound control. These mistakes reflect the effectiveness of the first control point, while the true cause is a mistake of the grower.

Of the registered mistakes 28,09% was notified to employees in the S&C office, 71,91% to S&C employees in the secondary location (adjacent to the distribution process). To search for the cause of these mistakes, € 101.837,- was paid in labor cost. The financial compensation to customers added up to € 251.610,87, which is 26,19% of the total compensation cost for RFH Naaldwijk in 2019.

A point of observation, however, is that 41,63% of the total registered mistakes, is caused by an unknown source or impossible to find proper evidence of a party causing it. Compared to the total amount of registered mistakes for cut flowers, the unknown source of mistakes with cut flowers represents 18,46%. This is a significant amount of mistakes, that is responsible for more than 1500 hours of searching, which cost the Search and Correction department € 40.848,- in salaries for 2019 [98, 132, 133, 134]. This means that a considerable amount of money is spent, because there is little transparency in the process or origins of mistakes, a typical symptom of a process that is not *in control*.

5.2 Business process: Cut flowers

The business process of the distribution of cut flowers, starting from three different sources (import, grower and the test facility) is visualised in Figure 6. The cut flower process has received 950.934 inbound auction trolleys in 2019, which resulted in 6.492.259 logistics transactions and 1.693.433 outbound auction trolleys. The logistics labor cost per cut flower transaction amounted up to € 1,13 for RFH Naaldwijk in 2019, of which € 0,02 is paid to rectify mistakes. The three control points, as represented in Figure 6, illustrate where exactly in the process is inspected on different aspects of quality. The first and second focus on quantity, mainly whether the right amount of packaging units are present on the auction trolley. The third control point is the barrier between the distribution process and the customer, aimed at filtering out mistakes made by distribution employees.

The selected business process is managed and executed by three different departments: Logistic Service for Suppliers (LSS), Logistic Operations (LO) and Logistic Service Customers (LSC), with Logistic Support (LS) for secondary processes (Appendix D.2). These departments are responsible for different parts in the process, which coincides with the principles of a functional organization structure [120]. The first part of the process is the responsibility of LSS, followed by LO, then LSC. For a functional organization to perform optimally, inter-department communication and transparency is essential. This can be realised through structured (digital) exchange of information and regular communication between managers on all levels [27].

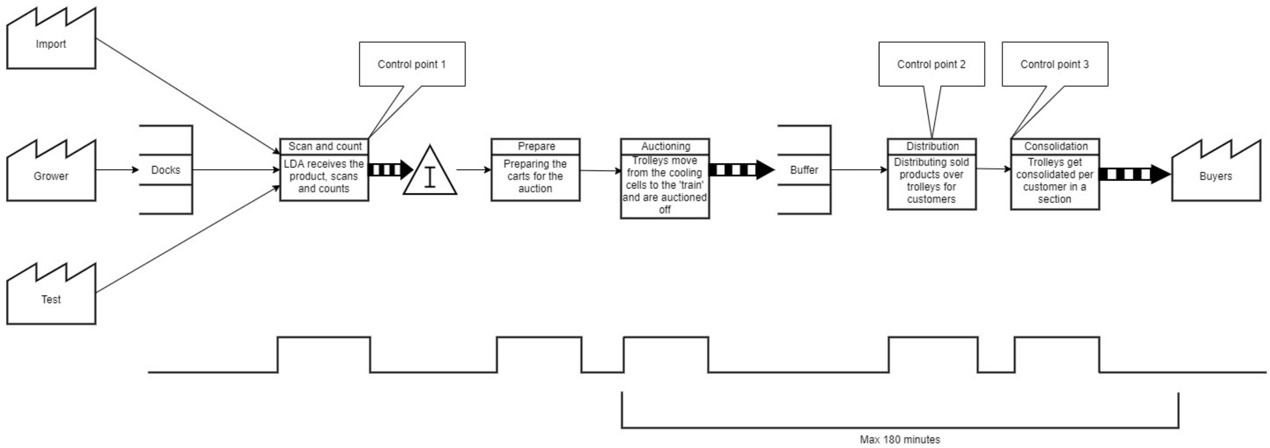


Figure 6: Simplified VSM for cut flowers in Naaldwijk

The employees in the cut flower process were responsible for missing 3.712 of supplied wrong quantities and making 15.129 mistakes, of which 5.031 or 33,25% were reported by customers. The amount of mistakes reported by customers can be expressed in transactions and delivered trolleys, resulting in 0,22% faulty transactions and 0,06% wrongly delivered trolleys. As a result, the performance can be described as 99,78% correct transactions and 99,94% correct deliveries. Inbound control (control point 1) and path-check (control point 3) were respectively 47,62% and 56,12% effective in their check, of which the missed mistakes of the former were caught in the distribution process.

Logistic Service Suppliers

The cut flowers' first contact with RFH is at the docks, where the supplier unloads the products for RFH employees to check for correct digital information and physical delivery note. The train of trolleys is then towed to a different location, the scan area, where another employee counts the products, checks for damaged products, and whether the auction trolley is complete. The trolley and delivery note are then scanned, linked and declared ready. The trolley is scanned by a different employee to check its destination, towed to the temporary cold storage to await the auctioning process and registered as arrived on the right track. After that, the process responsibility is transferred to the next department.

The inbound process takes place from 13:00 till 04:00 before auction, as the growers deliver their flowers to be auctioned off. The KPIs that this department reports and with which it controls its process with, are the throughput times. Trains with products should be moved towards the temporary storage as soon as possible (within 30 minutes after receiving the flowers), any delays are unwelcome and should be solved as soon as possible.

Logistic Operations
After the cut flowers are auctioned off and sold to buyers, they are pulled onto automatic tracks that transport the auction trolleys towards a buffer location close to the distribution space. At the buffer space, employees manage the automatic depositing process by directing auction trolleys and pushing them towards the front of the buffer lanes.

Distribution employees then get a pick-up command by the Voice Picking system for an auction trolley in one of the buffer lanes. They come over, attach a trolley to their vehicle and count whether the amount of products on the auction trolley is correct. Afterwards, they start distributing the products from that one trolley over different buyer trolleys. When a buyer trolley is filled to 75%, it is removed from the path by a distributor or a path managing employee.

The path manager counts the amount of units on the auction trolley and verifies this with the physical delivery note that gets attached to the trolley. The buyer's trolley is then put on a track for that buyer, where it stays until the track is filled with trolleys. A full track is sign for the next department to enter the process.

The KPIs with which this department monitors and controls its process, mainly concern productivity (transactions per person per hour) and end-time of the distribution process, for it to achieve the maximum of 180 minutes from auction moment to delivery moment.

Logistic Service Customers
When the track is full, the delivery notes are scanned to determine which buyer the trolleys in the train should go to, after which the employee tows the train to the physical location of that customer. The delivery employee knows where to deposit the train and sometimes confirms delivery, with use of a similar voice-operated system as the distribution. Its most important KPI is on-time delivery, similar to the distribution, to provide the service of under 180 minutes delivery to the customers' location.

Another team that is part of the LSC department, is Search and Correction (S&C). This team is responsible for solving most product-related failures throughout the complete business process. Employees that work in the process can signal mistakes, after which the 'searchers' or 'solvers' will find out what happened and solve the problem as well as possible. They are also accessible for buyers, who file complaints with this team when something is wrong with the products they received. S&C is the team that has access to, insight in and knowledge of, all parts of the process.

5.3 Operational Excellence

RFH infused its daily operations with continuous improvements in 2014 through a program known as 'Verbeteren Dagelijkse Dienstverlening (VDD)', which is involving into a strategic Lean Six Sigma tool and resulted in the KAIZEN Award in 2018 [52]. The accompanying introduction of Basics Right, a program that focuses on optimizing the basic processes, and its successor Infrastructuur Continu Verbeteren (ICV) are initiatives to keep improving operations and internal processes, increasing customer satisfaction and managing process cost. To substantiate the improvement goals, RFH introduced "Operational Excellence" as the general direction of operations.

The RFH Operational Excellence (OpEx) concept is designed as a maturity wheel, in which the spokes depict different aspects of the organisation. With help of an OpEx maturity scan, the level of maturity per aspect is defined for every department. The scan is used to gain insight in the status of Operational Excellence and prioritize focus points for the next period. There are thirteen periods in a year, to ensure enough time is available for changes to become ingratiated in the processes. This is an essential part of Operational Excellence, as maturity can only be achieved by building on a steadily evolving process, as opposed to a haphazardly improving and rebounding process [108, 130].

The overall goal of the OpEx strategy is to be able to provide safe, first-time-right and on-time services to customers, with an acceptable price aimed to perform predictably at high level quality. It is meant to support the employees and managers in the company to work with the business strategy to realise efficient processes that are *in control*. This will add value to the services and products that RFH delivers to her customers. The OpEx method is designed to apply to all levels of management and work floor, so it can become integrated in the entire company. As one of the sources for the OpEx framework is Lean Six Sigma, the framework is explicitly aimed at measuring performance and maturity. This is partly because it provides a quantified insight in the current state of the department, the other benefit is that it provides focus points for improvements.

The RFH OpEx framework is founded on five blocks that are present in every department and based on which performance is measured. These five blocks are strategy, control, processes, organisation and people. Within these blocks there are elements that represent aspects of that category, listed in Appendix D.3.

Every element has been divided into five levels, which represent the maturity of the process or department on the aspects of that element. Level four is the highest level. Each level has a detailed description of the deliverables that reflect the maturity, as well as a SMART definition of done (DoD). These explicit descriptions are necessary, to ensure an objective judgement of maturity.

The OpEx framework was introduced in Naaldwijk in 2019, with an initial maturity scan. This maturity scan is a yearly benchmark, meant to ascertain the status of OpEx implementation, monitor progress and ascertain the goal for the next year. This research focuses on the Control block and more specifically the KPI-element. A detailed description of the levels for that element is included in Appendix D.4. LSS and LSC reported level one, LO reported a level two maturity with regards to the KPI structure.

5.4 Key Performance Indicators

To monitor and control the cut flower process, RFH has defined several Key Performance Indicators (KPIs) that are reported on a periodical base to the different management levels, some of which are mentioned in the previous paragraph. The KPIs are categorized according to the OpEx categories of People, Safety, Quality, Delivery and Cost (PSQDC). The KPIs reported to RFH Operations Management Team, which is the management level that covers all locations, reflect on the overall performance of RFH Naaldwijk in these categories. That aggregation level is reported periodically and monitored weekly by the operational managers of the different departments in Naaldwijk. They discuss the performance and give details on possible counter or reinforcing measures. The KPIs discussed on the operational managers level pertain the overall performance of the departments, of which the cut flower process related KPIs are listed below:

Table 2: List of KPIs used on process level, adapted from internal document

PSQDC	Description	Reporting
Quality	Mistakes in packaging units	Weekly to team managers and operational managers
Quality	Mistakes made during distribution	Weekly to team managers, operational managers and department managers
Quality	Counting mistakes in path control	Weekly to team managers and operational managers
Quality	All delivery mistakes	Weekly to team managers and operational managers
Quality	Delivery damages	Weekly to team managers and operational managers
Delivery	End time of process after auctioning	Weekly to team managers, operational managers and department managers
Delivery	Throughput time auctioning	Weekly to team managers, operational managers and department managers
Delivery	Throughput time flowers dock to cold store	Weekly to team managers, operational managers and department managers
Cost	Labour cost more/less than expected	Weekly to team managers, operational managers and department managers

The KPIs that reflect process quality are all grouped in Quality, which are considered in this study. The definitions, descriptions, goals and measurement frequency of the KPIs are specified as stated in the table below. These KPIs are not considered leading for monitoring and controlling the process, as most departments focus on throughput time, on-time delivery and productivity, with an overarching focus on cost. The process quality KPIs do not immediately reflect on cost per department and therefore are not prioritized.

Table 3: Process quality related KPIs, adapted from internal document

Description	**Definition**	**Goal**	**Frequency**
Mistakes in packaging units	Number of mistakes found/ total number of mistakes registered	$\geq$ 50%	Weekly
Mistakes made during distribution	Number of faulty transactions/ total number of transactions	$\leq$ 0,15%	Weekly
Counting mistakes in path control	Number of mistakes found/ total number of mistakes registered	$\geq$ 94%	Weekly
All delivery mistakes	Number of delivery mistakes/ total number of transactions	$\leq$ 0,05%	Weekly
Delivery damages	Number of damages registered/ total number of transactions	$\leq$ 0,016%	Weekly

Although internal data provides specification of mistakes, the KPIs do not contain a way of determining the type of mistakes made. The quality KPIs as such, do not specify the exact mistake, nor do they reflect the effect of the mistakes. Secondly, the definitions are not based on the same viewpoint; The KPIs for mistakes in packaging units are expressed in the number of mistakes that are found over the total number of mistakes registered, providing a percentage of instances in which an employee did their job correctly. A similar calculation is made for the counting mistakes. The other three KPIs, however, are based on the instances an employee does not do their job correctly and makes a mistake. Furthermore, the goals of the KPIs have barely been adapted to developments or performance. For example, the goals for distribution mistakes have been set at this percentage for over fifteen years.

As the KPI-definition for the distribution process does not give specifics about the type of mistakes that are included in the calculation, this researcher has assumed that every mistake is taken into account. However, as the preliminary analysis was performed, it turned out there is a marked difference between the mistakes that originate in the process steps and the mistakes that are considered in the KPI calculation for the department reports. To underline the importance of correct and relevant KPI definitions, the researcher uses the performance based on the data as provided, comparing it with the targeted performance.

As the scope of this research focuses on the cut flower distribution, the data and performance related to the cut flowers are discussed. However, the inbound control process does not specify which category they have checked, so the inbound numbers are for potted plants and cut flowers. Additionally, the measuring method changed halfway through the year, which means there is only data till the 29th week of 2019. For the second half, the average of the first 29 weeks was used. The performance in the other two departments can be split between potted plants and cut flowers, mainly because of the metadata that comes with the customer complaints that are registered at S&C.

Some mistakes that are registered to the departments that are part of the scope, are not used in this analysis. These are not included, as the total amount of mistakes and resulting cost is small in relation to the other process steps. Additionally, the mistakes that qualify as miscellaneous are not considered, as they cannot be accounted for by a specific department or process step.

5.5 Quality performance

The KPIs are registered and processed per day, however, the information is not actively reported on a daily basis. Most performance information is reported on a weekly basis to management and the work floor through an *Obeya* structure (weekly review/preview meetings) or through digital dashboards. These digital dashboards are either built in Excel or fabricated with use of another digital tool. The mistake data as registered by S&C for 2019 is used to assess performance on these KPIs. The complete results of this assessment can be found in Appendix D.7. A short overview of most important findings is stated below.

Table 4: Process performance based on data

Description	Performance	Goal	Result
Mistakes in packaging units	47%	$\geq$ 50%	Target not reached
Mistakes made during distribution	0,22%	$\leq$ 0,15%	Target not reached
Counting mistakes in path control	73%	$\geq$ 94%	Target not reached
All delivery mistakes	0,015%	$\leq$ 0,05%	Target reached
Delivery damages	0,011%	$\leq$ 0,016%	Target reached

Logistic Service Suppliers

Inbound control received 950.934 auction trolleys, of which 7.086 with a mistake in the amount of cut flower packaging units. The employees have found 47,62% of these mistakes, which means that 3.712 auction trolleys with wrong quantities are then entered into the distribution process. Missing the mistakes made by growers, costs € 7.020,- in labor cost for searching and sums up to € 46.814,- compensation to customers.

For inbound control, it was found that the target of finding 50% of the mistakes in packaging units was only reached 11 times in the first half of 2019. As the data acquisition method changed, it is assumed that it would likely have been around 22 weeks in total.

Logistic Operations

The distribution employees should filter out the wrong quantities by counting before they start with the distribution of the products and report it immediately. The missing products are then compensated to the buyers directly, any surplus will either be returned to the grower or auctioned off the next day.

Every time an employee transfers a packaging unit to another trolley counts as a logistics transaction in the distribution process. The cut flower process contained 6.492.259 transactions in 2019, of which 14.177 were faulty. These wrong transactions are caused by an employee making a mistake, such as misplacing the packaging unit, placing too much or too little packaging units on the buyer's trolley, scanning the wrong trolley or scanning it too late, and picking a packaging unit from the wrong batch. 33,7% of mistakes in quantity or damages of a product is reported by the employees themselves, as the secondary location of S&C is close by.

The mistake is usually fixed fairly easy, by either compensating to the buyer or buffering the surplus awaiting a customer notification of a shortage. The total amount of compensation paid to customers as a result of a mistake in the distribution process, was € 142.843,- in 2019 (56,77% of total cut flower compensation). Searching for the causes or resolving batch switches cost € 88.993,88 in labor cost for S&C (87,39% of searching cost for cut flower mistakes).

The distribution of cut flowers claims to have reached its target for most of 2019. However, when analyzing the data on mistakes reported that were found to originate in the distribution process, it turned out that the department had no weeks it reached the KPI target. The difference in performance according to the department and the performance according to the data, lies in the type of mistakes that are considered in the calculations. Damages as a result of the distributors' activities are not included as a mistake, as it is generally assumed that, if the employee gets a negative note for causing damage, they will be less likely to come forward with it. Not notifying the S&C department of the damage, would mean the customer receives damaged items, which is not preferable. Other mistakes that are not considered, are information linking errors, possibly because of the relatively small percentage of occurrence, but as the performance calculations were copied from past reporting software, the original argumentation has been lost.

Every trolley is checked in the next process step: path control, 56,12% of the mistakes that end up in the path are found, 20,24% is missed. The other 23,64% of mistakes that pass are of a kind that a path-checker does not check on. The employee would need more information and time for a thorough check to be able to catch those mistakes. An under-performance was found for path-check, where they did not manage to reach their target of finding 94% of mistakes made by distribution employees.

Logistic Service Customers
In 2019, 1.693.433 auction trolleys were delivered to customers in the building of RFH Naaldwijk. 952 of these were delivered at the wrong location (23%) or delivered with damage (72%), with a small percentage of trolleys that had a miscellaneous mistake. Searching for the cause of the mistakes cost € 5.823,- in labor cost and resulted in € 61.952,- paid to customers as compensation. Delivery happens with trains of up to 20 trolleys. Each trolley can hold anywhere between one and thirty transactions. The delivery target is to have a minimum of 0.05% mistakes made in relation to the total amount of transactions that take place in the distribution process.

This department also claims to have scored below the target in 2019. However, as a delivery mistake is one or more wrongly delivered auction trolleys, this KPI gives a skewered visual of the performance of the delivery team. One delivery mistake or damage can affect multiple transactions on the auction trolleys, but it is not registered to reflect the ratio of transactions to a transport unit. A more realistic calculation is the amount of mistakes divided by the total number of deliveries, but that data was not available. The next best calculation is the dividing mistakes by the total number of delivered trolleys. If the latter calculation is used, the target is not reached on both accounts as visible in Table 5.

Table 5: LSC performance different calculation

Description	**Performance**	**Goal**	**Result**
All delivery mistakes (transactions)	0,015%	$\leq$ 0,05%	Target reached
Delivery damages (transactions)	0,011%	$\leq$ 0,016%	Target reached
All delivery mistakes (trolleys)	0,056%	$\leq$ 0,05%	Target not reached
Delivery damages (trolleys)	0,041%	$\leq$ 0,016%	Target not reached

The targets are not reached with an exceedance of 0,006% for the overall mistakes and 0,030% of the damages during delivery. While the absolute numbers are not large in the entire picture of delivered trolleys, the difference in percentages does reflect on the internal monitoring system. The calculation of performance for the LSC department does not give a fair or realistic reflection of the actual process. Curiously, both Naaldwijk and Aalsmeer use this definition for the department, both reaching target every periodic review.

5.6 Cost of poor quality

For the total amount of transactions that took place in 2019, the mistakes that originate in the cut flower process added up to 0,29% (18.766). Of these registrations, over two-thirds is found and solved internally, leaving 33,25% of the registered mistakes to be reported by customers. Overall, this means the transactions have a close to perfect performance to the customers (99,92%).

Solving mistakes takes up time and effort, which contribute to the cost of poor quality (COPQ) in addition to the financial compensation to the customer. For this case, there are two categories of COPQ that are applicable: internal failure cost and external failure cost. The former is the sum of costs associated with defects that are found and solved before the customer receives the order. The latter is the sum of costs that result from a customer encountering a mistake [75].

When translating the performance to cost, the mistakes that have been assigned to the departments and process steps are used as cost driver. The duration of the search and resolution of these mistakes can be extracted from the data source. In addition to that, the financial compensation that was provided to buyers, is fined on the department where the mistake or damage was caused. The fines which were received for the year 2019, where € 46.814,- for LSS, € 142.843,- for LO and € 61.952,- for LSC. The cost for searching, solving and concluding the mistakes, based on the average hourly rate of a searcher, was € 7.020,- for LSS, € 88.993,- for LO and € 5.823,- for LSC. For clarity, these numbers are listed in the table below.

Table 6: Cost per department in 2019

Department	**Compensation**	**Labour cost**	**Total**
LSS	€ 46.814,31	€ 7.020,56	€ 53.834,87
LO	€ 142.843,86	€ 88.993,88	€ 231.837,74
LSC	€ 61.952,70	€ 5.823,47	€ 67.776,7
	€ 251.610,87	**€ 101.837,91**	**€ 353.448,78**

The total cost that has been compensated to buyers of products that ended up damaged or missing in 2019, is € 981.240,-, of which the cut flower process contributed 46, 4% with € 455.406,-. It should be noted that 41,63% of mistakes that the S&C is notified of, is not traced back to an origin and the cost of compensation is fined to the S&C itself. Without that number, the total compensation cost for the cut flower process is € 251.610,-, of which the distribution was fined 56,8%, inbound control contributed for 18,6% and delivery took 24,6%. As the compensation is fined to an entire department, or area in case of delivery compensations, it is nigh impossible to retrace exactly what caused the S&C department to compensate the customer.

Damaged and missing products are compensated most frequently, so the fines are entirely designated to these causes and booked once a week.

5.7 Conclusion

This chapter answered sub-questions five and six, explaining what the current situation concerning process control is at RFH Naaldwijk and how the company performs at its own KPIs.

In the current situation, there is some kind of system that is used to monitor and control the process. It is based on the OpEx strategy that succeeded the initial improvement programs. This strategy contains a maturity scan, and it has been executed for the different departments on the current situation (2020).

The OpEx maturity for Naaldwijk, specifically the state of KPIs, was determined at level one for LSS and LSC, and level two for LO. This maturity state reflects on the manner of documentation, control and monitoring that takes place in the different departments. This is the framework, not the actual performance, so the levels can be seen separately from the reported and calculated performance.

The leading key performance indicators are focused on throughput time, on-time delivery, productivity and all over cost. KPIs pertaining process quality and faultless process steps, are reported, but not considered important. These KPIs are the percentage faulty trolleys missed at inbound control, the percentage of mistakes caused in the distribution process, the mistakes that are missed by path control, all delivery mistakes and delivery damages.

Performance on the process quality KPIs does not reach target for three of the KPIs (one for LSS and two for LO), while it does for the two KPIs for LSC. However, as the latter calculates the KPI performance over amount of transactions, the score does not reflect the process that handles entire auction trolleys in trains. The LO department semi-consciously excludes certain mistakes from its calculations, which explains the difference in their claimed performance in 2019 and the performance calculated from the data.

The fact that process quality KPIs are considered less important and do not reflect on the departments financially, leads to a decreased focus on motivating employees to reach targets. LO reports some of its performance back to the employees, the other departments do not. All internal mistakes are preventable, as they are the result of human error.

To further decrease the mistakes that end up at the customer, the path-check work sequence should theoretically prevent the mistakes in quantity from slipping through. Most of these are caught, as the relatively low cost per mistake reflects the short time S&C employees spend on solving the problem.

As cost is an important performance driver for RFH, the process quality can be translated into direct and indirect costs per department. The fined amounts are direct cost, as they are claimed on the account number of the department, while the labour cost of searching is an indirect cost as it is paid by S&C. It turns out that all three departments have considerable monetary impact on the cost of RFH Naaldwijk, both through labour and compensation cost. LO, as the largest and as the department responsible for most human activities, is the biggest contributor both in direct and indirect costs.

6 Final framework

As the LO distribution process is the source for most internal mistakes, it serves as the key process for which the framework will be fitted. This chapter describes the application of the preliminary framework with use of the steps introduced in chapter 4. The sub-paragraphs all cover one step, after which the final design with case specific elements is presented.

1. Analysis of objectives (6.1);
2. Development of reference processes (6.2);
3. Determination of relevant (K)PIs (6.3);
4. Detailed breakdown of critical process steps and (K)PIs (6.4).

6.1 Case-related objectives

The first step in applying the framework is determining the objectives that govern the process in the scope. Chapter 5 describes the context and general circumstances of the distribution of cut flowers, the future developments and their effect on that process is explored below.

Ambitions of RFH are to become a Cross Chain Collaboration Center (4C) for the global floriculture trade, directing the digital auctions and financial transactions for all international stakeholders [38]. The need for expanding beyond a physical auction platform, is reflected by the negative trend of products sold through auction, 61% of all trolleys in 2019, already lowered to 57% in 2020 [98, 99]. To achieve the expansion, as well as a successful adaption of the new logistics concept of picking instead of distributing, the internal process should be *in control* and prepared for the shift from push to pull operated flow.

The OpEx maturity scan on KPIs for Naaldwijk in 2020 detailed that, for the cut flower related processes and department, the overall average was level one. Only the distribution process claimed to have level two KPI-maturity, however the case study provided some missing links in the current KPIs. Especially the clear connection between team and department goals was found missing. The (K)PI description should be linked to the quality, delivery or cost drivers and have a structural control on the results. An objective that is included in functional requirement number 3: (K)PIs must be linked hierarchically. This requires KPIs to be based on critical processes, while being balanced by process and output performance indicators (functional requirement 2). The (K)PIs have to be based on the earlier mentioned PSQDC drivers. Every employee should know and understand the (K)PIs, and the managers should review the performance on a daily basis. Both of which are stated in non-functional requirements 1 and 4, in paragraph 4.2.

Since the introduction of voice picking, the distribution process has made steps towards poka-yoke, but the consistent occurrence of mistakes proves the process is not entirely error-proof. Counting before starting with distribution has a lot of room for an employee to not execute the proper checking procedure or make a mistake while executing it. Either altering the procedure or reinforcing the importance of 'perfect' trolleys would be the Lean answer to these issues. The process does allow for employees to act when they find a mistake (either one caused by previous processing or caused by themselves). A distribution employee can step out of the process with the faulty trolley to notify the close-by S&C employee.

In addition to these objectives, the system should provide insight in cost as a result of control and improvements in the process (FR 4). Cost is an important driver for management of RFH, indicating that results from another (K)PI will be felt more stringent if there is a cost coupled to it. Furthermore, the system should be applicable to other departments, even if it requires some adaptations. These adaptations can be made with use of the steps followed in this chapter.

6.2 Reference process

The distribution of cut flowers consists of several steps that are executed by employees. These steps have been detailed in chapter 5 and can be summarized in: Retrieving the trolley, counting the products and/or packages, transport to the paths with empty trolleys, transferring the packages to the empty trolley and linking the products to it digitally. As chapter 5 states, this process is responsible for the largest part of the total amount of mistakes and related cost, and thus the main reason for the existence of S&C and the second control point. It is also the most complex process for mistakes to originate, as there are seven mistakes that can be traced back to it. The mistake codes that are registered in the software and serve as input for the data analysis are listed in Table 8.

Table 7: LO Distribution mistake types

Code	**Translation**
1. NUMMERFOUT	Trolley mistake
2. RUILFOUT	Batch mistake
3. SCHADE	Damage
4. AANTAL FOUT	Quantity mistake
5. INF KOPPELF	Information link mistake
6. TE LATE OK	Late OK
7. KOPF G SCAN	Linking mistake

The first one : trolley mistake (1), it describes the mistake of putting a packaging unit with flowers on the wrong trolley, usually one next to the designated auction trolley and completing the transaction in Voice for the wrong trolley. 2) Batch mistake, this means two (or more) batches have been switched on the trolley. The buyer receives the correct species of cut flower, but not the right colour or stem length. 3) Damage means one or more damaged products. When this is appointed to the distribution, it is mostly the result of a fall. 4) Quantity mistake, this code is attributed when the distributor places too much or too little packaging units on an auction trolley. The buyer will then receive less or more than they bought. 5) Information link mistake, it means the distributor placed the products on one trolley, but linked the product to another. 6) Late OK, a link to the auction trolley that is confirmed after the path-checker printed the receipt. Usually the path-checker reports this and the receipt can be reprinted after adaption. 7) Linking mistake, happens when the product is placed on the right auction trolley, but the distributor omitted to link it (to any trolley). Mistakes 1, 3, 4, 5, 6 and 7 are visible for the path-checker, thus these should be filtered out before they reach the buyers.

The general cause of these mistakes is the pressure on productivity and speed in the distribution process. Throughput time and productivity (expressed in a weighted percentage of transactions per hour) are the primary performance indicators on which the distribution process is managed. Distribution employees will receive feedback on their productivity only when it dips below the required rate, feedback on mistakes is only provided when they make too much of them or during periodical assessment.

Due to the focus on productivity, employees sometimes omit to check and count the quantity on the trolley as they transfer it from the after auction buffer. In that case, a wrong quantity of packaging units can slip through their initial check, thus resulting in a surplus after the employee finishes distribution or shortage in the final transaction. Regardless of counting before distributing the products, miscounting and placing more or less than the required quantity on the buyers' auction trolley will result in a surplus or shortage. Additionally, when an auction trolley contains more than one product batch of unequal quantities, the employee could switch batches and then encounter a surplus or shortage.

6.3 Relevant key performance indicators and dimensions

Determining relevant performance indicators and dimensions, starts with calculating the performance on the proposed KPIs (FTR, SQL and COPQ) and analysing whether these indicators actually reflect on the performance of the process.

6.3.1 First time right

The level of first time right transactions is calculated by subtracting the number of registered mistakes from the total number of transactions, and dividing that number through the total amount of transactions. As the framework facilitates both the average FTR in a week and the number of days the target was reached, these are calculated to determine the current performance. For brevity's sake, only the FTR index for the year 2019 and the number of days the target was reached is given. An overview of the performance in 2019 per week, is included in Appendix D.8.

On average, the FTR index was 99,78%, which means that over 2019, the average percentage of perfect transactions was below the target of 99,85%. When looking at the days the department achieved the target, the performance appears to be quite low: 16 days out of 253. This leaves 237 days during which the LO distribution employees made more mistakes than they should.

Basing judgement only on the first KPI (FTR index) could provide a false impression of stability and high performance, leading to the assumption that the process is in control and marginal improvements are needed to reach target. Combining the first with the second KPI (FTR target reached), brings the instability of the performance to the attention of the responsible managers. Instability and not reaching a target, are symptoms of a process that is not (statistically) *in control*, thus requiring attention and improvements. To acquire information about the stability of the process, it is important to include KPIs that expose all aspects of the process, not only the final output.

6.3.2 Sigma Quality Level

An SPC tool commonly used in Six Sigma methodology, is the np-chart for nonconforming units to determine whether the process is in control [32]. The chart uses the average of transactions and mistakes per week in 2019 for lower and upper control limits, visible in Figure 7, exact calculations can be found in Appendix D.9. As the absolute number of mistakes is related to the number of transactions, they have been normalized into DPMO per week, which can be compared to set control levels. The process of distributing cut flowers has been described in paragraph 5.2, presents two opportunities for a mistake per packaging unit: during transport from buffer to distribution paths and when executing the transaction (placing the unit on another auction trolley).

However, not every mistake is possible during both opportunities. Damage can occur in both, other mistakes are primarily made in the second opportunity, as they concern faulty transactions. The DPMO is therefore calculated with a single opportunity for defects/mistakes. Note that, as the np-chart uses the control levels that have been calculated with the mean and variability of the results (averaging at 0,22% faulty transactions), the chart does not reflect the process capability of performing within specification levels of 0,15%.

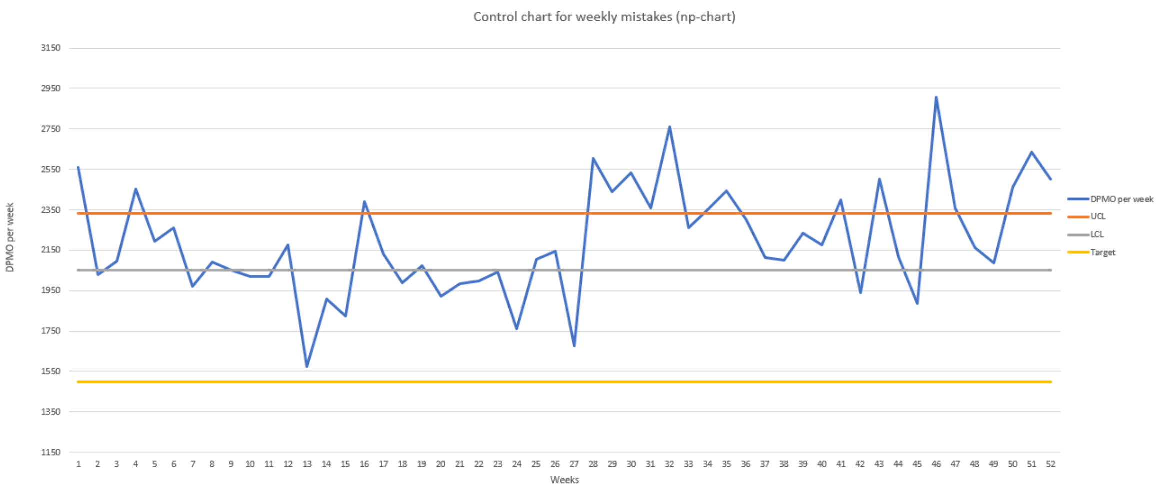


Figure 7: Control chart (np-chart) for the distribution process

The orange and gray lines depict, respectively, the upper and lower control limits, based on the DPMO data in 2019. The chart clearly shows that the process knows a variance that lies beyond the control limits, as both the upper and the lower levels are exceeded more than once. This is interpreted as a lack of statistical control of the process, as one of the goals of six sigma is to minimize variance. The yellow line represents the current target in DPMO, which is not reached over the 52 weeks that are included in 2019.

Table 8: LO Distribution mistakes in 2019

Code	Total	Percentage	Code	Total	Percentage	DPMO (σ quality level)
1. Trolley mistake	973	6,9%	5. Information link mistake	965	6,8%	
2. Batch mistake	3366	23,9%	6. Late OK	117	0,8%	
3. Damage	1257	8,9%	7. Linking mistake	24	0,2%	
4. Quantity mistake	7406	52,5%				2183,3 (4,4)

Table 8 shows the types of mistakes and their occurrence in 2019, as well as the overall DPMO and the short-term Six Sigma level. The DPMO is calculated by dividing the total amount of mistakes by the transactions multiplied by the amount of opportunities (1), after which the result is multiplied by one million [75]. The DPMO converts to a sigma level of 4,4 for the current process, calculated with the inverted normal distribution + 1.5.

With more than half of the mistakes a quantity mistake, it implies that distributors either are too hasty in their transaction and do not count properly when transferring products to the different auction trolleys. The second most occurring mistake, the batch switch, could be the result of inattention from the distributor. The more experienced distribution employees are appointed the auction trolleys with more than one batch, because it is assumed their experience will limit the amount of mistakes. However, as the data clearly proves, it is still difficult to always grab the product from the right batch. The other five mistakes are not as frequent as the previously mentioned ones. Most of these are spotted, either by the distributor or the path-checker, as they finalize the transactions and print the receipt.

It is assumed the number of mistakes is greater than the number of mistakes registered, but not all buyer check their goods thoroughly, hence missing a surplus or a shortage when the trolley is delivered to their RFH location. If an error is discovered after a certain time or after departing from the auction location, it will not be registered, as it is no longer RFH's responsibility to solve. RFH Naaldwijk limits this reaction time window to a maximum of three hours after the end of the distribution process. However, this sometimes results in a customer that has a shortage of a product, while another customer with a surplus of the same product has already left. S&C is then unable to solve the shortage and will compensate the missed products to the customer.

6.3.3 Cost of poor quality

Labour cost for solving mistakes made in LO can be categorized to fit the different mistakes, as it is the result of the registered time a searcher or solver has spent on the notification in the software. In the data analysis, the total labour costs are split in different mistakes and their contributions, visible in the table below.

Table 9: Specified cost for LO 2019

Mistakes	Number		Labour cost		€/mistake
Trolley mistake	974	6,9%	€ 2.909,47	3,3%	€ 2,99
Batch mistake	3.380	23,8%	€ 42.713,12	48,0%	€ 12,64
Damage	1.262	8,9%	€ 2.857,39	3,2%	€ 2,26
Quantity mistake	7.443	52,5%	€ 37.394,17	42,0%	€ 5,02
Information link mistake	977	6,9%	€ 2.891,11	3,2%	€ 2,96
Late OK	117	0,8%	€ 51,97	0,1%	€ 0,44
Linking mistake	24	0,2%	€ 176,66	0,2%	€ 7,36
Total	**14.177**		**€ 88.993,88**		**€ 87,79**

Table 9 shows that, while the batch switch might only occur for 23% of the time, it does take up nearly half of the S&C labour cost for the distribution steps. These mistakes are mostly found and reported by buyers, which means the searcher has to find out where the original batch is and switch them out between buyers. This takes a lot of time, as the buyers' areas are not physically close to each other in the building. Following the batch mistake, the most frequent mistake is a mistake in quantity (placing too much or to little on the buyers' trolley), which occurs 52,5% of total mistakes for LO and costs around € 5,- per mistake to find the source.

6.4 Critical process steps and detailed PIs

The key performance indicators determined in the previous step, reflect the performance of the critical process. This process is made up of a sequence of critical process steps, visualized in Figure 8. After depositing the empty trolley, the employee moves back to the buffer to pick up a new trolley, until all trolleys have been distributed.

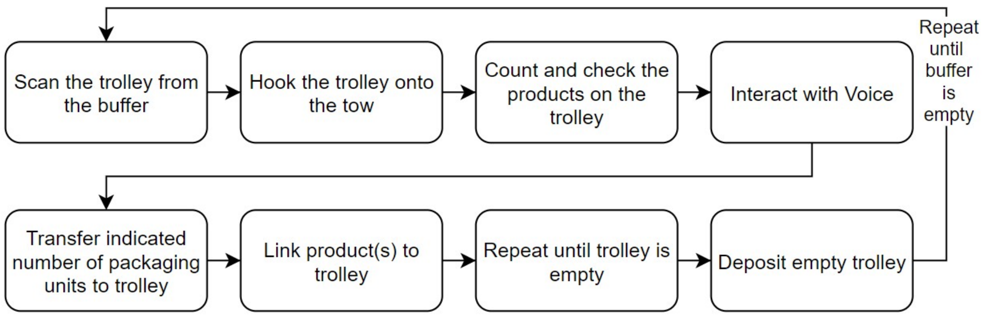


Figure 8: Detailed description of critical process steps

Most mistakes happen during the transfer of packaging units from the growers' trolley to the buyers' trolley, as this is the actual transaction. Damages however, can happen at any time throughout the process, and mistakes in relation to software only happen during the step in which the distribution employee links the products to the trolley. A mistake in on-time delivery can occur at any moment in the process, but is only noticed as the customer receives the products.

The first time right performance and the sigma quality level of the process is determined by the amount of mistakes made. The impact of these mistakes differs, both on the first time right index and on the eventual cost of poor quality. The difference is caused by the timing of catching the mistakes: internally caught mistakes are solved with less effort and do not impact customer satisfaction.

To describe the performance in the KPI FTR, there should be PIs that reflect the number of mistakes, the different type of mistakes for distinguishing internal and external effects, and output of the process. These PIs are also input for the sigma quality level KPI and function as an element of the calculation of the COPQ PI. The table below contains KPI definitions following the adapted list from Van der Vorst et al [124].

Table 10: Specified performance indicators for FTR and SQL

(K)PI	Name	Objective	Equation
Weekly KPI	First Time Right target reached	Indicates how many days per week the process performs within limits	$D_1 + D_2 + D_3 + D_4 + D_5$ (where D_x is 1 if target is reached)
Weekly KPI	First Time Right index	Indicates the average FTR index for the process	$FTR_1 + FTR_2 + FTR_3 + FTR_4 + FTR_5$ / Number of auction days (where FTR_x is the daily FTR index)
Weekly KPI	Sigma Quality level	Indicates the SQL for the process	$(1,5 + (invnormcdf(FTR_{index}))$ (where FTR_{index} is the weekly FTR index)
Daily KPI	First Time Right index	Indicates the daily FTR index for the process	(Total number of transactions - total number of mistakes)/ Total number of transactions
Daily PI	Quantity mistakes per million opportunities	Reports on the daily DPMO for quantity mistakes	(Number of quantity mistakes / Total number of transactions) x one million
Daily PI	Batch mistakes per million opportunities	Reports on the daily DPMO for batch mistakes	(Number of batch mistakes / Total number of transactions) x one million
Daily PI	Damages per million opportunities	Reports on the daily DPMO for damages	(Number of damages / Total number of transactions) x one million
Daily PI	Trolley mistakes per million opportunities	Reports on the daily DPMO for trolley mistakes	(Number of trolley mistakes / Total number of transactions) x one million
Daily PI	Information link mistakes per million opportunities	Reports on the daily DPMO for information link mistakes	(Number of information link mistakes / Total number of transactions) x one million
Daily PI	Delivery time mistakes per million opportunities	Reports on the daily DPMO for delivery time mistakes	(Number of late transactions / Total number of transactions) x one million
Daily PI	Other mistakes per million opportunities	Reports on the daily DPMO for other mistakes	(Number of other mistakes / Total number of transactions) x one million

The cost of poor quality is calculated with use of internal and external COPQ PIs. The result of these PIs is an approximation of the labour and compensation cost for mistakes that employees find and mistakes that are reported by the customer.

The hourly rate of an average S&C employee is multiplied with the sum of the search time for the internally found mistakes for the internal COPQ and the search time for mistakes that end up at the customer for external COPQ. To both values, the respective compensated cost is also added, resulting in the total sum of labour and compensation cost for internally and externally found mistakes.

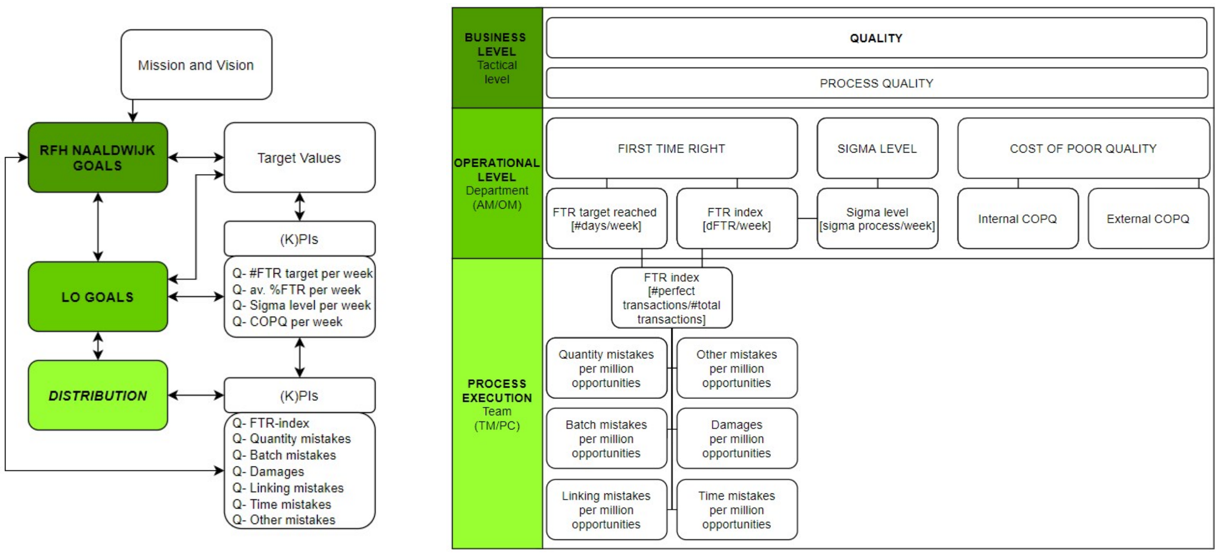
Table 11: Specified performance indicators for COPQ

(K)PI	Name	Objective	Equation
Weekly PI	Internal Cost of Poor Quality	Indicates the monetary results of internally caught mistakes	Search time internally found mistakes x € 26 + compensation cost
Weekly PI	External Cost of Poor Quality	Indicates the monetary results of externally caught mistakes	Search time externally found mistakes x € 26 + compensation cost

While the (K)PIs have been defined, some elements from the original table are missing, such as source, responsible party and drivers [124]. These elements will be specified once the framework is implemented and a pilot run has started, as the practical feasibility of the model is tested partially by determining availability of data.

6.5 Final design

Taking the process configuration into account, as well as the focus on LO, and combining that with the initial GPI-RFH adaption, results in the second iteration of the concept, visualized in Figure 9, and in Appendix E.



(a) GPI-RFH

(b) Detailed (K)PIs

Figure 9: The final design for RFH

The final framework includes the (K)PIs as they have been detailed in Tables 10 and 11. The key performance indicators FTR, SQL and COPQ function as higher level indicators on the operational manager (OM)/department manager (AM) level. These KPIs are used to monitor the quality performance per week. The OM uses the results to track changes, monitor the trends and activate the team managers to initiate improvements when the trend is a negative one. With help of the daily (K)PIs, team managers should be able to locate and isolate the cause of a negative trend, providing a concise area where an improvement is necessary.

The daily (K)PIs also serve as a way to inform the process coordinator and employees about the performance of the process. Informed employees take responsibility for the process and, especially with daily feedback, will be encouraged to improve their personal performance [102].

It is especially important to maintain the hierarchy in the KPI and PI links, as they reflect the circle of influence of the level that is tasked with monitoring and controlling the process for those specific performances or output. Secondly, the financial PIs are kept away from the daily process execution, to prevent focus on the output instead of the process aspects.

The final framework is a system of formulas with input and output. The system is a mathematical reflection of the (K)PIs that are included in Figure 9, of which Appendix G contains the extended formulation. The system encompasses the KPIs and PIs which indicate performance of the distribution process, the manner in which they interconnect and the main influencing factors that function as input. The underlying connections are visualized in Figure 10 (Appendix F) and explained beneath it.

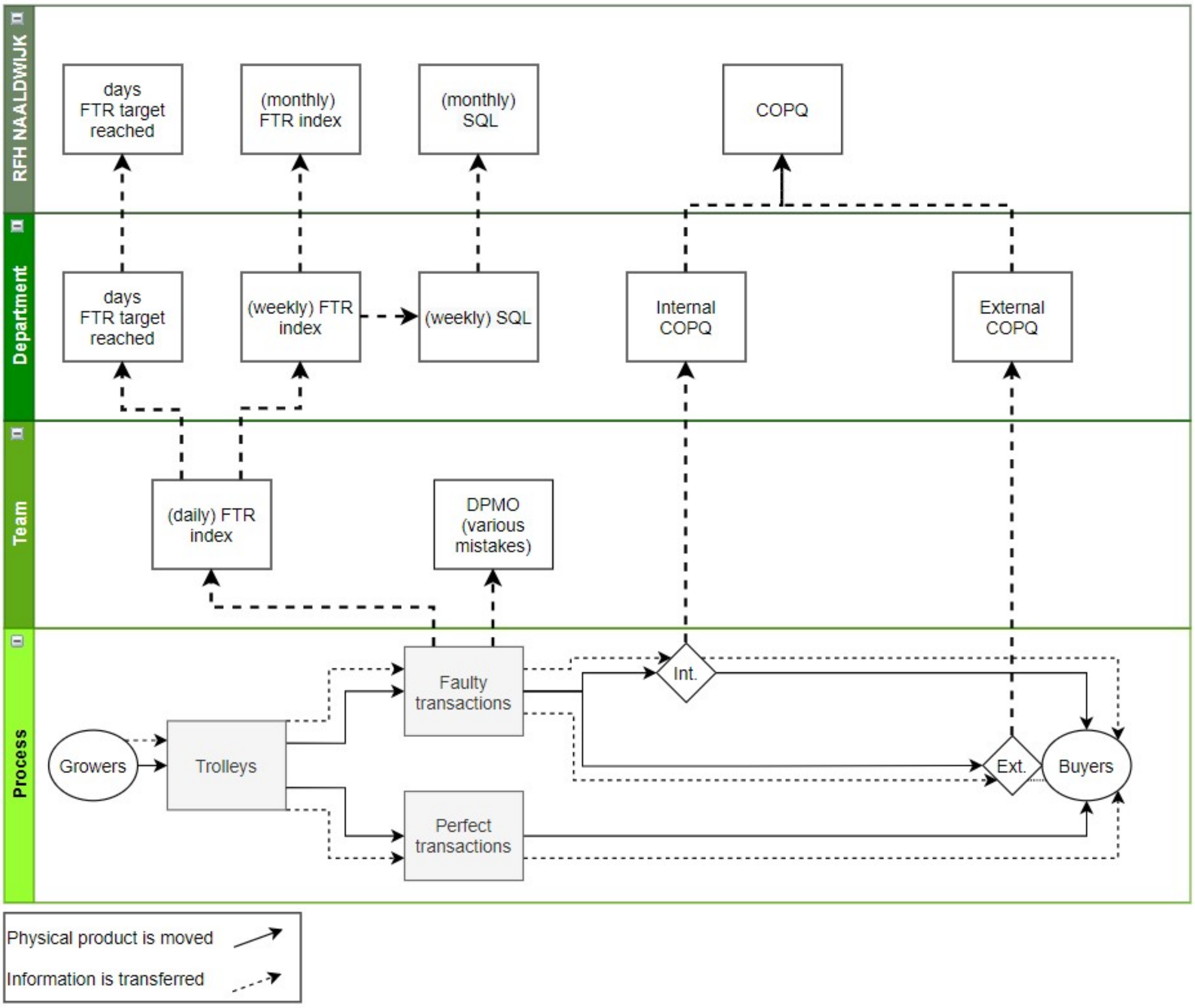


Figure 10: Swimlane overview of the system

The process input is pictured on the left, the distribution is visualized in the lower lane. The trolleys entering the process result in faulty and perfect transactions, which are then delivered to the buyer. The input of the system is defined as auction trolleys, which have the characteristics of batches per trolley and expected resulting transactions. The actual number of trolleys and the specifics of the characteristics are only known after the process has started, so the input used for these calculations is the forecast from the previous year. Of the faulty transactions, a number is caught internally, either by the distribution employee or the path checker, the rest ends up being reported by the buyer.

Faulty transactions are the source for the FTR index and the DPMO for specific mistakes. The DPMO PI is for internal monitoring and control, and is not reported to the department level, they are all monitored with use of an np-chart, after being normalized to DPMO. The FTR index is reported and used as input for the FTR KPIs, as the connections visualize, while simultaneously providing information on the control of the process.

KPI average FTR index per week:

$$\mu FTR_w = \frac{\sum_{d=1}^{5} FTR_{wd}}{d_1 + d_2 + d_3 + d_4 + d_5} \qquad (\forall w \in W)$$

KPI FTR target reached per week:

$$T_{FTR_w} = \sum_{d=1}^{5} T_{FTR_{wd}} \qquad (\forall w \in W)$$

KPI SQL per week:

$$SQL_w = 1,5 + (invnormcdf(FTR_w) \qquad (\forall w \in W)$$

For the mistakes that originate in the process, which are found either by employees or customers, the line is directly linked to the COPQ as there is no level of reporting in between. As the compensation is transferred on a weekly basis, it cannot be used to monitor the daily process performance. The indirect cost, the labour cost for search time, it is the output of another team, which is also reported weekly.

PI Internal COPQ per week:

$$COPQ_{wi} = (\sum_{i=1}^{6} ST_{wi} * 26) + (\sum_{i=1}^{6} C_{wi}) \qquad (\forall w \in W, \forall d \in D)$$

PI External COPQ per week:

$$COPQ_{we} = (\sum_{e=1}^{6} ST_{we} * 26) + (\sum_{e=1}^{6} C_{we}) \qquad (\forall w \in W, \forall d \in D)$$

6.6 Conclusion

The sub-questions that are answered in this chapter are:

7. Which factors influence process quality?
8. How should the designed system be adapted for Royal FloraHolland?

The factors that influence process quality for the distribution of cut flowers, are seven mistakes made in the distribution process and whether the transactions are delivered on time. The cause is not defined in this research, but generally assumed to originate in human behaviour. The mistakes are either found by the distribution employee, the path-checker or the customer, after which they are reported to the Search and Correction team. Although the cost of these mistakes does not influence the process quality, it is included as the result of poor quality, of at most € 12,64 per batch mistake.

The proposed framework is adapted through four design steps that have been extracted from literature and best practices in the automotive industry. The steps include the analysis of the department's objectives, mapping the reference processes, determining relevant indicators and detailing the critical process steps with accompanying indicators.

The resulting system includes all functional and non-functional requirements stated in chapter 4, as well as the objectives found in the first step. This ensures the applicability of the system on the case study.

In short, complying with both the theoretical requirements and the practical objectives, produced a layered framework, in which the indicators have a hierarchical link to each other and the process. The hierarchy forces the indicator to report on those aspects that can be influenced from that particular level. Furthermore, the system calculates its values with use of formulas that normalize the input, which results in values that reflect the process capability and thus function as information for monitoring and control. The latter two are further facilitated in the daily and weekly feedback loops that are integrated in the framework.

7 Results

This chapter describes the practical application of the final framework on the data that is available from the case study. It answers the sub-question pertaining the effect of the designed system on the process and performance of LO in its current and future state. Where the initial analysis in chapter 5 provided insights in the current performance based on the basic elements of the framework, this chapter presents the performance of the model as it is used for calculations.

After verifying that the model works correctly, it is validated. The qualitative validation focuses on the managerial aspects of the framework, resulting in a conclusion on the rightness of fit. To determine the feasibility of the system, the data sources are analyzed for ability to provide required data, and the current management structure is assessed.

The quantitative validation is done through an analysis of fit for the proposed performance measurement system, by assessing the relative influence of the input and process variables on the proposed (K)PI calculations. Ultimately, short term fluctuations in input should not affect the KPI results, while the opposite is true for the financial PIs. Using the right process variables should be able to provide insight to the how well the process is executed, which means there should be a direct link to the indicator calculations.

Finally, the model is used to predict the impact of the framework after initial implementation and after a longer period of time.

7.1 Verification

To determine whether the model is correct, the equations are ran with the data acquired from 2019. If the results fall within 10% of the originally calculated results in paragraphs 5.6 and 6.3, the model is considered accurate enough to use [127]. As the initial parameters are based on the performance in that year, the KPI values for FTR and SQL do not differ from each other. Both remain respectively 16 days, 99,78% and 4,4.

The cost of poor quality calculated in paragraph 5.6, adds up to € 231.837,-. The combined COPQ for internally and externally found mistakes as calculated through the model is € 207.787,-. The difference lies in the averages that are used to determine the compensation per type of mistake. However, as the prices at which the products are sold, will also vary, the 10% difference is acceptable.

As the results all stay within the limits of acceptable differentiation, the calculations in the model work and can be used to estimate the effect of the framework.

7.2 Quantitative validation

The previous paragraph determined that the model works, however, for the correctly calculated results to be useful to estimate the effect on this particular process, the model needs to be validated.

As the framework, its levels, and the feedback frequency fit the current performance management methods, its managerial aspects are considered to be the right ones for this particular case study. The data that is required to calculate the (K)PI values is accessible, even as it is not reported detailed enough as of yet. With the proposed performance measurement system, the specification of data will receive a boost. Due to the increased focus of RFH Naaldwijk on the OpEx framework, of which the level requirements have been included in the objectives in chapter 6, the framework fits the ambition to move towards a higher level maturity for process management with KPIs. Therefore, the system is considered the right one, based on its context.

In order to determine whether the proposed indicators are useful throughout variation in variables, the correlation between process factors and mistakes was analyzed. For the variables that are included in the calculations of the (K)PIs, there should be correlation with the mistakes, which the formula should translate to a value that reflects on the process capabilities. Since, to facilitate changes in the process, either due to alterations in the configuration of the process or the input, and still aid the monitoring and control of it, the framework should not be sensitive to input variation. However, the framework should react to process variable changes, as these fall within the circle of influence for improvements and optimizations, which should be reflected in process capability.

The input and process variables are listed below:

- (Expected) Transactions (input)
- Batches per trolley (input)
- Number of employees in the process (process variable)
- (Expected) Productivity (process variable)

The transactions vary per day and are assumed to influence the mistakes directly, as more transactions leave more opportunities for mistakes. The number of batches per trolley as input variable, reflects the level of difficulty of handling the transactions for the employee, as it requires more alertness on what packaging unit from which batch to grab for transfer. The number of employees that work in the process is determined on the expected number of transactions. More employees in the area could influence the mistakes made, as peer pressure and relative chaos increases.

Productivity is the result of dividing the number of transactions by the number of hours worked, reflecting the speed of an individual in transactions per hour. A higher speed would imply more pressure on quick execution and thus more mistakes. This variable is one that can be influenced by employees in the process, so a relation between it and the mistakes would highlight an area for improvement. The next sections highlight these expected relations and analyze whether they are statistically present, for the sum of all mistakes, quantity mistakes, batch mistakes, damages and time mistakes. The specific mistakes are selected, because together the quantity- and batch mistakes, and damages make up more than 50% of all mistakes in LO. Additionally, time is introduced as a mistake for this model, to fit the late deliveries within the same parameters.

The assumed cause of most mistakes is human behavior such as inattention or counting discrepancies. To ascertain whether this human behavior is influenced by process factors such as an increase in transactions or a shortage/surplus of employees in the process, the data was analyzed. An ANOVA (Analysis Of VAriance) has been applied to determine the statistical correlation and its level between the listed process factors.

7.2.1 All mistakes

To acquire insight in the general context of mistakes, the variation of total amount of mistakes is compared to the variation of all listed aspects. The results of this initial analysis are used to base the estimations for expected results of analysis of correlations for specific mistakes.

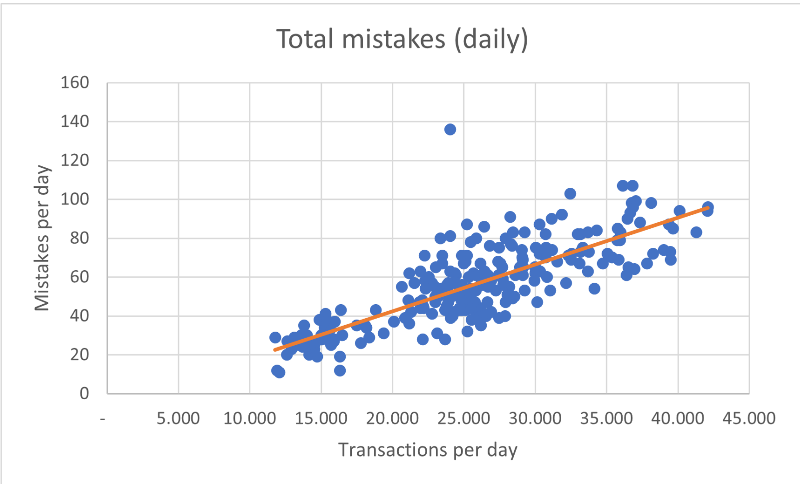


Figure 11: Scatter plot depicting the correlation between transactions and mistakes

Transactions and mistakes

First, the correlation between the variance in transactions and mistakes is analyzed. One would expect the amount of mistakes to correlate strongly with the amount of transactions, thus more transactions would lead to more mistakes. Analysis results in the conclusion that there is indeed a strong positive correlation ($r(251)=0.81$, $p<0.0001$) between the transactions and mistakes. This supports the legitimacy of using the normalized DMPO of mistakes as an indicator on process quality, as the opportunities (transactions) do not vary in the DPMO scale. The latter contributes to determining whether the fluctuations fall within acceptable variation limits. A visualization of the correlation is presented in Figure 11, the single outlier is of unknown source. A similar occurrence is visible in Figures 12 and 13. It happened on a Tuesday in November, a day with a relatively normal count of transactions and no reported system malfunction.

Batches per trolley and mistakes
The level of difficulty of a trolley, or the required alertness on picking the right packaging unit, is reflected by the number of batches per trolley. The result of the statistical analysis underlines that this input variable cannot be used to predict the total number of mistakes, as it produced a significantly weak negative correlation (r(251)=-0,26, p<0,0001). This can be explained by the practice of only letting experienced employees handle trolleys with more than one batch on it, even as it does not match the initial expectations.

Employees and mistakes
The second process factor is the amount of employees working to distribute the cut flowers. There are two ways to quantify this: either by effective number of employees or by the amount of labour hours that have been deployed. It is expected that there is a positive relation between the amount of hours and the amount of mistakes, as more employees make more mistakes if the relative mistake per employee remains the same.

Between the amount of hours and the amount of mistakes, there is a strong positive correlation (r(251)=0,81, p<0,0001). The amount of employees and amount of mistakes also displays a strong positive correlation (r(251)=0,73, p<0,0001). However, the average number of mistakes per employee and the number of transactions show moderate positive correlation (r(251)=0,58, p<0,0001), suggesting that there is some form of influence, but it is not very apparent as depicted in Figure 12.

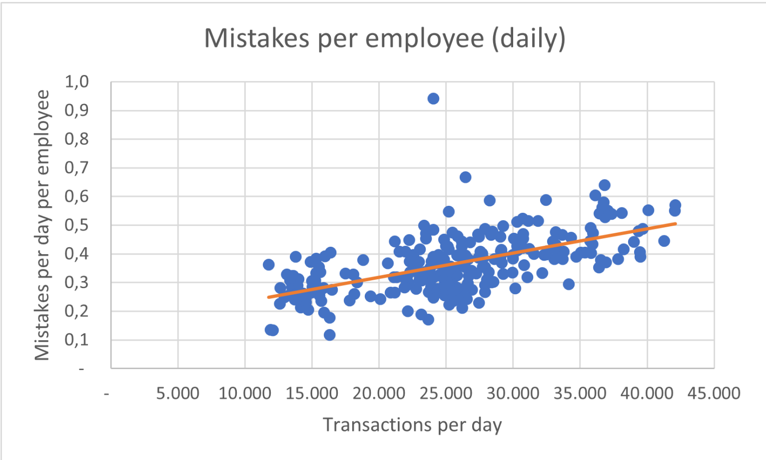


Figure 12: Scatter plot depicting the correlation between transactions and mistakes per employee

Productivity and mistakes
The productivity of distribution employees is reported on a daily basis (non-quality KPI). There could be a relation between how productive the employees are and the amount of mistakes they make. The initial assumption is that a higher productivity (more transactions per hour) indicates a higher speed of execution, which would result in more mistakes.

Analyzing the data resulted in finding a weak negative correlation (r(251)=-0,46, p<0,0001) between productivity and mistakes. This means there is some influence, but not of great value. When the productivity increases, there is a decrease in number of mistakes, which is counter-intuitive when considering the increased speed of transactions.

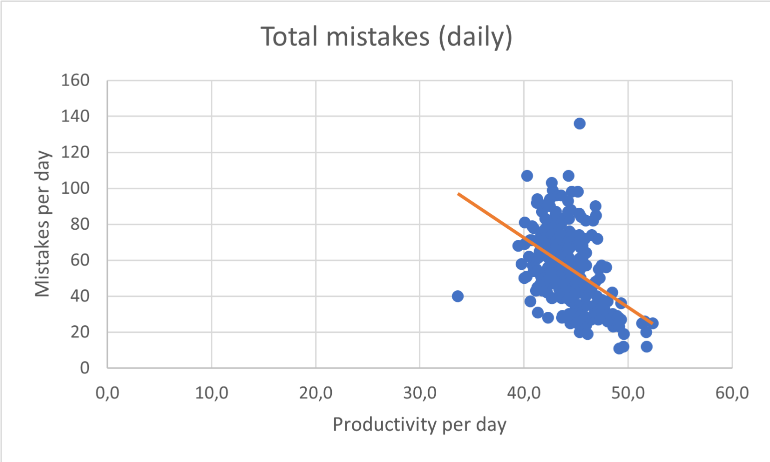


Figure 13: Scatter plot depicting the correlation between productivity and mistakes

7.2.2 Quantity mistake

As the most frequent occurring mistake, the quantity mistake is analyzed to determine whether it is influenced by the number of transactions, batches per trolley, employees in the process and productivity. Expectations are that the total number of transactions will have a weak to moderate correlation with the number of transactions, as a high number of transactions implies there will be more transactions of one unit per time. The number of batches is not expected to influence the number of quantity mistakes, as the mistake has little to do with picking the right batch. Employees and productivity are expected to have a moderate to strong impact on quantity mistakes, as counting requires concentration and higher speed or more chaos in the environment could disrupt the concentration.

For the quantity mistake and the daily transactions there is a weak positive correlation ($r(251)=0,36$, $p<0,0001$), implying that there is limited statistical influence on the quantity mistakes by the workload. A similar result is found for the number of quantity mistakes and the average number of batches on a trolley ($r(251)=0,24$, $p=0,0001$). Both of these result coincide with the expectations and based on these input variables alone, the PI for quantity mistakes could be expressed and used in percentages or DPMO. Contrary to the results of the previous analysis, the number of employees in the process does influence the number of quantity mistakes made on a daily basis. The correlation found was moderately strong, in a positive manner ($r(251)=0,66$, $p<0,0001$), as was expected.

Productivity has a weak negative correlation with quantity mistakes ($r(251)=-0,24$, $p<0,001$). It can be concluded that a higher speed of execution in transactions incrementally influences the amount of quantity mistakes made. A visualization of this, is included in Figure 14. There is one outlier, on the left, a Tuesday in May, which is caused by a disruption in the buyers' software.

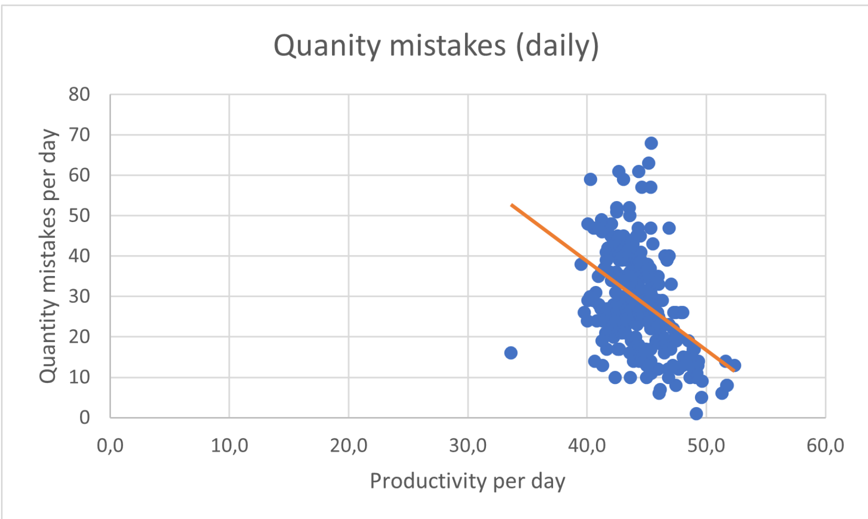


Figure 14: Scatter plot depicting the correlation between productivity and quantity mistakes

7.2.3 Batch mistake

Batch mistakes are the second most frequent mistakes that occur in the distribution process. This mistake too is analyzed to determine whether the transactions, batches per trolley, number of employees and productivity influence it. Transactions are expected to have a similar effect on batch mistakes as on the total number of mistakes: a moderate to strong positive influence.

As the average number of batches on trolleys is an additional process factor that specifically links to this mistake, it is expected to influence the batch mistakes considerably, as a higher amount of batches on a trolley would lead to more batch mistakes. In line with the expectations for the quantity mistakes, it is expected that the number of employees and productivity will have a moderate to strong influence on the resulting number of batch mistakes. Similar to the quantity mistake, the batch mistake supposedly comes form a lack of concentration.

Changes in the workload (total number of transactions per day) have a moderate positive correlation (r(251)=0,54, p<0,0001) to the amount of batch mistakes. Like the total number of mistakes, it is a logical consequence that more transactions resulting in more mistakes would positively relate to the number of a specific type of mistake.

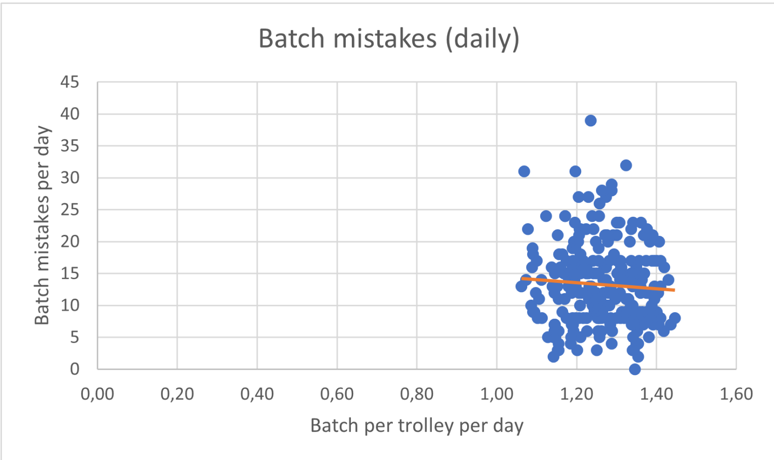


Figure 15: Scatter plot depicting the correlation between the average batches on a trolley and batch mistakes

Contrary to what was assumed, the average number of batches per trolley per day does not influence the batch mistakes. The correlation that is the result of the calculation is a very weak negative one (r(251)=-0,06, p>0,05), implying that there is scarcely any effect of a change in batches per trolley on the batch mistakes. This unexpected relation is visualized in Figure 15. Analysis of the relation between employees in the process and batch mistakes, resulted in a moderate positive correlation (r(251)=0,58, p<0,0001).

However, the productivity has a weak negative correlation (r(251)=-0,33, p<0,0001) to the amount of batch mistakes that are made. This coincides with the effect of productivity with quantity mistakes, although it influences batch mistakes relatively less strongly.

The found correlations do not give a solid foundation on which to introduce more PIs for batch mistakes or base it on something else than a normalized number, so similar to quantity mistakes, the batch mistake PI will only have a DPMO indicator to monitor the variance.

7.2.4 Damages

The inclusion of damages in the PIs is to increase the awareness of inattention and to aid the calculation of COPQ, as a damage always results in compensation to the customer. The number of transactions is expected to influence the damages in a moderate to strong way. Batches per trolley presumably do not have an influence on the damages that occur in the process. Employees and productivity however, are expected to influence the damages and thus infer the use of DPMO for the PI.

Analysis found a close to moderate positive correlation between damages and the number of transactions (r(251)=0,47, p<0,0001), which is a considerably weaker influence than expected beforehand. This could imply that the workload does not influence the employees likeliness to drop a product, either by driving carelessly or handling it clumsily.

The number of batches per trolley has a stronger influence than expected, although it is still a weak negative correlation (r(251)=0,35, p<0,0001) visualized in Figure 16. This manner of correlation is possibly linked to the fact that trolleys with more batches are handled by more experienced employees or that there is less distance to be travelled with a full trolley. A full causality analysis could provide an explanation for this result, but is not pursued in this research.

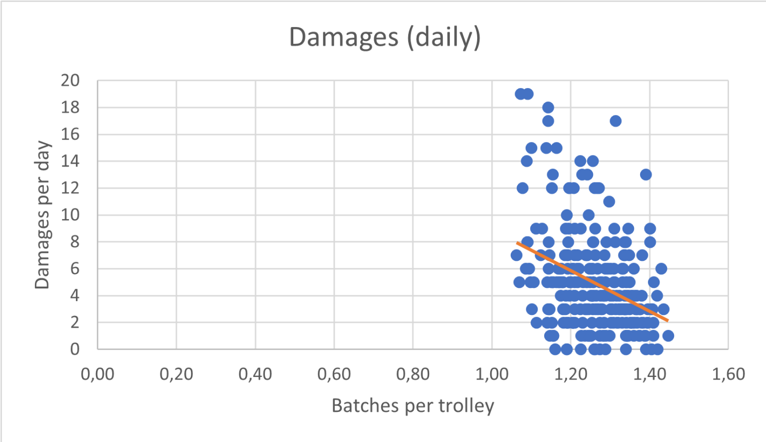


Figure 16: Scatter plot depicting the correlation between the average batches on a trolley and damages

As for the number of employees in the process, it follows the other mistakes, the analysis shows a significant positive correlation, albeit not a strong one (r(251)=0,36, p<0,0001). Still, this influence is strong enough to use DPMO in the PI, limiting the effect of the variation in transactions on the comparison of the PI to a target.

Lastly, the productivity versus damages analysis resulted in an expected correlation. Conforming to the general effect of productivity on mistakes, the influence on damages is also a significantly weak negative correlation (r(251)=0,28, p<0,0001).

7.2.5 Time mistakes

Time mistakes are transactions that have not been delivered within the agreed 180 minutes after auction. This mistake is partially due to the LO process and should thus be incorporated to the the system with a PI. To ensure the PI is robust and will produce accurate results through variation in input, the same analysis is done as for the other mistakes.

Transactions are expected to influence the time mistakes marginally, because the scheduled number of employees in the process is adapted to ensure the timing stays within the 180 minutes. Employees in production, as well as productivity, are expected to have a notable influence, seeing as these are the direct drivers for timely delivery. Batches per trolley supposedly will not affect the timing of delivery. As the time mistake is not registered as such for the LO department, it is also compared to the total number of mistakes, to determine whether more 'regular' mistakes also means an increase in late transactions.

The total number of transactions has a moderate positive correlation (r(251)=0,54, p<0,0001) with the number of late delivered transactions, which is stronger than the expectation. This is presumably due to the fact that more transactions means more time mistakes. An unexpected result is the correlation between time mistakes and batches per trolley. The analysis returned that it is a moderate negative correlation (r(251)=0,47, p<0,0001), the strongest influence yet and possibly explained by increased transactions per batch per trolley, which means less transport. However, this is an assumption that is not further investigated in this research, as this study does not serve as root cause analysis for mistakes.

Another surprise, is the effect the number of employees in production have on the number of late transactions. It was assumed there would be a strong connection, most likely a negative one, where a higher number of employees would mean less late transactions. The statistical correlation turned out to be barely existent and positive to boot (r(251)=0,22, p<0,001), visualized in Figure 17. The outliers to the left and top of the cluster, are caused by various disruptions in the logistics and buyers' software. One possible explanation for this minimal influence could lie in the contribution of the process after distribution, when trolleys are buffered, grouped and then delivered to the customer, as this data is about the overall cycle time.

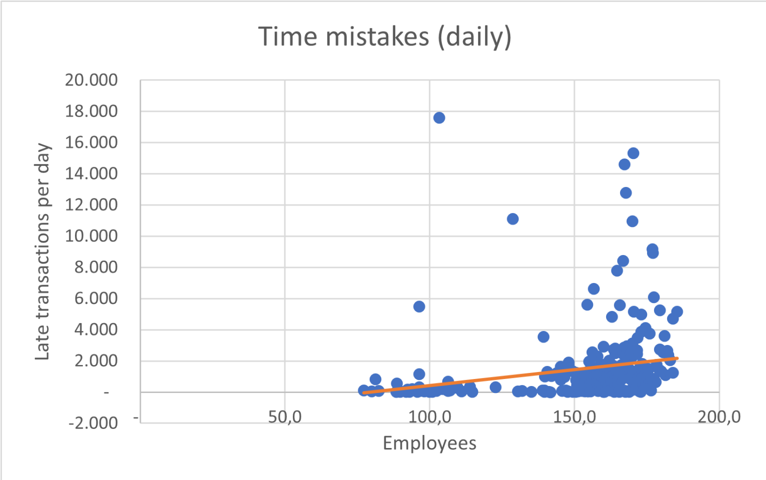


Figure 17: Scatter plot depicting the correlation between the number of employees and late transactions

Finally, the total number of mistakes in comparison to the time mistakes lead to a weak positive correlation ($r(251)=0{,}43$, $p<0{,}0001$), which could be explained by the common input of the two process performance indicators: total number of transactions. However, it does not imply a direct causal connection.

On-time delivery is an important aspect of process quality in the LSS philosophy and is a frequently used KPI in both literature and practice, as described in chapter 3. Given the fact that currently available data is about the total cycle time of a transaction from auction moment to physical delivery, it is hard to determine which aspects of the distribution process affect it and how that can be translated to a performance indicator for LO. To be able to include a time mistake PI, the data should be specified and split between the two departments.

7.2.6 Synopsis

The number of transactions has a weak to moderate positive correlation with all specified mistakes, indicating that the absolute numbers of transactions influence the eventual number of mistakes. Therefore, the use of a DPMO calculation with transactions as input eliminates the effect of short term fluctuations and enables the np-chart to set constant control limits. This makes the outcome of the PI relatively insensitive to the variation of transactions, thus reflecting more specifically on the process itself.

None of the specific mistakes displayed a correlation with the number of batches on a trolley that was stronger than weak, except for the time mistakes. This implies that this input variable is not a significant cause of mistakes, be it a quantity or batch mistake, nor does it increase damages to the product. Using it to determine whether the process is functioning and in control, would not be indicative of the actual capability and thus not included in any calculation.

The number of employees in the process influences all mistakes with a positive correlation, albeit on a different scale. The strongest influence is on both quantity and batch mistakes, implying that chaos in the process contributes to making mistakes, backing the assumption that the cause of most mistakes lies in the human factor. Since this process variable only moderately influences a select number of mistakes, and there are other KPIs in use that monitor the employees, it will not be included in the proposed framework at this time. However, it is one of the first that should be added when expanding the framework, as it qualifies as an input process variable that can be adjusted by the LO department themselves.

Neither of the specific mistakes experiences more than a weak influence from the productivity. Most are of a negative correlation, except for the time mistakes. As productivity is the outcome of the number of transactions, number of employees and end time of the process, it is a process outcome as much as the mistakes are.

Thus, for process quality, productivity is not a strong indicator and it should not be included to prevent over-analyzing with no useful results. Usefulness in this case is relative to the manner in which the PI contributes to providing information about the process quality and possible improvement opportunities. It could be a good fit for another PI that indicates education levels, as the expected cause of a higher productivity with decreased mistakes is the level of experience of the employee. An experienced employee is expected to be more productive, while making less mistakes, than a less experienced temporary employee.

7.3 Variants

In order to test the framework on the case, three variants for input and performance are defined. This subparagraph explains the changes and differences to the initial calculations in both chapters 5 and 6, as well as the measures necessary to achieve the variant. The two parameter variants are run on the base scenario (2019) and the two input scenarios, to quantify possible future outcomes. Further insight in the effect of the parameter variants (reaching target and implementing framework), could be achieved by setting up a pilot for a minimum of four weeks and a maximum of six months to acquire enough data that covers all holidays and influential periods. A pilot run lies outside of the scope of this study, but would be recommended to render a realistic reflection of the requirements and impact of the framework.

7.3.1 Experiment with input variables

The analysis in the previous paragraph provided insights in the durability of the PIs in relation to transactions. To test whether that is expressed in the model as well, the variables are adjusted and then entered in the calculation for both daily (K)PIs and weekly (K)PIs, reflected in a yearly score. The variables will be plugged into a calculation with percentages of mistakes and the framework with DPMO to reflect the value of specifically reporting in normalized numbers. It is expected that the changes in input, will not affect the DPMO or the percentage of mistakes, but changes will be visible in the COPQ, both internal and external.

The initial experimental calculation will use a higher amount of transactions as input. As RFH wants to grow and cater to large and small buyers as well as transition to a new logistics concept, the increase of transactions is a realistic possibility in future. With the transition to fulfilment, the process will change from push to pull, changing the way the products flow through the process. While it will have effect on the configuration of the process and its check points, literature states it will not affect the KPIs. The expected growth is unknown, so for the sake of this experiment, the transactions per day will increase incrementally (5%).

Secondly, the number of transactions will be decreased. Due to the transfer from auctioned products to direct sales, it is also a realistic scenario to test whether the system can exist even when the input becomes less. The number of trolleys that were auctioned decreased with 4% between 2019 and 2020, this percentage will be used as the expected decrease of input.

For either of these variants to happen, RFH Naaldwijk does not necessarily need to change anything in its distribution process, with the exception of implementing the new logistics concept. The latter is a location transcending project and is therefore not something the location specifically needs to change. The influx of trolleys for auction is dependent on the commercial departments, market strategies of growers, holidays and weather forecast. All of which are outside the circle of influence of LO and thus do not require actions or adjustments in the process.

7.3.2 Reaching target

The data-analysis of the current state resulted in a DPMO of 2183,3 and a sigma level of 4,4, while the target is a DPMO of 1500 with a sigma level of 4,5. Therefore the second variant is one in which all process variables remain stable, while the target of 0,15% faulty transactions (DPMO of 1500) is reached with use of the system. All PI and KPIs are calculated for this variant with percentages for specific mistakes and cost, as the absolute number of mistakes is changed, but reported in DPMO.

For RFH Naaldwijk to reach their FTR target as it is currently set (0,15%), the LO department will have to actively monitor and control the mistakes made each day. Informing the employees of their mistakes and cooperate to find elements of the process that can be optimized to minimize the number of mistakes.

Reaching the target is not impossible in the current situation, as it has been done in 2019 on 16 days. Delving deeper into the root cause of the mistakes and seeking to solve these, will most likely decrease the number of mistakes made. A 55% decrease in the top three mistakes made: quantity and batch mistakes, as well as damages, would result in the target being reached. Applying this framework to the current distribution process, will require the adaptation of the proposed (K)PIs and altering the reports both to the higher level as to the floor. This includes the use of np-charts for visibility of performance in relation to statistical control and reaching the target.

To realize a successful implementation, including future cycles of continuous improvement of the system itself, there should be a function or team responsible for monitoring process quality (Process Quality Control: PQC). This person or team receives the data from different departments and maintains a dashboard in which the PIs and KPIs are visualized and reported to the teams that execute the process. The PQC also actively cooperates with various teams to direct them in finding the root causes of mistakes and eliminating them. As this research does not include the design of a functional dashboard, the PQC will initially have to do so, ensuring the dashboard communicates with all relevant systems and software packages.

Since the start of this research, changes have been made in the reporting and monitoring of mistakes, resulting in an increased number of days the target was reached. Specific mistakes are now reported daily and can be traced back to individuals. The cost is not as transparent yet, so the next step would be to enable something similar to activity based costing, or lean accounting with the inclusion of the COPQ indicator to further increase knowledge about the impact of mistakes on the bottom line.

7.3.3 Long term effect

Historical data suggests that the application of a quality performance measurement system that incorporates six sigma tooling, leads to a short term (5 years -> 2024) increase of 0,86 SQL. This variant uses the increase in SQL to retroactively calculate the KPIs and PIs, using the historical mistake percentages. The result is the effect of implementing the framework and its hierarchy, as well as the feedback frequency and yearly review of the targets.

To achieve these long term effects, RFH should implement the framework and embed it into its continuous improvement flow. This ensures periodical reviews to check whether the targets and (K)PIs still fit the process, prompting the performance measurement system to develop alongside the company and its processes.

7.4 Test results

This paragraph describes the values of (K)PIs that have been calculated with the different variants. The results are categorized per indicator to mimic the output of the model and summarized into one year for brevity. More extensive results are found in Appendices G.3 and G.4. The first subparagraph describes the results for first time right, then the sigma quality level is explained, followed by the outcome for cost of poor quality.

7.4.1 First time right

The FTR KPI has two weekly KPIs, one that reports on the number of days the FTR target is reached, and one that calculates the average FTR index per week. For the different variants, the outcomes of the calculations have been listed in Table 12. When entering the variance of number of transactions, no change in output is observed. This is supported by the statistical analysis earlier in this chapter, as the calculations normalize the absolute number of transactions and mistakes.

Table 12: First time right KPI results

Variant	FTR target reached per day	FTR Index	Difference
2019 (0)	16	99,78%	-
-4% Transactions	16	99,78%	0%
+5% Transactions	16	99,78%	0%
Reaching target (0)	232	99,89%	0,11%
Reaching target (-4%)	232	99,89%	0,11%
Reaching target (+5%)	232	99,89%	0,11%
Future state (0)	253	99,98%	0,20%
Future state (-4%)	253	99,98%	0,20%
Future state (+5%)	253	99,98%	0,20%

If the process improves to the point of reaching the current mistake target, the effect is immediately visible. Not only would the FTR target be reached nearly every day, the average FTR Index would increase with 0,11% to 99,89%. The reason for deviation of the number of days the target is reached, is due to the fact that for calculation purposes, only the absolute number of quantity mistakes, batch mistakes and damages was decreased. This evidently still leaves room for variation in total number of mistakes. Achieving the theoretical SQL increase of 0,86 through implementation of the system, would lead to an average SQL of 5,33. To achieve this in the calculations, a realistic decrease of 90% of all mistakes was applied. This affects the output to present 253 days in which the target FTR is reached, with an average of 99,98% of the transactions executed perfectly. Successfully implementing the proposed system would increase the average FTR performance of the process with 0,20%.

In addition to more days the target is reached, the process variation has decreased, hence the process is more *in control* after implementing the framework. To visualize this, the np-chart for all mistakes is included below.

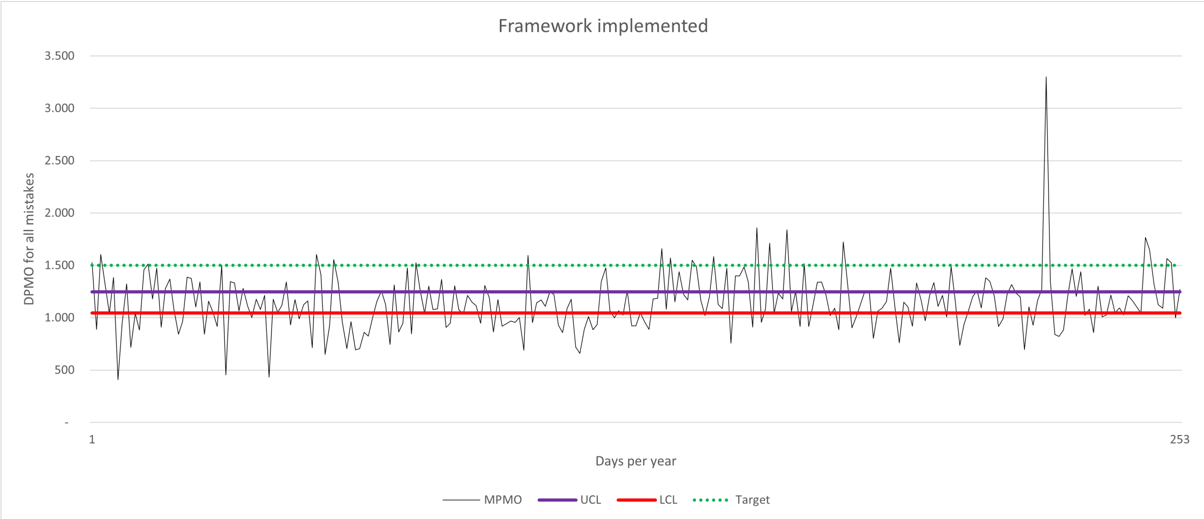


Figure 18: NP-chart after implementation

The dotted green line represents the target, and it is clear that most days in 2019 the maximum number of mistakes per million opportunities was not reached. The upper and lower control limits are still crossed, but the difference between the lines has decreased to 200, instead of the 300 it was before. As explained earlier, the daily fluctuation of 2019 is used to reflect the dynamics in the process, which caused the outlier late in the year.

7.4.2 Sigma quality level

A direct result of the FTR index is the SQL, calculated in a separate KPI for specific monitoring. This KPI is moderately affected by the first three changes to input and process performance, as visualized in Figure 19. N stands for the initial model, R uses the current targets, E is the long term system. The number represent the input variance. The first change is observed as the targets for time and all mistakes are reached, the SQL increases from 4,36 to 4,55. A seemingly incremental change, but it reflects a decrease of 2156 to 1145 DPMO on average per day, which accounts for the 55% decrease in daily quantity mistakes and batch mistakes, as well as 55% less damaged products or packaging units.

The largest change happens when the system is set to reach the theoretical SQL target of 5,33, which is a 0,97 difference to the current situation, and a 0,86 difference to the second variant of reached targets. The shift in SQL translates to a decrease in average daily mistakes of 97%, which means virtually no mistakes are made during distribution. This includes damages, but not time mistakes, as they cannot be attributed to LO entirely as of yet. As 90% reduction is mistakes was assumed more realistic, the actual expected SQL will be closer to 5,02, which is still a 0,66 increase.

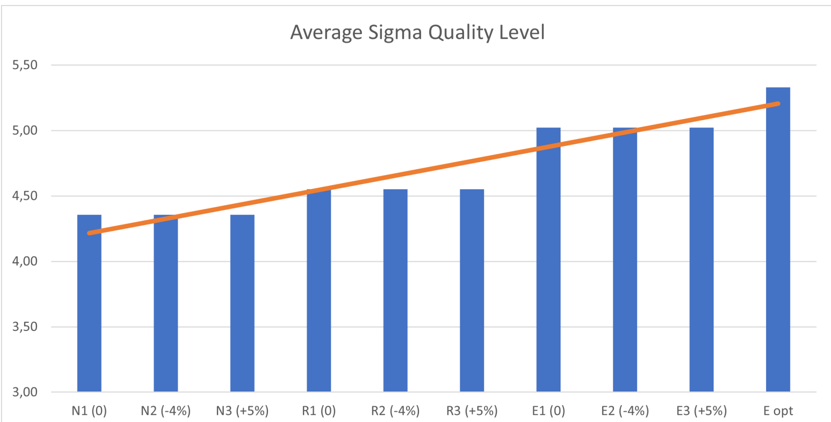


Figure 19: Bar chart with the effects of the experiments and variants on SQL.

7.4.3 Cost of poor quality

The category COPQ is split into an internal and external PI, of which the internal PI reports on the mistakes that are caught internally, and the external PI on the ones that reach the customer. Contrary to the normalized KPIs for FTR and SQL, the COPQ PIs are calculated with absolute values, based on the average cost per mistake in 2019, for if the percentage of mistakes does not change, the actual number of mistakes does.

Table 13 shows the effect of the experiments with transactions different variants. The calculations for the experiments are based on several average numbers, both search time per specific mistake per day and the compensation per week are the averages over 2019. This results in a deviation from the COPQ reported in chapters 5 and 6, so when quantifying the monetary effects of the performance management system, the percentages are leading.

Table 13: Cost of poor quality results

Variants	**Internal COPQ**	**Difference**	**External COPQ**	**Difference**	**Total**	**Difference**
2019 (0)	€ 145.109,89	-	€ 62.677,98	-	€ 207.787,87	-
-4% Transactions	€ 143.358,74	-1,2%	€ 62.677,98	-1,4%	€ 205.190,-	-1,3%
+5% Transactions	€ 147.298,82	+1,5%	€ 62.677,98	+1,7%	€ 211.035,07	+1,6%
Reaching target (0)	€ 122.193,97	-15,6%	€ 62.677,98	-13,2%	€ 176.446,57	-14,9%
Reaching target (-4%)	€ 121.359,46	-19,4%	€ 62.677,98	-16,5%	€ 175.102,46	-18,5%
Reaching target (+5%)	€ 123.237,11	-18,0%	€ 62.677,98	-14,5%	€ 178.126,70	-16,9%
Future state (0)	€ 105.709,12	-32,0%	€ 62.677,98	-34,7%	€ 149.338,26	-32,8%
Future state (-4%)	€ 105.534,00	-37,4%	€ 62.677,98	-43,9%	€ 149.078,48	-39,3%
Future state (+5%)	€ 105.928,01	-37,1%	€ 62.677,98	-43,5%	€ 149.662,98	-39,0%

As the number of transactions vary, the absolute number of mistakes does too and consequently the cost of poor quality varies as well. For the expected decrease of transactions, the internal COPQ decreases with 1,2%, where the external COPQ decreases with 1,3%. This would be the result of growth for RFH, but no change in the monitoring and control of process quality. Applying the monitoring and control system, while maintaining current targets, could lead to close to 15% decrease in COPQ if the number of transactions stabilizes. If the number of transactions follows the historical trend of decreased transactions and the target for FTR is reached, the decrease in COPQ is 18,5%.

One notable result is for reaching target through decreasing 55% of most frequent occurring mistakes and damages, as the external COPQ decreases relatively less than the internal COPQ. This coincides with the fact that a large part of the most frequent occurring mistakes and damages is caught internally, and an improvement on that count increases the internal performance, affecting the external performance slightly less. In the case of customer satisfaction, this could be said to be a positive sign, as fewer mistakes affect the customer. It also underlines the importance of splitting the cost between internal and external performance, as it provides insight that assists with prioritizing which mistakes to tackle first.

If RFH wants to minimize the effect on customers, it will have to find a way to ensure less mistakes end up externally, either by improving the quality checks or decreasing mistakes in general. If the focus lies on controlling the effect of mistakes internally, the most effective mitigation would be the decrease in mistakes, but RFH Naaldwijk could also explore a different way to solve mistakes.

7.5 Synopsis

Through verification and validation, the model was judged to both be correct and fit the case study. The (K)PIs use the right parameters for calculations, providing reliable outcomes for the simulated future states. Additionally, the structure of the framework makes is more than acceptable for the company, fitting in with its process control ambitions. The effect of input variance was tested through the variation of transactions that come through the process, with all other parameters set as they were determined in the current state. Two adjusted influxes of transactions are used, namely a decrease of 4% transactions and an increase of 5% on a daily basis. This variant did not affect the FTR KPIs, nor the SQL KPIs, as these KPIs are calculated with use of normalized parameters, which did not change. It did affect the COPQ PIs that are calculated with use of absolute numbers of mistakes, of which the results followed the + or - sign of the variant.

The initial effect of implementing this system is reaching the current targets. Therefore reaching the targets is used as a variant to calculate what the result would be if that occurs. All (K)PIs reflected change in some manner, the FTR Index increased with 0,11%, the SQL with 0,19 and the total COPQ decreased with a maximum of €32.685,41,- (for -4% transactions), all based on a year's time. This is a very promising result, as it proves that, without changing the targets, but with a hierarchical focus on specific indicators, the overall performance would benefit. Especially money speaks, and an improvement that possibly saves over € 32.000,- per year, should seriously be considered.

The theoretical sources account for an average increase of 0,86 in SQL after implementation of the LSS philosophy. The time frame is not set, but it is safe to assume that it is over several years. The increase of SQL would have to result in 97% less mistakes, which is deemed not realistic, the results are thus calculated with -90% mistakes. Based on the data extracted from 2019, the effective implementation of the quality performance system and the accompanying LSS philosophy, could eventually lead to a considerate improvement in all (K)PIs. The FTR KPIs present increases, which are reaching the target every operational day and a 0,20% increase in average FTR performance. The decrease in daily mistakes is translated to an expected decrease of 39,3% COPQ on a yearly basis. When implementing the system, this could be the final results, but as was mentioned before, it will likely take a number of years to get there.

Overall it seems that the implementation of the system will result in better performance and lower cost for the LO department, which answers sub-question 9. However, the system is far from perfect as it operates on various assumptions, generalizations and averages. Some of these are due to the nature of available data and some are the result of the scope. This can be countered by setting up a pilot of a number of weeks to measure the actual results of focusing on reaching target and another pilot with use of the framework. For even more reliable results, both time mistakes and cost for mistakes should be specified to apply to LO and individual mistakes. Especially the distinction between internal and external cost of poor quality could be more realistic, if the data would provide clear information about who found the mistakes and what exactly is the compensation issued. Also, as discussed earlier, the fact that current time KPIs do not split between departments, results in the system almost entirely excluding on-time delivery for LO. This is quite the opposite of what theories and literature recommend.

8 Conclusion and recommendations

This chapter contains the conclusion of the research, the discussion and reflection on the research process, subjects on which further research remains to be done and recommendations. The first paragraph answers the sub-questions, leading up to the eventual main research question. The second paragraph discusses the conclusions and answers, reflecting on the pitfalls and elements of influence that were out of scope for this study. The final paragraph presents the recommendations for further research as well as implementation of the proposed system.

8.1 Conclusion

In the course of this study, all sub-questions are answered through various methods in the different chapters. The answers are summarized below.

1. What is zero-defects logistics?
Zero-defects logistics has its roots in Lean Six Sigma and is used as an aspect of Total Quality Management. Through its methods and tools, it aims to achieve zero-defects in its process output, be it either a product or a service, as well as minimizing the defects within the process itself. It is commonly used by applying statistical process control and integrating a quality related philosophy throughout the whole company.

2. What is state-of-the-art in performance measurement models?
The state-of-the-art in performance measurement varies on the industry it is applied to and the point of view process engineers have while designing the system. A recently developed, generic model, the Goals, Performance and Indicators model (GPI model), is found to be applicable to the cut flower distribution process, as it provides a model which only requires the correct selection of process performance indicators.

3. What are best practises for quality performance measurement in different industries?
The industries that are included in answering this question, are postal services, automotive and a variety of logistics companies. Both specified frameworks, application methods and operationally tested KPIs are found from these sources. Especially useful is a method of applying a hierarchical framework on automotive industry.

4. How would the optimal quality performance measurement and control system be configured?
The optimal quality performance measurement system contains different levels of management, starting bottom up with a process level, operational level and tactical level. When applying the system to more than one department, the strategical level can be included. The (K)PIs that are defined in the system, report on first time right, sigma quality level and cost of poor quality on a weekly basis. For first time right, that encompasses both the average percentage of first time right per week and the number of days the target was reached. The sigma quality level is based on the average first time right percentage. The cost of poor quality specifies both internal and external cost of poor quality, with both PIs reporting on the cost of searching for mistakes and compensating lost/damaged products. Following the hierarchy in management levels, the KPIs have PIs as input, which report on the daily first time right percentage and the defects per million opportunities for specific mistakes in the process. The PIs are calculated based on the daily output of the process and their results are communicated back to the employees on the work floor. The generic system is applied on a specific process by following four steps that include determining the objectives of the context, describing the reference process that the system will monitor and control, determining the relevant (K)PIs and detailing the critical process steps to fit the indicators.

5. What is the current situation concerning process control at Royal FloraHolland?
Based on various Lean Six Sigma tools, Royal FloraHolland uses an operational excellence framework to continuously improve its monitoring and control structure. RFH uses the categories People, Safety, Quality, Delivery and Cost to groups its KPIs. Specifically for quality, there are five KPIs currently in use that apply to the cut flower distribution. These KPIs are reported weekly to team managers and higher in Naaldwijk.

6. How does Royal FloraHolland perform in terms of process quality?
Three of the five existing quality KPIs reported below target performance in 2019. The ones below target are the percentage of mistakes found in inbound trolleys, the percentage of mistakes made during distribution and the percentage of mistakes found after distribution. The two delivery KPIs were both above target. While the current state of quality monitoring and control does not report on the financial effect of mistakes, this is analyzed to form a complete image of the situation, with the cost of poor quality summing up to over € 350.000,- for 2019.

7. Which factors influence process quality?
As the Logistics Operations department produces most internal mistakes, it is used to specify the initial framework to fit the case study. The process steps executed by LO create one opportunity for seven mistakes, excluding mistakes in timely deliveries. Of these seven mistakes, quantity mistakes, batch mistakes and damages are the biggest contributors to the number of mistakes made yearly.

8. How should the designed system be adapted for Royal FloraHolland?
As the previously defined steps are followed, the case-related objectives are found to relate to the future plans of Royal FloraHolland concerning the new logistics concept, as well as the requirements that stem from the Operational Excellence strategy it enforces. Using these objectives and specifying the scope to the process during which the packaging units with cut flowers are transferred from one trolley to another, the performance indicators for first time right, sigma quality level and cost of poor quality are defined. Relating the performance indicators to the critical process steps and further specifying them leads to a final quality performance measurement and control system that fits the distribution process in Naaldwijk.

9. How would the system affect the process and performance in current and future state?
To be able to answer this question, the system was quantified into a mathematical model that uses the data from 2019 as input. Three different input variants were used to calculate the effect of reaching the current targets and maintaining the system for a long time. In both instances the same input variants resulted in increasingly higher process quality and consequently increasing cost compared to the base year 2019. Eventually the FTR index will increase to 99,98%, with the target being reached every operational day. The maximum decrease in cost lies around 39%, depending on the number of transactions that go into the process and the product prices.

In conclusion, the answer to the main research question:

How can the quality performance of a distribution process for cut flowers be measured and controlled to incorporate zero-defect logistics?

The quality performance of a distribution process for cut flowers can be measured and controlled with the incorporation of zero-defect logistics, by applying a hierarchical KPI and PI framework, with indicators that are specified on the circle of influence of the business levels. The KPIs report on weekly and daily first time right, and sigma quality level, while the PIs report on weekly cost of poor quality and daily first time right and mistake specific defects per million opportunities. These indicators are generic enough to be applied on every aspect of the process, with some minor adaptions to fit the other departments, ensuring a uniform method of monitoring and control of process quality. To ensure the uniformity and continuity in the quality performance measurement system, a person or team is appointed as Process Quality Control, whom are responsible for monitoring the quality and reporting anomalies.

8.2 Discussion and reflection

Before the start of this project, a performance measurement model for the logistics in the floricultural supply chain was something that had not been explored in literature, much less in practice. Through a KPI selection and design process extracted from the automotive industry's best practices, this report presents the operationalization of one particular performance measurement model: the GPI model, aimed at monitoring and control of a cut flower distribution process. The framework fits the case study and therefore fills the found research gap in the reviewed literature and theories. Additionally, to enable the composition of formulas necessary for calculations in the model, a swim lane chart was used. As this is not a standard visualization to base a model on, it adds a unique design step to the academic body of knowledge.

This research focused on the cut flower process in RFH Naaldwijk, specifically the distribution steps during which the products are placed from one trolley on the other. The scope leaves several process steps in the cut flower process itself out of the focus, as well as completely overlooking the potted plants process that happens in the same building.

The narrowness of the scope provided the focus to dig deep into the data, specifying the mistakes and leaving time to analyse the data for correlations, after which it was relatively easy to finalize the design. Experimenting and then determining the influence on the performance was also simplified by the scope, as it limited the number of (input) variables and process influences. However, the other process steps and processes are present in the business reality, which renders the results of the calculations reliable, although hypothetical. In other words, the results calculated with the limited influences, especially on productivity of employees, will differ from the actual results that can be achieved after implementation.

Further research that includes all aspects of the process, simulating the distribution, but also including transport, product specifics and customer deliveries, would result in a more complete verdict on the effect of implementing this quality performance measurement system. As for the implementation itself, the system requires another design iteration that incorporates the available sources and produces the actual dashboard with all KPIs and PIs with which the process quality can be monitored and controlled. A useful feature would be an algorithm that signals anomalies automatically and warns when, where and which anomalies occur. Another aspect that could benefit from further research, is the organisational shift that is initiated by appointing a process quality control team or person. This shifts the process responsibility from a functional organisation to a process orientated organisation, which encompasses a different hierarchy and altered communication lines. It would be beneficial to explore exactly how that new process orientated organisation is configured and what a functional organisation for the distribution of cut flowers should do to transition towards that orientation.

8.3 Recommendations

Based on the analysis of the current state of performance measuring of the cut flowers process at RFH Naaldwijk, a number of recommendations can be made as a result of this study. The first recommendation is to realize more transparency and structure in the registration of mistakes, search time and costs, as well as compensation cost. Being able to specify the time and cost made by the S&C team to specific process steps, provides a clear picture of both impact and output of mistakes per step. By being able to specify those indirect cost, the motivation for employees, both on the work floor and in management level, to change and improve the process is easier to enthuse. Transparency also provides the tools and input to calculate the effect of certain adjustments, as well as the return on investment when the change requires funds.

Secondly, in concordance with the proposed framework, RFH Naaldwijk and more specifically LO, should redefine their KPIs and PIs to reflect the elements of the process that can be influenced on the respective levels. Current KPIs on the work floor are of the same aggregation level as on the tactical level, rendering the sense of ownership by distribution employees virtually non-existent. The new definitions should clearly state what the purpose is of the indicator, how it is reported, how frequent it is reported and to whom, who is responsible for retrieving and calculations, as well as who is the actor that is responsible for controlling that process step.

Thirdly, it is strongly recommended to appoint a team or person to be responsible for process quality. This Process Quality Control person or team (PQC) will simultaneously function as the source of information, and audit the departments on their process quality factors. This is recommended to ensure ownership and continuity of the focus on quality, as well as increase uniformity through the whole process. The PQC should be closely involved with any changes that will happen in the logistics process, as process quality can result in high cost if it is not monitored and controlled properly. Seeing as the Searching & Correction team already takes on parts of the role of the PQC, the easiest transition would be to formally appoint a person or persons in that team as PQC. This appointment needs the support of all departments, their operational and general managers, as well as the team managers, because their cooperation and willingness to change is indispensable for the improvement of quality and diminution of cost.

Finally, it is recommended to implement the proposed framework to monitor and control the whole process, seeing as it gives insight for a considerable decrease in labour and compensation cost. It should be done following a pilot phase of four to twelve weeks, in order to leave enough time for information analysts and managers to come to an agreement on sourcing, responsibilities and reporting. After it has been adopted by LO, it can be copied, adapted slightly and implemented in LSS and LSC as well, achieving uniformity in control of the entire cut flower process.

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Appendices

A Academic paper

Designing a Process Performance Measurement System for Zero-Defects Logistics: A Case Study at the Dutch Flower Auction

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Abstract

This paper describes the design process of a process performance measurement system for zero-defects logistics in the cut flower distribution, with a focus on process quality, including the application on a case and the expected results calculated with a mathematical model. The proposed preliminary framework is based on a combination of theoretical sources and best practices found in various industries, specified to fit the zero-defects requirements found in literature. The design is then applied on the distribution process of cut flowers at Royal FloraHolland in Naaldwijk and adjusted to match the available process data. The mathematical model that is developed with use of a process diagram, is used to run several variants of the future state. Calculations endorse the expectation that implementing the system leads to increased process quality and a decrease in financial impact of poor quality.

Key words

Performance measurement; process quality; zero-defects; Dutch flower auction; Lean Six Sigma; key performance indicators

1. Introduction

Since Michael Porter analyzed the Dutch Flower Cluster in 2011, several developments have taken place, continuing the innovative features of the internet for globalization and digitization in the industry [1–6]. Part of these developments is the increasing focus on process quality, flexibility and responsiveness throughout the entire supply chain [7–9].

Historically, sources support that a fitting process performance measurement system can steer a logistics process towards higher process quality and eventually zero defects [10–12]. However, the reviewed sources did not contain information about if and how such a system could fit the floricultural supply chain, nor to what extend a process quality performance measurement system benefits it.

Therefore, this research explores the design and effect of a process performance measurement system that facilitates the focus on process quality in the distribution process of cut flowers.

During the first four research phases of Define, Measure, Analyze, Design and Evaluate (DMADE) that are customary in Lean Six Sigma (LSS) design for new processes and products, a selection of theoretical models are operationalized to fit the cut flower distribution [13–16]. Followed by the evaluation of the design through quantifying the system with use of a swim lane diagram, in order to calculate the expected impact of process performance measurement.

To specify the subjects that are elaborated on in the research phases, the main research question is supported by nine subquestions, all of which are listed below.

How can the quality performance of a distribution process for cut flowers be measured and controlled to incorporate zero-defect logistics?

1. What is zero-defects logistics?
2. What is state-of-the-art in performance measurement models?
3. What are best practises for quality performance measurement in different industries?
4. How would the optimal quality performance measurement and control system be configured?

5. What is the current situation concerning process control at Royal FloraHolland?
6. How does Royal FloraHolland perform in terms of process quality?
7. Which factors influence process quality?
8. How should the designed system be adapted for Royal FloraHolland?
9. How would the system affect the process and performance in current and future state?

The **Define** phase entails definition of theoretical context and finding literature to aid filling the gap, answering sub-questions one to four. The second phase, **Measure**, extends on the case study for practical reference by answering sub-question five. In the **Analyze** phase, the performance of the case is calculated to answer question six and seven. Sub-question eight is answered by operationalizing the final framework on the case study, which is the **Design** phase. Finally, the model is verified, validated and used to calculate the effect of implementation, thus completing the **Evaluate** phase.

2. Define

This phase pertains the review of available academic sources and using the results to design a preliminary framework. The answers to the first four sub-questions are illustrated in the following subsections.

2.1 Literature review

The three most used quality management methods, Total Quality Management (TQM), Lean and Six Sigma, share the ultimate goal of reaching zero-defects in a process or product [17–19]. Although the tools that are part of the application of the aforementioned methods differ at some points, the general consensus is: for a company or process to achieve a result close to zero-defects, the focus on process quality and improvements is a philosophy that should be integrated in the entire organisation [20–23]. The combination and analysis of reported sigma level increases as a result of the implementation of zero-defects philosophy, produced an estimated increase of 0.86 sigmas in process variance [24].

To facilitate the focus on process quality and the philosophy to move towards zero-defects, control of the process is required [25, 26]. Process performance management has been around to achieve just that since the previous century [27, 28]. A recently developed model, which links Goals, Processes and Indicators (GPI) in its concept, offers a generic framework which requires only operationalization to fit a process and facilitate its performance measurement [29, 30].

In order to monitor the performance of a process, a performance management system uses (key) process indicators ((K)PI) that quantify the process flow [31, 32]. (K)PIs are only useful if they are integrated in the organisation and fed with reliable and accurate data, reporting periodically to the right level, with the results and targets connected to the strategic vision [33–35]. The most frequently used (K)PIs in the reviewed literature, were cost of operations and cost of service, followed by on-time delivery, overhead cost, damaged/failed products, lead-time and customer satisfaction [24].

In addition to the theoretical sources, best practices from the automotive industry, postal services and various logistics industries are reviewed, to acquire the best possible combination of sources for the preliminary design. Since the automotive industry is accepted as the mother of Lean philosophy and zero-defects processes, literature concerning it is explicitly reviewed to find methods which could be transferred to the florichain [36]. A particularly useful example from the automotive industry, is a development model that considers the supply chain as a whole, while maintaining flexibility to incorporate new practical and theoretical insights. The framework dictates five steps to follow in order to design a holistic monitoring system [37].

Another useful example pertains the use of a KPI tree to underline the hierarchical connections and a difference between monitoring and improvement KPIs. The latter is used as input for the continuous improvement effort embedded in the framework [38]. Studying the postal services publications, provided insight in the use of the information acquired in one department, to improve operations in another and categorizing (K)PIs to prioritize them [39, 40]. The review of publications on various logistics industries produced several sources that claimed similar findings as mentioned above, albeit with a nuance to fit the respective organisation [41–43].

2.2 Preliminary design

To explore how the optimal quality performance measurement and control system should be configured, objectives, functional and non-functional requirements are extracted from the reviewed sources.

The design objectives are that the design should focus on the process from start to finish, regardless of departments and team responsibilities [85,129]. Selected (K)PIs should report on performance of the process influenced by the level it reports to [70]. The design should be specific enough to be operationalized, but generic enough to fit other processes [38].

The functional requirements for the design are:

- FR 1: (K)PIs must be specified to tactical, operational and process level, omitting financial (K)PIs in the latter [33, 39];
- FR 2: (K)PIs must report on (critical) process steps [37, 38, 44];
- FR 3: (K)PIs must be linked hierarchically [42, 45];
- FR 4: (K)PIs must report on perfect orders, defects per million opportunities, cost of poor quality/bottlenecks, on-time

delivery and sigma levels [16,46].

The non-functional requirements are:

NFR 1: A daily feedback loop for process KPIs [47];

NFR 2: A weekly update for operational KPIs [47];

NFR 3: A description of (K)PIs specifies exactly what information/data is to be measured, at which interval and with what goal [31,43];

NFR 4: Employee is made to feel responsible for quality [48,49].

Using the objectives the GPI model by Simeunovic et al. is modified to fit the focus on operationalizing selected (K)PIs [30]. This results in an initial overview design as seen in Figure 1.

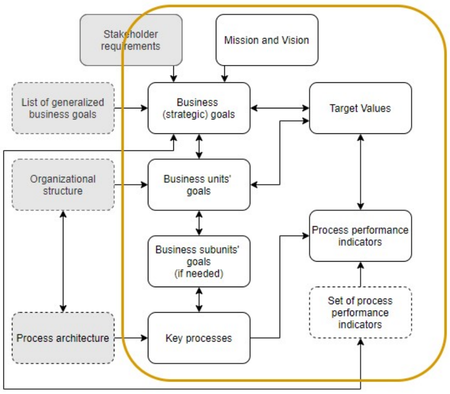

Figure 1: Concept 1

When including the functional and non-functional requirements, and levels based on Ante et al. and Dörnhöfer et al., it results in the framework depicted in Figure 2 [37,38].

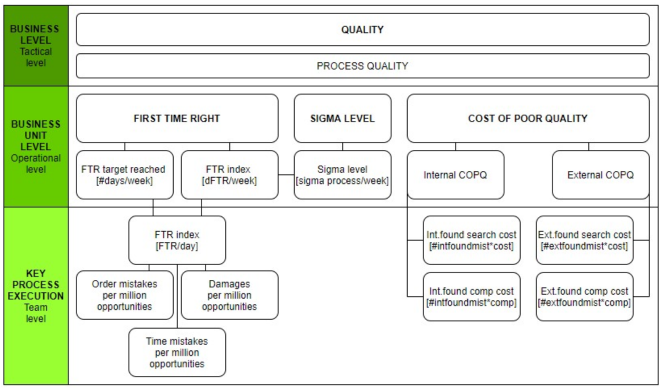

Figure 2: Concept 2

3. Measure and Analyze

This section details on the answers to sub-questions five, six and seven, elaborating on the Measure and Analyze phases of the research process.

3.1 Royal FloraHolland

As the largest cut flower auction in the industry, Royal FloraHolland operates under the watchful eye of the global floricultural network [50,51]. To keep up with international shift in focus to quality, efficiency and responsiveness, RFH has embarked on a journey of cooperation with a digital platform and a transportation consortium to further extend the level of service it can offer her associates [7,52,53].

The final goal for RFH is to become the fulfilment partner for growers and buyers in the floricultural industry, facilitating every aspect of the supply chain efficiently, transparent and for the best price [54,55].

3.2 Cut flower process

The business process that is used as subject of the case study, is that of cut flowers through the auction location in Naaldwijk, executed by the Logistics Operations department (LO). For the design process, the scope is fixed on the distribution of cut flowers in packaging units, after auction, before they are delivered to the buyers.

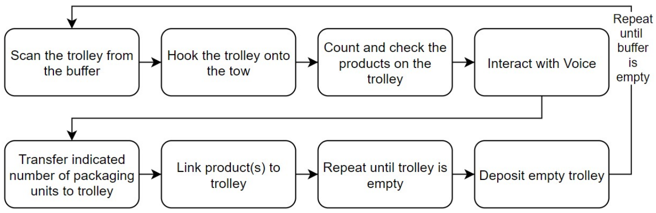

Figure 3: Business process scope: distribution

The process consists of eight steps, that are repeated until the supply of auction trolleys with cut flowers in packaging units ends. It is especially interesting for the design, as this process is where most mistakes originate. As the packaging units are transferred manually from one trolley to another, requiring both caution to prevent damages and focus to prevent counting or linking mistakes.

3.3 Process performance

The quality performance of the distribution process is reported on by one key performance indicator (KPI), from the search and correction department to the distribution teams, and to the higher managerial level of the department. The KPI reflects the total number of mistakes made during the distribution process and is expressed in a percentage of the total number of (manual) transactions that took place during the daily operations. For the reference year, which was 2019 to eliminate the external influence of the global pandemic, the department reported the KPI weekly. The KPI has a target of a maximum of 0,15% mistakes of all transactions per auction day, which was exceeded for every week, with only a couple of days the process reached the target or stayed below the maximum number of mistakes.

The mistakes that originated in the distribution process cost RFH Naaldwijk € 232.000,- in 2019, where the directly compensated sum for damaged or lost products was close to € 143.000,-, and the indirect cost for the labour of searching for the cause added to a rounded sum of € 89.000,-.

The factors that influence the process quality directly are seven mistakes with human cause in the distribution process and the late delivery of the transferred packaging unit with cut flowers. However, the late delivery is not specified to find causes in the LO department, therefore it is not listed in the departments' KPIs.

Both the performance on the company's own KPI and the resulting cost do not indicate that the process quality is in control, thus implementing a process performance measurement system could severely benefit both the total number of mistakes made, as well as the company's bottom line.

4. Design

This section describes the operationalization of the proposed framework on the selected business process, thus complementing the groundwork the original authors did and extending the academic body of knowledge.

The application of the framework is done with use of the abbreviated design steps Dörnhöfer et al. used in their performance measurement system development method [37].

After the (K)PIs are operationalized, the framework is translated to a mathematical model, enabling a forecast of the effects of implementation, both short and long term.

4.1 Final design

The first step taken to generate the final design, is the analysis of case-related objectives, ensuring the fit of the framework to the operational circumstances. These objectives are a supplement to the earlier stated theoretical objectives, increasing both the practical and theoretical application of best practices.

RFH wants to both expand and change the services it offers her growers and buyers. Delivering on the promised level of service, requires a performance measurement system that evolves alongside the improvements and developments in the process. On the short term that means it should fit the new logistics concept [55].

To increase employee involvement in continuous improvement, RFH Naaldwijk has started the implementation of an operational excellence strategy. For the framework to be accepted in the organisation, it should fit this strategy by incorporating the required maturity level on KPIs and their use.

Lastly, the framework should be applicable to the process steps before and after the ones in this particular scope.

Applying these objectives and the available mistake data specifications to the preliminary design, results in the final design visible below.

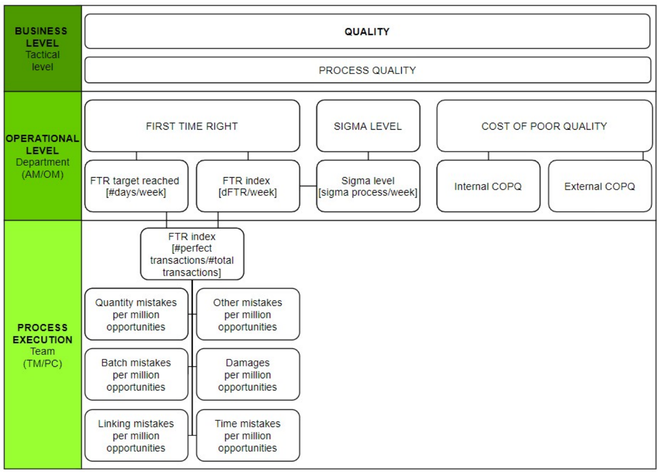

Figure 4: Final design

This design includes the following (K)PI categories: First time right (FTR), sigma quality level (SQL) and cost of poor quality (COPQ).

The KPI category FTR is split in two weekly reported KPIs. One reports on the number of days the FTR target was reached, the other reports on the average level of FTR during that week as a percentage of total number of transactions. The input for these weekly KPIs is a daily KPI of the FTR level, that is split in PIs for specific mistakes per million opportunities. The mistakes reported are: quantity mistakes, batch mistakes, damages, linking mistakes, time mistakes (late deliveries) and other mistakes not specifically listed. This specification is done to enable focused control measures when the process exceeds the maximum number of mistakes, which fits the continuous improvement strategy RFH implemented.

The SQL KPI is one metric, reported weekly, 'which quantifies the level of control by resulting in the number of sigmas the process variance experienced through that week.

The COPQ category are two PIs, as the cost is the result of where the KPIs report on: Quality. By not focusing on cost, the essence of zero-defects logistics philosophy is impressed on the framework [46]. The PIs report on internal and external COPQ, dividing the labour and compensation cost between mistakes that were found internally by employees and mistakes that were reported by customers.

All data required to calculate the KPIs is available through current communication lines, although it does require specification per department, to further clarify exactly what causes the mistakes and what the results are, both in FTR levels and in the COPQ.

4.2 Model

To enable the calculation of expected effect on the process of implementing the final framework, it requires the quantification into a mathematical model. In order to achieve this, a swim-lane diagram was used to visualize the process and its overarching levels. The diagram is visualized in Figure 5.

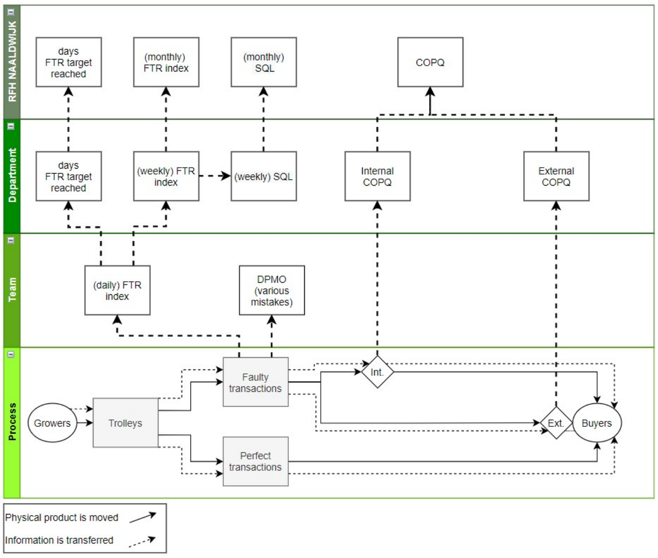

Figure 5: Swim-lane diagram LO

With the connections that the swim-lane specified, the following equations were used to calculate the weekly (K)PIs, omitting the daily (K)PIs for brevity's sake:

KPI average FTR index per week:

$$\mu FTR_w = \frac{\sum_{d=1}^{5} FTR_{wd}}{d_1 + d_2 + d_3 + d_4 + d_5} \qquad (\forall w \in W) \qquad (1)$$

KPI FTR target reached per week:

$$T_{FTR_w} = \sum_{d=1}^{5} T_{FTR_{wd}} \qquad (\forall w \in W) \qquad (2)$$

KPI SQL per week:

$$SQL_w = 1,5 + (invnormcdf(FTR_w) \qquad (\forall w \in W) \qquad (3)$$

PI Internal COPQ per week:

$$COPQ_{wi} = (\sum_{i=1}^{6} ST_{wi} * 26) + (\sum_{i=1}^{6} C_{wi}) \qquad (\forall w \in W, \forall d \in D) \qquad (4)$$

PI External COPQ per week:

$$COPQ_{we} = (\sum_{e=1}^{6} ST_{we} * 26) + (\sum_{e=1}^{6} C_{we}) \qquad (\forall w \in W, \forall d \in D) \qquad (5)$$

With the following parameters:

- $FTR_{w(d)}$: First time right per (day in a) week
- $T_{FTR_{w(d)}}$: First time right target reached per (day in a) week
- ST_{wdsi} : Average search time for internally found specific mistakes per day per week
- ST_{wdse} : Average search time for externally found specific mistakes per day per week
- C_{wi} : Compensation for the customer for internal found mistakes per week (€ 798,32)*
- C_{we} : Compensation for the customer for external found mistakes per week (€ 1.948,68) *

* Varies based on product price for auction, the average of 2019 is used

4.3 Verification and validation

For the results of the calculations to be useful as forecasting method, the model requires verification and validation. To verify whether the model is correct, more specifically, whether it is a realistic representative to use averages for search times and compensation cost. As the baseline mistake parameters are based on the data from 2019, the verification run results in the same KPI values as the initial performance assessment produced, with the added KPI for SQL:

- FTR target was reached a total of 16 days in 2019;
- FTR average was 99,78%;
- SQL was 4,4.

However, the results for COPQ differed from the initial calculations; the model calculated the combined COPQ to be around € 210.000,-, while the actual amount for 2019 was closer to € 231.000,-. As the compensation cost will always depend on the daily selling price of that particular product, this difference is accepted, deeming the model correct in its calculations.

To determine whether it is the correct model, the model is validated with use of statistics and by comparing the structure and hierarchy to RFH Naaldwijk's internal requirements. As it was designed with the latter in its objectives, the model fits within the managerial context of RFH Naaldwijk.

The statistical analysis focused on determining correlation between input and process variables, and the (K)PIs. To result in reliable values that can be used in a control chart, the model should calculate the KPIs and PIs reporting on process capability in a manner that is not sensitive to input variation. However, the units used to calculate process performance, should have a connection to the process, in order for the indicators to be useful in controlling it.

After analyzing the correlation between the input variables, number of expected transactions and batches per trolley, and the proposed (K)PIs, it could be concluded that the use of DPMO for PIs results in useful information when using the number of expected transactions as input. The number of batches per trolleys. however, showed nearly no correlation and should thus remain excluded from calculations.

For the process variables: number of employees and productivity, a similar analysis was done. This resulted in a slight indication that the number of employees affect the number of mistakes in a patterned manner, but as that metric is already reported in another KPI at RFH, it was not included to calculate the expected number of mistakes. Even though productivity is listed as process variable, it is the outcome of the process, as it is not a set number that the department determines daily or weekly. This, coupled with its limited correlation with the mistakes reported in PIs, lead to its remaining excluded from the model.

Both verification and validation returned that the model is correct and will result in a reasonably reliable forecast of the effect of implementing the framework.

5. Evaluate

To answer the final sub-question, namely how the system would affect the process and performance in its current and future state, the mathematical model is used to calculate the effect on the short term (current state) and long term (future state) configuration of the process.

To mimic possible input changes, both short and long term configurations are calculated with three different levels of input. The first input variant is the baseline of transactions in 2019, the second is based on the historical decrease of transactions with four percent due to a shift away from the auction, and the third is based on the expected increase of transactions with five percent due to the change in logistics concept of distributing the packaging units.

5.1 Variants

The short term impact of implementing the framework is defined as reaching the current target of 0,15% mistakes on the total number of transactions, translated to 1500 DPMO and a sigma level of 4,5. To facilitate this decrease of mistakes, the process was calculated to produce 55% less quantity and batch mistakes, and cause the same percentage less damages.

To calculate the long term impact, the historical increase of SQL of 0,86 is used to alter the DMPO and the number of mistakes retroactively.

To facilitate the successful implementation of the framework, it is recommended to appoint a person or team to be responsible for the quality of the process: Process Quality Control (PQC). This not only ensures that there is a champion for the system, it also centralizes the data gathering and reporting, simplifying communication lines.

5.2 Results

Running the two variants with the different input levels, gives a quantification of the expected results of successfully implementing the framework, and thus answering the final sub-question. The outcome is grouped per indicator in the framework, to mimic the use of the system and its results over a year. The baseline of 2019 is included, as well as a short term decrease in transactions and a long term increase due to developments in the process.

First time right

The FTR KPI indicates a steady increase of transactions that are right the first time, ultimately resulting in FTR level of 99.98% over a year. During that year, the target was reached on all auction days. The process shows to be increasingly more in control, as there is more information about the origin of mistakes in the distribution process.

Variant	FTR target	FTR Index	
2019 (0)	16	99,78%	-
Target(0)	232	99,89%	0,11%
Target(-4%)	232	99,89%	0,11%
Future(0)	253	99,98%	0,20%
Future(+5%)	253	99,98%	0,20%

Sigma Quality Level

The KPI for sigma quality level shows the increase of the sigma level parallel to the increase of FTR, which is unsurprising since the latter functions as input for this KPI. The first increase is from 4,4 to 4,6, a decrease of close to 1000 DPMO in the process. Towards the future state, the calculations result in an increase from 4,4 to 5,3. This would theoretically mean the number of mistakes would decrease with 97%, which was deemed unrealistic and thus scaled down to 90%. The final SQL will then be 5, bringing the process close to the optimum of 6 sigma mistake variation.

Cost of poor quality

As a result of the mistakes made in the process and based on an average compensation per mistake, the cost of poor quality shows the expected impact on the bottom line. As the selling prices vary, the impact on the yearly cost in percentages is used as final result of the calculations.

Variants	Internal COPQ		Total COPQ	
Target(0)	€ 122.193,97	-15,6%	€ 176.446,57	-14,9%
Target(-4%)	€ 121.359,46	-19,4%	€ 175.102,46	-18,5%
Future(0)	€ 105.709,12	-32,0%	€ 149.338,26	-32,8%
Future(+5%)	€ 105.928,01	-37,1%	€ 149.662,98	-39,0%

Variants	External COPQ		Total COPQ	
Target(0)	€ 62.677,98	-13,2%	€ 176.446,57	-14,9%
Target(-4%)	€ 62.677,98	-16,5%	€ 175.102,46	-18,5%
Future(0)	€ 62.677,98	-34,7%	€ 149.338,26	-32,8%
Future(+5%)	€ 62.677,98	-43,5%	€ 149.662,98	-39,0%

The tables illustrate the possible impact on the company's cost for poor quality in the distribution process of cut flowers ranges from 18,5% in the year after implementation (short term) to as much as 39% after the future state has been realized.

There is a difference between the relative decrease in cost for internal and external COPQ, which is due to the type of mistakes that are made. The most expensive ones are those caught by customers, so if both internal and external found mistakes decrease with an equal amount of mistakes, it will have a higher impact on the external COPQ.

As for all variants there is an expected decrease in COPQ, it can be concluded that the quality performance measurement system has the potential to change the process for the better.

6. Conclusion

The research question posed at the start has been answered throughout the research phases, combining the answers to the sub-questions into the general conclusion.

Zero-defects logistics is a philosophy that extends defects in products to achieving no defective elements in a process. It is an element of quality management as it is used in popular methods such as TQM, Lean and Six sigma. Based on the reviewed sources, the state-of-the-art in performance measurement is different for the industries that were included. However, the design process combined features of three models to result in the preliminary design, of which two are from the automotive industry.

The optimal quality performance measurement and control system is configured as a layered framework, that has different hierarchical levels that fit the managerial levels of the company. The (K)PIs are linked and they all have reporting frequencies that fit the level they are reported to. At least three (K)PI categories are considered necessary: first time right, sigma quality level and cost of poor quality. These give a multi-dimensional image of the performance, including its financial effect. The (K)PIs reporting on process capability are calculated to mitigate the influence of input variation.

The process at Royal FloraHolland does not appear to be in statistical control, as it exceeds its maximum number of mistakes frequently. These excesses are caused by seven mistakes that are the result of human actions in the distribution process for cut flowers.

To fit the proposed framework to the business process, it was matched to the objectives and critical process elements with use of an abbreviated list of design steps. This resulted in the hierarchical levels to be specified to the teams and the department that is responsible for the process. Furthermore, the (K)PIs were adapted to fit the available data and reporting frequencies.

Finally, after quantification, verification and validation, the mathematical model was deemed useful for forecasting the implementation and thus used to calculate the impact on current and future state. For both current and future state, the expected input variation was used, which resulted in significant savings on the internal and external COPQ. The short term implementation could save as much as 18,5% in the combined COPQ, where long term results come closer to 39%. Both potential savings would justify the implementation of the framework.

In conclusion, the quality performance of a distribution process for cut flowers can be measured and controlled with use of the proposed framework, whilst incorporating the zero-defect logistics philosophy. The framework is expected to result in a higher percentage of FTR transactions and a lower sum of money lost to rectify or compensate mistakes.

7. Recommendations

Though this research reported a successful step towards operationalization of GPI model with use of best practices from the automotive industry and Lean Six Sigma methodology, it did not implement the resulting framework in the process. It is recommended to do so through a pilot run for the department, with an initial focus on cut flowers, and if it turns out to be successful and acceptable, it can be extended to encompass the entire process.

Furthermore, it was only fitted to the distribution process of cut flowers in Naaldwijk. To ensure the generic fit and thus theoretical value, it should be operationalized to fit more processes in different industries.

Thirdly, while the use of a swim-lane diagram as a basis for quantification into a mathematical model worked in this design process, there are few academic sources that back this method. Exploring the wider application of a swim-lane diagram is another possible subject for future research that is recognized.

The final recommendation is to expand on the appointment of a Process Quality Control unit, both to find more theoretical justification as well as practical arguments to do so in combination with a hierarchically layered framework. The scope of this research did not include this interesting subject.

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B Tables and figures

B.1 Research gap

Reference	SCM	Auction operations	BPM	PPMS	GPI	Lean/push-pull	PPI/KPI	Floriculture	Service industry	Other industries	Literature	Framework/model	Simulation	Case study
Kueng (2000)			X	X						X	X	X		
Neely et al (2000)				X						X	X	X		X
Krauth et al (2005)				X					X		X			X
Aramyan et al (2006)	X						X			X	X			
Rodriguez et al (2009)							X			X	X	X	X	X
Glavan (2011)				X						X	X			
van Dooijeweert (2014)							X		X		X	X		X
Iuga et al (2015)					X		X			X	X	X		X
Kucukaltan et al (2016)				X			X				X	X		
Blasini & Leist (2013)				X			X		X		X			X
Van Looy & Shafagatova (2016)				X			X			X	X			X
Hailiye (2019)														
Simeunovic et al (2020)					X		X			X	X	X		X
Chen (2015)	X							X			X	X	X	X
Keizer et al (2015)	X							X			X			
Vd Vorst et al (2016)	X		X					X			X			X
Binneveld (2017)		X				X		X			X	X		X
Lin (2019)	X							X			X			X
This research		X			X	X	X	X			X	X		X

Figure 20: Visualization of research gap

B.2 GPI Model

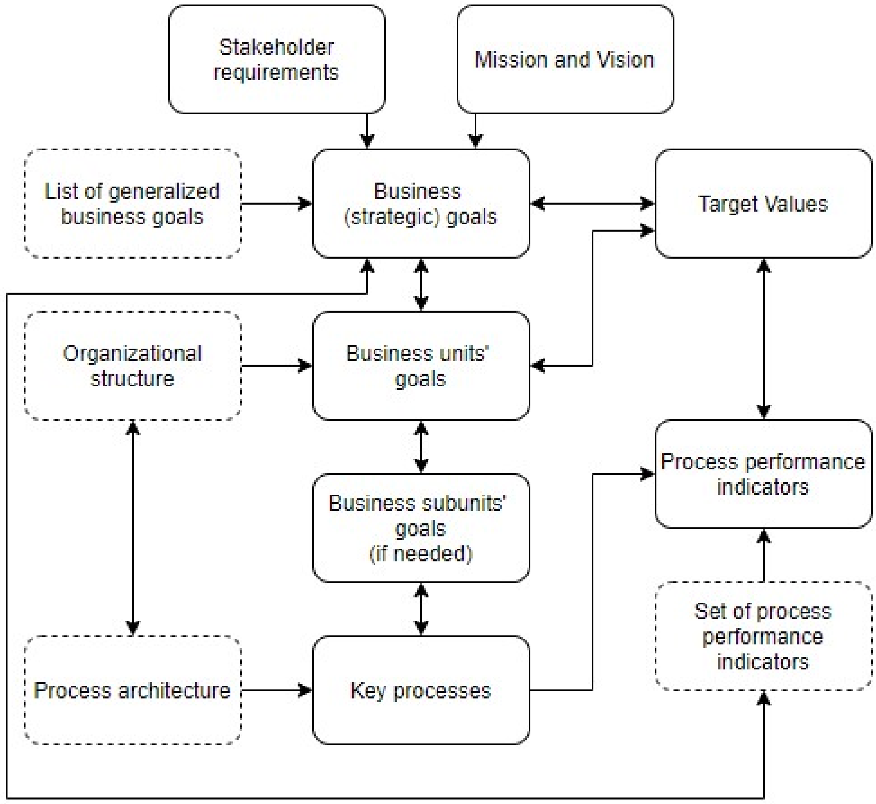

Figure 21: The GPI model as designed by Simeunovic et al [111]

B.3 Key performance indicators

KPI name/description	Krauth et al. 2005	Aranyan et al. 2006	Rodriguez et al. 2009	Glavan, 2011	van Dooijeweert, 2014	Iuga et al. 2015	Kucukaltan et al. 2016	Simeunovic et al. 2016	Haliye, 2019		Torman, n.d.	AuditShipment, n.d.	Datapine, n.d.	
Cost (operations)	X	X		X			X	X	X				X	7
Cost (service)	X			X	X			X	X			X	X	7
Delivery (on-time)	X			X			X	X			X	X		6
Cost (overhead)	X	X		X					X				X	5
Product (damaged or failed)		X			X	X		X				X		5
Time (lead-time)				X		X		X					X	4
Customer (satisfaction)		X			X	X								3
Capacity (transport)							X		X					2
Capacity (utilization)	X								X					2
Customer (complaints)						X		X						2
Delivery (frequency)	X			X										2
Delivery (total number)	X												X	2
Orders (accuracy)											X		X	2
Orders (failed)	X							X						2
Orders (perfect)	X										X			2
Process (conformance)			X	X										2
Production (volume)						X		X						2
Profit		X					X							2
Quality (output)				X		X								2
Quality (preventive measures)				X				X						2
Cost (controllable by facility)									X					1
Cost (failure)	X													1
Cost (fulfilment per order)									X					1
Cost (prevention)	X													1
Cost (scraps and repairs)						X								1
Customer (total number)	X													1
Delivery (time late)											X			1
Equipment effectiveness						X								1
Labour (productivity)	X													1
Labour (utilization)	X													1
Orders (late)		X												1
Orders (lost)		X												1
Orders (total)	X													1
Process (continuous improvement)	X													1
Process (unplanned interuptions)						X								1
Profit (saved by prevention)						X								1
Quality (process)		X												1
Quality (waste)								X						1
Quality (perceived)				X										1
Time (throughput)					X									1

Figure 22: Table with product and process quality related KPIs from sources

C First draft

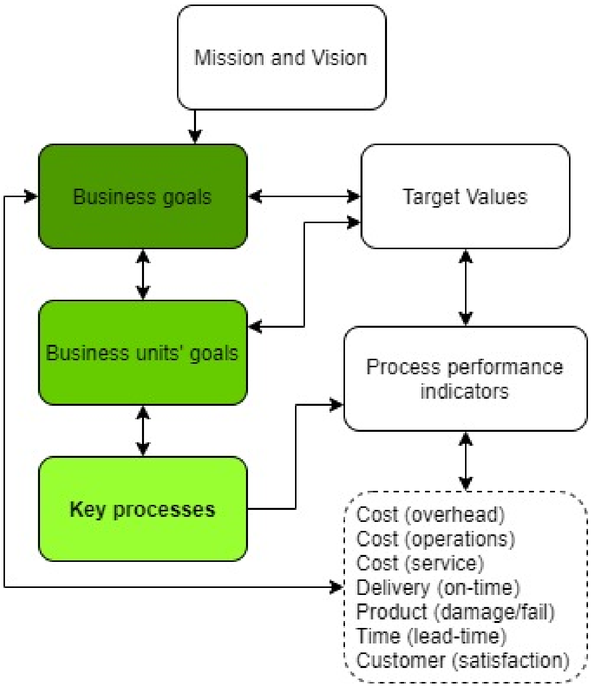

Figure 23: GPI-RFH first draft

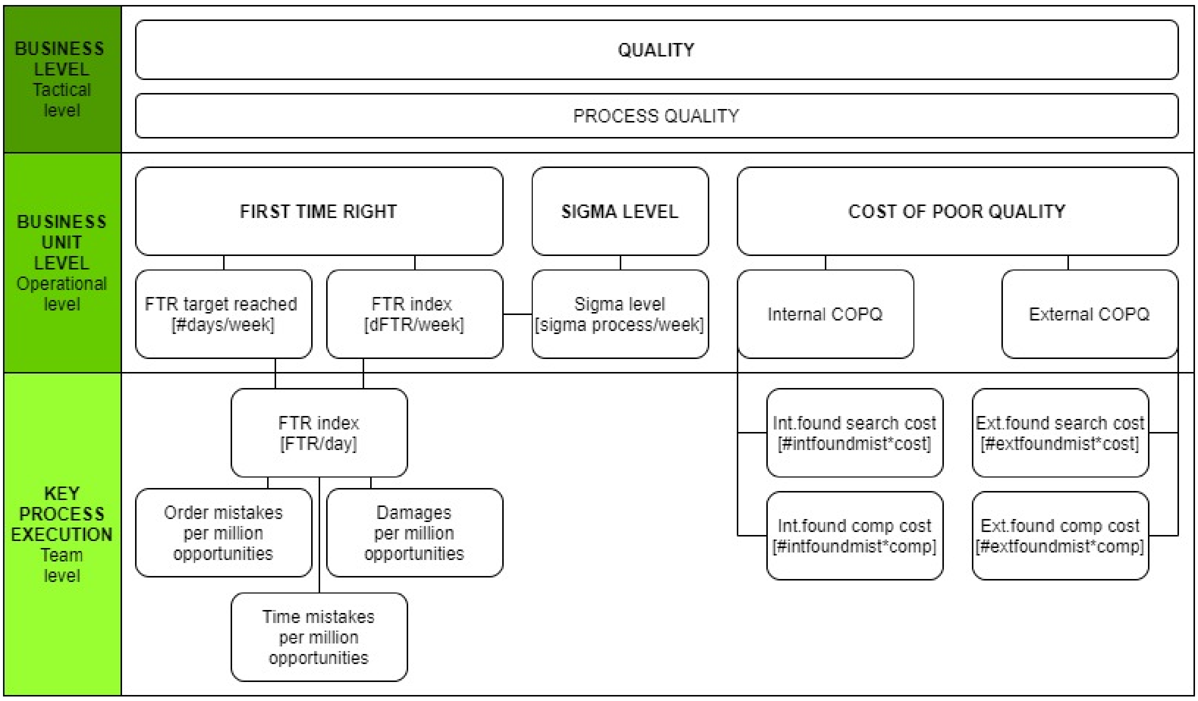

Figure 24: GPI-RFH levels first draft

D Royal FloraHolland

D.1 Organisation chart RFH

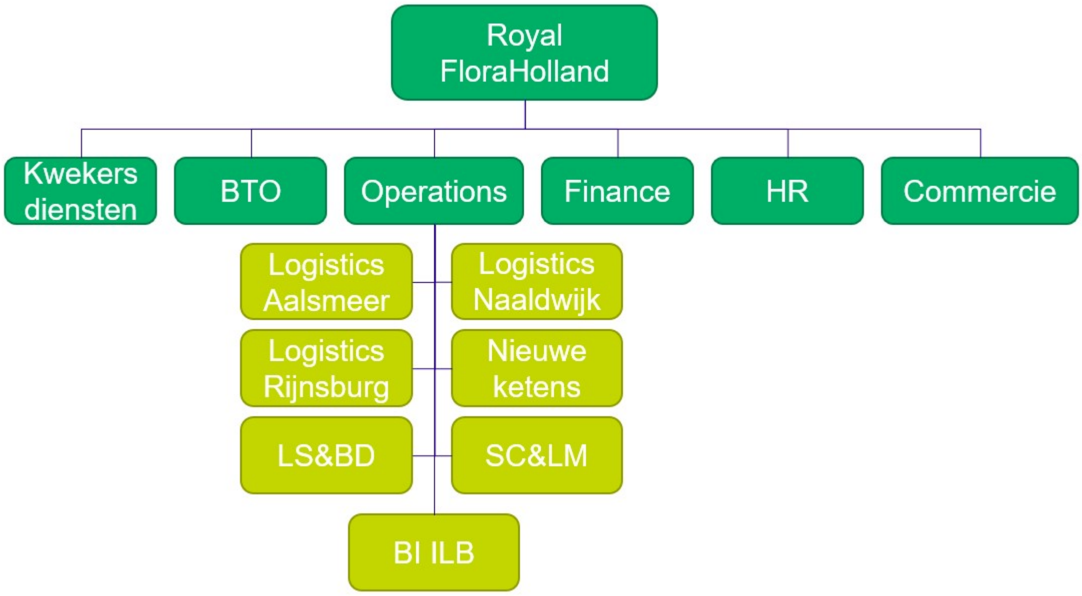

Figure 25: Organisation chart, adapted from internal document by author

D.2 Organisation chart RFH Naaldwijk

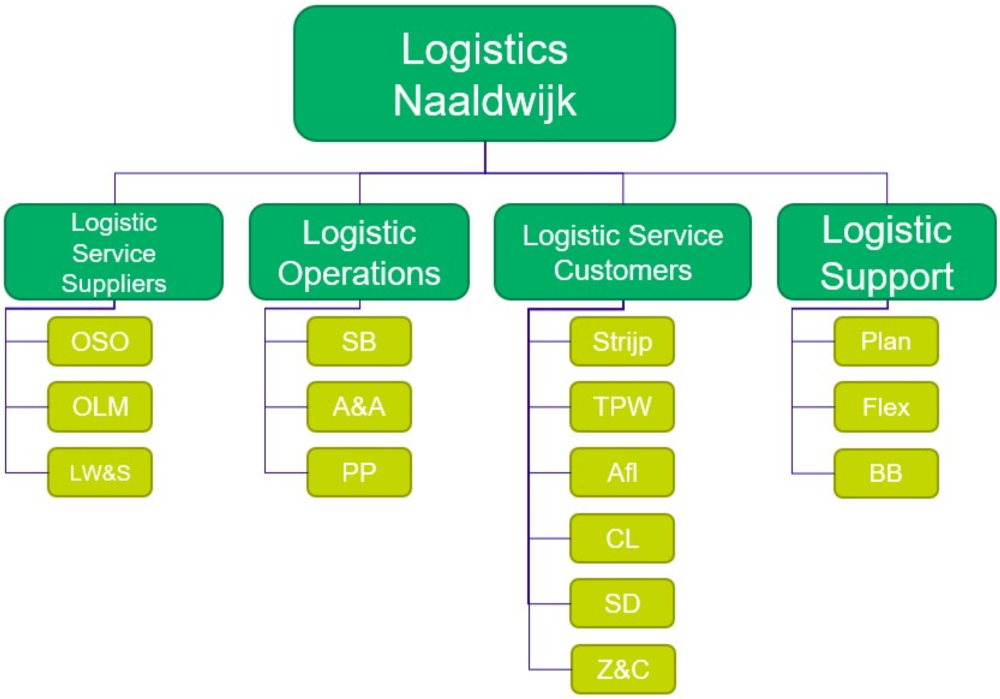

Figure 26: Organisation chart Naaldwijk, adapted from internal document by author

D.3 Operational Excellence Framework

Table 14: OpEx blocks and elements, adapted from internal document

Block	**Element**	**Block**	**Element**
Strategy	Business strategy	Control	Management Accounting
Strategy	Opex strategy	Control	(Supply) Chain Management
Strategy	Customer Interaction	Control	Key Performance Indicators
Process	Work Space Organisation	Control	Business Intelligence
Process	Work Standardization	Control	Infrastructure Continuous Improvement
Process	Employees and Resources	Organisation	Roles and Responsibilities
Process	Visual Management	Organisation	CI Organisation
People	Problem Solving Mindset	Organisation	Communication
People	Safety Culture		
People	Change and Improvement Capacity		
People	Leadership		
People	Cooperation and Team Work		

D.4 Operational Excellence KPI table

Table 15: KPI level 1, 2 and 3 requirements, adapted from internal document

Level	**Minimal requirements**	**Done if**
1. Graphs provide a reviewing snapshot of the process	No clear direction or target for the team Directive leadership required for results	KPIs are listed in management reports KPIs indicate output (only)
2. Graphs include trends to recognize patterns in retrospect. The KPI targets are synchronised to department goals	No united effort towards the target Directive and inspirational leadership required for results	KPIs are visible for team managers KPIs are presented in trend lines KPIs have a clear target Department and team targets are linked KPIs have clear definitions, sources and calculations Stuctural weekly feedback loop
3. Leading KPIs are based on critical processes. A balanced set of PPIs and output KPIs supports the leading KPIs.	Clear target and reason behind the target Inspirational leadership and communication required for results	KPIs are known to all team members All KPIs are based on PSQSC drivers Review and control happens on a daily basis

D.5 Process flows

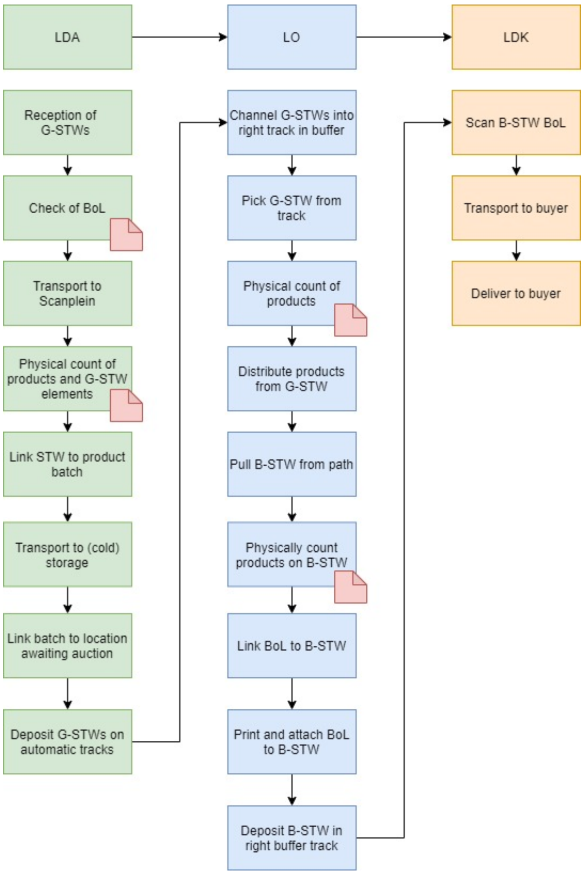

Figure 27: Logistics cut flower process Naaldwijk

D.6 Cost tables and figures

Table 16: Specified cost for LSS 2019 (source: author)

Faulty trolleys	**Number**	**Labour cost**	**€/mistake**
Missed	3712	€ 7.020,56	€ 1,89
Total	7086		

Table 17: Specified cost for LSC 2019 (source: author)

Mistakes	**Number**	**Labour cost**		**€/mistake**
Delivery	219	€ 2.086,90	35,8%	€ 9,53
Damage	687	€ 3.455,18	59,3%	€ 5,03
Total	**952**	**€ 5.823,47**		**€ 14,56**

D.7 RFH Naaldwijk Performance

Weeknr	Transaction	Mistakes	Percentage	Labour cost	Compensation
1	81283	208	0,26%	€ 1.050,61	€ 1.428,68
2	110334	224	0,20%	€ 1.141,03	€ -
3	112203	235	0,21%	€ 1.441,90	€ 1.688,13
4	114509	281	0,25%	€ 2.105,17	€ 2.011,87
5	116660	256	0,22%	€ 1.861,40	€ 5.082,67
6	136581	309	0,23%	€ 1.565,12	€ 1.817,86
7	128368	253	0,20%	€ 1.289,88	€ 4.288,67
8	130578	273	0,21%	€ 1.275,97	€ 3.052,82
9	137495	282	0,21%	€ 1.966,08	€ 3.646,37
10	123348	249	0,20%	€ 1.330,85	€ 3.728,08
11	127586	258	0,20%	€ 1.153,94	€ 2.762,85
12	124018	270	0,22%	€ 1.681,72	€ 1.891,64
13	132070	208	0,16%	€ 1.703,14	€ 2.334,29
14	130317	249	0,19%	€ 1.467,18	€ 2.208,37
15	128775	235	0,18%	€ 1.401,99	€ 2.332,83
16	113374	271	0,24%	€ 1.756,38	€ 2.473,26
17	148160	316	0,21%	€ 1.123,03	€ 2.574,65
18	132113	263	0,20%	€ 1.552,63	€ 2.165,33
19	147553	306	0,21%	€ 2.314,61	€ 3.286,79
20	136233	262	0,19%	€ 1.793,65	€ 3.548,19
21	144079	286	0,20%	€ 1.872,29	€ 2.883,04
22	129103	258	0,20%	€ 1.454,95	€ 3.419,93
23	139187	284	0,20%	€ 1.395,36	€ 2.168,66
24	114222	201	0,18%	€ 1.139,20	€ 2.406,75
25	128238	270	0,21%	€ 1.475,32	€ 2.395,51
26	124425	267	0,21%	€ 1.927,29	€ 4.271,66
27	124129	208	0,17%	€ 1.220,56	€ 2.875,30
28	119457	311	0,26%	€ 2.297,95	€ 1.784,65
29	119628	292	0,24%	€ 2.335,96	€ 2.684,26
30	108126	274	0,25%	€ 1.813,42	€ 1.430,27
31	111819	264	0,24%	€ 1.694,45	€ 2.281,53
32	115206	318	0,28%	€ 2.752,40	€ 2.673,38
33	123293	279	0,23%	€ 1.488,33	€ 1.964,82
34	130732	307	0,23%	€ 1.937,01	€ 1.971,84
35	128997	315	0,24%	€ 2.051,00	€ 2.711,16
36	132143	304	0,23%	€ 1.681,85	€ 2.059,45
37	131393	278	0,21%	€ 1.612,18	€ 3.014,31
38	135330	284	0,21%	€ 1.555,55	€ 2.262,67
39	136978	306	0,22%	€ 2.041,54	€ 3.300,66
40	136573	297	0,22%	€ 1.942,89	€ 2.921,10
41	127639	306	0,24%	€ 1.920,05	€ 1.921,91
42	127848	248	0,19%	€ 1.415,60	€ 1.936,57
43	135418	339	0,25%	€ 2.269,27	€ 2.756,43
44	128493	272	0,21%	€ 1.781,27	€ 4.955,12
45	115963	219	0,19%	€ 1.298,73	€ 1.651,17
46	119332	347	0,29%	€ 3.101,50	€ 2.309,17
47	115634	273	0,24%	€ 1.661,65	€ 3.946,28
48	119392	258	0,22%	€ 1.884,66	€ 2.152,88
49	113563	237	0,21%	€ 1.682,50	€ 6.847,26
50	111267	274	0,25%	€ 1.538,27	€ 6.144,09
51	128196	338	0,26%	€ 2.259,93	€ 1.840,40
52	74407	186	0,25%	€ 1.114,27	€ 2.578,28

D.8 Initial KPI Values

Weeknr	DPMO	FTR	# FTR	SQL
1	2558,960668	99,76%	0	4,31
2	2030,199213	99,81%	1	4,39
3	2094,418153	99,80%	1	4,37
4	2453,955584	99,76%	0	4,32
5	2194,411109	99,79%	0	4,36
6	2262,393744	99,78%	0	4,34
7	1970,896174	99,81%	1	4,40
8	2090,704407	99,80%	0	4,37
9	2050,983672	99,81%	1	4,39
10	2018,67886	99,80%	0	4,38
11	2022,165441	99,80%	1	4,38
12	2177,103324	99,78%	1	4,35
13	1574,92239	99,85%	3	4,46
14	1910,725385	99,81%	0	4,39
15	1824,888371	99,82%	1	4,41
16	2390,318768	99,77%	0	4,33
17	2132,829374	99,79%	0	4,36
18	1990,720065	99,80%	0	4,37
19	2073,831098	99,80%	0	4,37
20	1923,175736	99,81%	0	4,39
21	1985,022106	99,80%	1	4,39
22	1998,404375	99,80%	0	4,38
23	2040,420442	99,80%	1	4,38
24	1759,73105	99,84%	2	4,44
25	2105,46016	99,79%	0	4,36
26	2145,871007	99,79%	0	4,36
27	1675,676111	99,83%	0	4,43
28	2603,447266	99,74%	0	4,30
29	2440,900124	99,76%	0	4,32
30	2534,08061	99,75%	0	4,31
31	2360,958334	99,77%	0	4,33
32	2760,272902	99,73%	0	4,29
33	2262,902192	99,77%	0	4,34
34	2348,315638	99,76%	0	4,32
35	2441,917254	99,76%	0	4,32
36	2300,538053	99,78%	0	4,34
37	2115,790034	99,79%	0	4,37
38	2098,573856	99,79%	0	4,37
39	2233,935376	99,78%	0	4,35
40	2174,66117	99,78%	0	4,35
41	2397,386379	99,77%	0	4,33
42	1939,803517	99,81%	1	4,39
43	2503,359967	99,75%	0	4,31
44	2116,846832	99,78%	0	4,35
45	1888,533412	99,81%	1	4,40
46	2907,853719	99,71%	0	4,26
47	2360,897314	99,76%	0	4,32
48	2160,948807	99,78%	0	4,35
49	2086,947333	99,79%	0	4,36
50	2462,545049	99,76%	0	4,32
51	2636,587725	99,74%	0	4,30
52	2499,764807	99,76%	0	4,32
	2.194,13	**99,78%**	**16**	**4,36**

D.9 NP chart calculations

Calculations based on Dahlgaard et al., Munro et al. and Krajewski et al. [32, 59, 75]
The NP chart tracks non-conforming units and numbers of failures in the process, based on the binomial distribution.

- n_{total}: total number of opportunities
- n: opportunities per week
- d_{total}: total number of mistakes
- d: average mistakes per week
- $p : d/n$
- $\bar{p} : d_{total}/n_{total}$

$$UpperControlLimit(n \times p) = nx\bar{p} + 3\sqrt{n \times \bar{p}(1-\bar{p})}$$
$$LowerControlLimit(n \times p) = nx\bar{p} - 3\sqrt{n \times \bar{p}(1-\bar{p})}$$

$$\begin{aligned} 2019 &: \\ n_{total} &= 52.000.000 \\ n &= 1.000.000 \\ d_{total} &= 114.095 \\ d &= 2.194 \\ p = \bar{p} &= 0,002194 \\ UCL(n \times p) &= 2.335 \\ LCL(n \times p) &= 2.054 \end{aligned}$$

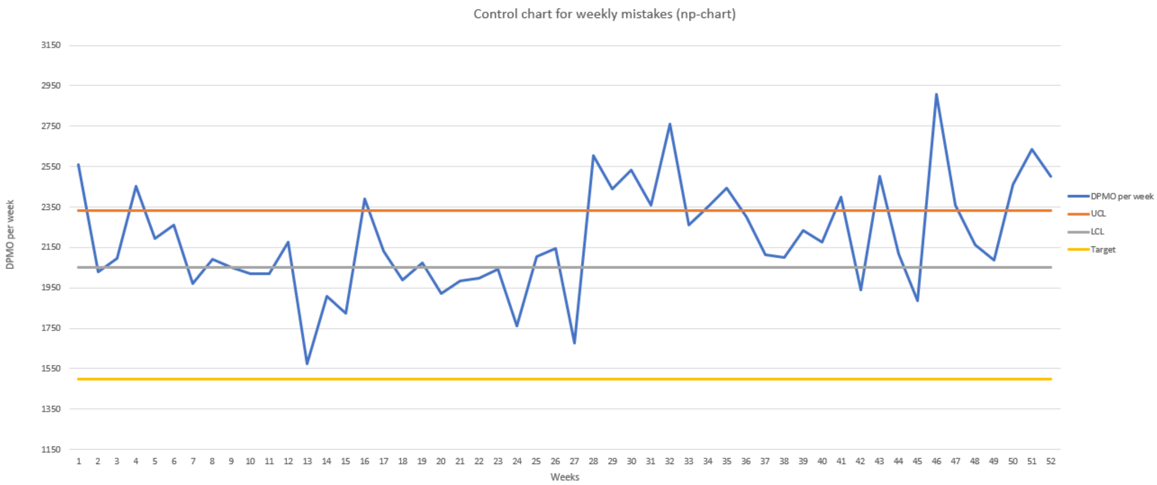

Figure 28: NP chart for 2019 in appendix

E Final Design

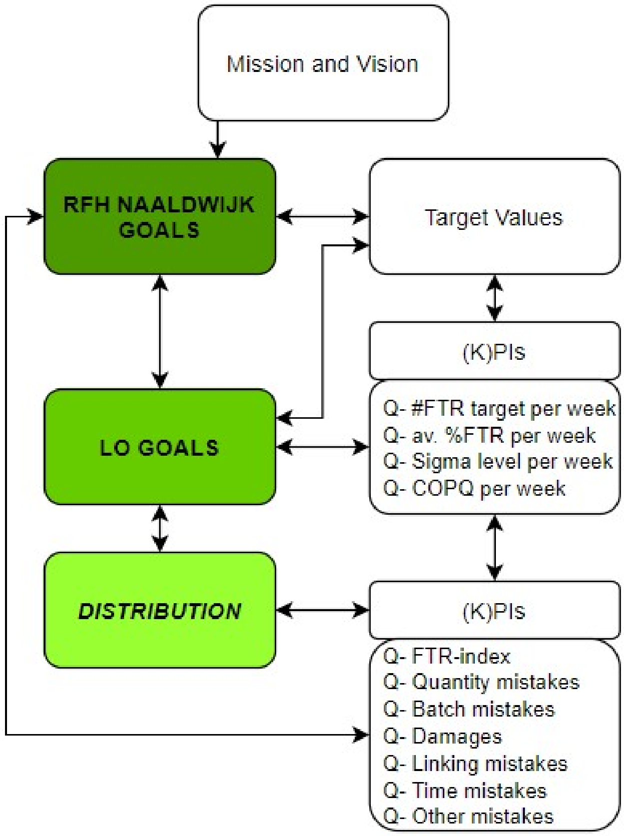

Figure 29: Final GPI application

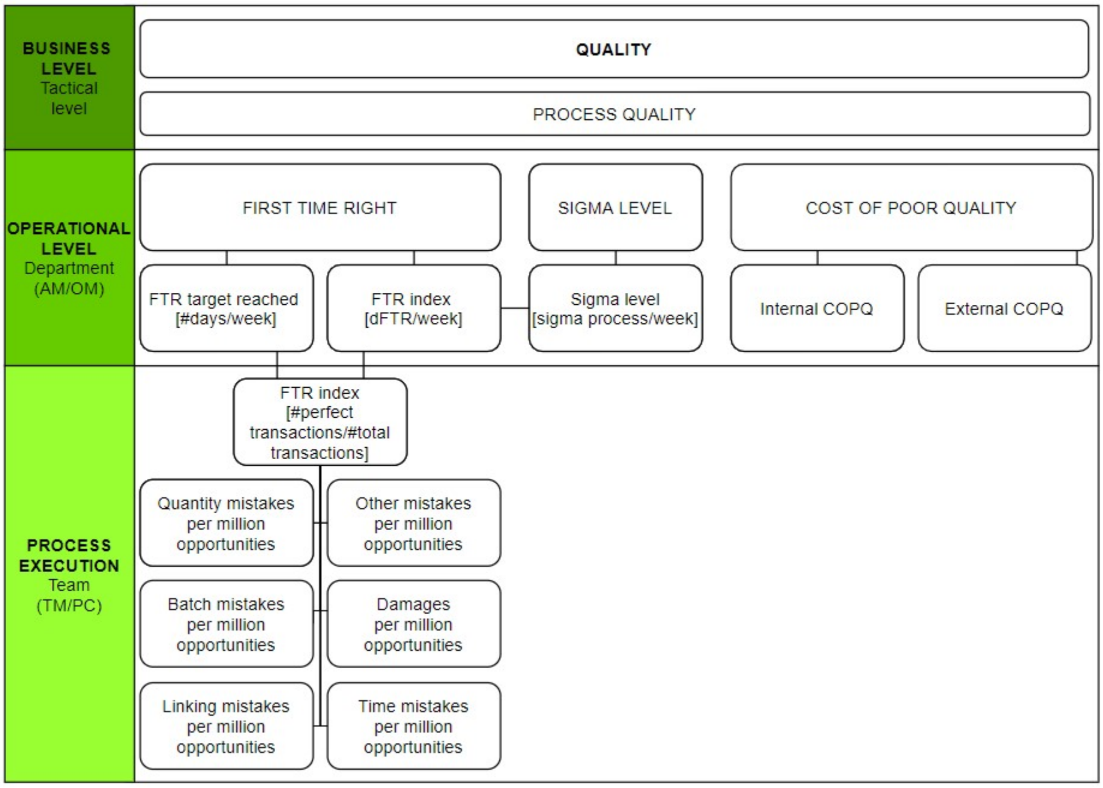

Figure 30: Final Dörnhöfer application

F Model visualization

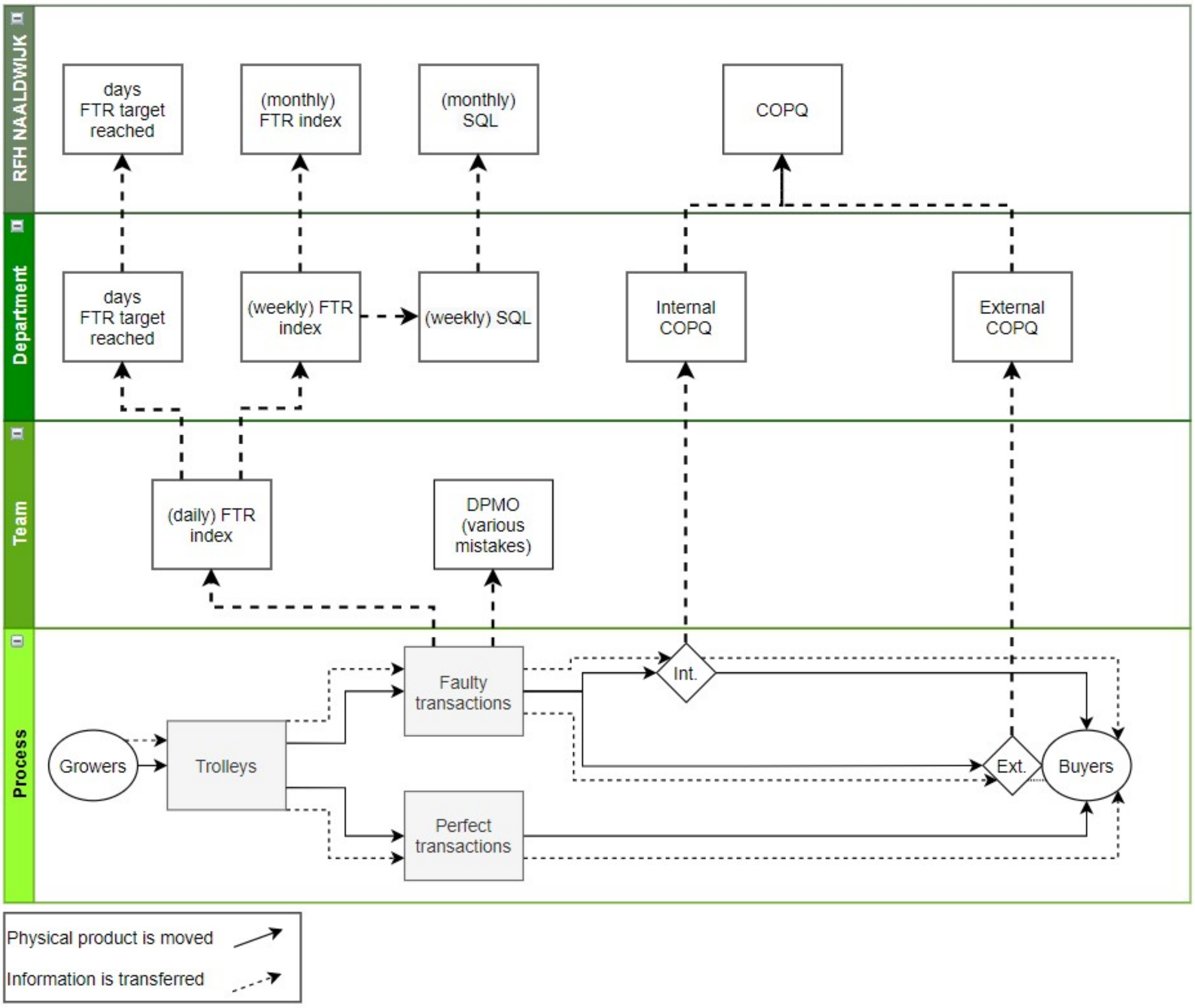

Figure 31: Visualization of the system

G Extended notation of mathematical model

G.1 Parameters and indices

Parameters:

- $FTR_{w(d)}$: First time right per (day in a) week
- $T_{FTR_{w(d)}}$: First time right target reached per (day in a) week
- TR_{wd} : Number of transactions per day in a week
- TM_{wd} : Sum of mistakes (excluding time mistakes) per day in a week
- pTM_{wd} : Historical percentage of faulty transactions (excluding time mistakes) per day in a week *
- M_{wds} : Number of specific mistakes per day in a week
- $DPMO_{wds}$: DPMO for a specific mistake per day in a week
- $M_{w(d)si}$: Number of specific mistakes found internally per (day in a) week
- $M_{w(d)se}$: Number of specific mistakes found externally per (day in a) week
- μST_{wdsi} : Historical average search time for internally found specific mistakes per day per week
- μST_{wdse} : Historical average search time for externally found specific mistakes per day per week
- pM_{wds} : Historical percentage of specific mistakes per day in a week **
- $pM_{w(d)si}$: Historical percentage of specific mistakes found internally per (day in a) week **
- $pM_{w(d)se}$: Historical percentage of specific mistakes found externally per (day in a) week **
- C_{wi} : Compensation for the customer for internal found mistakes per week (€ 798,32)***
- C_{we} : Compensation for the customer for external found mistakes per week (€ 1.948,68) ***

* Used when variations in input are simulated
** Used for the purpose of simulation, not used in applied system
*** Varies based on product price for auction, an average is used
Indices:

- Weeks (W) = 1, 2,..., 51, 52
- Days (D) = 1, 2, 3, 4, 5
- Mistake types (S) = 1, 2, 3, 4, 5, 6
- Internally found mistakes (I) = 1
- Externally found mistakes (E) = 2

G.2 Formulas

KPI average FTR index per week:

$$\mu FTR_w = \frac{\sum_{d=1}^{5} FTR_{wd}}{d_1 + d_2 + d_3 + d_4 + d_5} \qquad (\forall w \in W) \tag{1}$$

KPI FTR target reached per week:

$$T_{FTR_w} = \sum_{d=1}^{5} T_{FTR_{wd}} \qquad (\forall w \in W) \tag{2}$$

KPI SQL per week:

$$SQL_w = 1,5 + (invnormcdf(FTR_w) \qquad (\forall w \in W) \tag{3}$$

PI Internal COPQ per week:

$$COPQ_{wi} = (\sum_{i=1}^{6} ST_{wi} * 26) + (\sum_{i=1}^{6} C_{wi}) \qquad (\forall w \in W, \forall d \in D) \tag{4}$$

PI External COPQ per week:

$$COPQ_{we} = (\sum_{e=1}^{6} ST_{we} * 26) + (\sum_{e=1}^{6} C_{we}) \qquad (\forall w \in W, \forall d \in D) \tag{5}$$

PI FTR index per day:

$$FTR_{wd} = \frac{TR_{wd} - TM_{wd}}{TR_{wd}} \qquad (\forall w \in W, \forall d \in D) \tag{6}$$

PI DPMO for specific mistakes per day:

$$DPMO_{wds} = (\frac{M_{wds}}{TR_{wd}}) * 1.000.000 \qquad (\forall w \in W, \forall d \in D, \forall s \in S) \tag{7}$$

Secondary calculations:

$$T_{FTR_{wd}} = \begin{cases} 1 & \text{if } FTR_{wd} \geq \text{target} \\ 0 & \text{otherwise} \end{cases} \qquad (\forall w \in W, \forall d \in D) \tag{8}$$

$$TM_{wd} = \sum_{s=1}^{6} M_{wds} \qquad (\forall w \in W, \forall d \in D, \forall s \in S) \tag{9}$$

or

$$TM_{wd} = TR_{wd} * pTM_{wd} \qquad (\forall w \in W, \forall d \in D) \tag{10}$$

$$M_{wds} = TR_{wd} * pM_{wds} \qquad (\forall w \in W, \forall d \in D, \forall s \in S) \tag{11}$$

$$ST_{wi} = \sum_{d=1}^{6} \sum_{s=1}^{6} M_{wdsi} * \mu ST_{wdsi} \qquad (\forall w \in W, \forall d \in D) \tag{12}$$

$$ST_{we} = \sum_{d=1}^{6} \sum_{s=1}^{6} M_{wdse} * \mu EST_{wdse} \qquad (\forall w \in W, \forall d \in D) \tag{13}$$

G.3 Framework performance implementation short term

Baseline	FTR Index	# FTR	SQL	iCOPQ	eCOPQ
1	99,87%	1	4,5	€ 2.133,94	€ 863,52
2	99,90%	5	4,58	€ 2.153,34	€ 893,85
3	99,89%	5	4,57	€ 2.245,01	€ 1.010,02
4	99,87%	4	4,52	€ 2.512,82	€ 936,93
5	99,89%	5	4,55	€ 2.337,79	€ 1.035,90
6	99,88%	5	4,54	€ 2.242,28	€ 925,96
7	99,89%	5	4,58	€ 2.334,19	€ 886,09
8	99,88%	5	4,55	€ 2.248,57	€ 978,22
9	99,90%	5	4,59	€ 2.384,10	€ 1.008,87
10	99,89%	5	4,56	€ 2.342,42	€ 914,47
11	99,89%	4	4,56	€ 2.204,20	€ 976,92
12	99,88%	4	4,54	€ 2.403,64	€ 1.001,17
13	99,92%	5	4,65	€ 2.349,69	€ 1.019,42
14	99,90%	5	4,58	€ 2.394,45	€ 923,71
15	99,90%	5	4,59	€ 2.272,64	€ 982,42
16	99,88%	4	4,53	€ 2.558,99	€ 968,83
17	99,88%	4	4,53	€ 2.200,07	€ 952,78
18	99,89%	5	4,57	€ 2.291,46	€ 1.043,10
19	99,89%	5	4,55	€ 2.491,57	€ 1.189,97
20	99,90%	5	4,58	€ 2.365,42	€ 959,60
21	99,90%	4	4,58	€ 2.314,12	€ 1.238,00
22	99,89%	4	4,56	€ 2.219,09	€ 1.013,10
23	99,89%	5	4,57	€ 2.270,63	€ 1.042,36
24	99,91%	4	4,63	€ 2.226,52	€ 999,73
25	99,89%	5	4,55	€ 2.240,31	€ 1.005,13
26	99,89%	5	4,57	€ 2.189,87	€ 1.177,46
27	99,91%	5	4,61	€ 2.159,69	€ 1.016,65
28	99,87%	3	4,5	€ 2.329,08	€ 1.236,74
29	99,87%	4	4,51	€ 2.456,82	€ 1.153,92
30	99,87%	4	4,51	€ 2.193,24	€ 1.371,65
31	99,88%	5	4,54	€ 2.250,93	€ 1.106,38
32	99,86%	4	4,49	€ 2.528,32	€ 1.206,56
33	99,88%	4	4,53	€ 2.219,17	€ 1.042,28
34	99,88%	4	4,52	€ 2.391,03	€ 1.109,76
35	99,88%	4	4,52	€ 2.366,71	€ 1.047,44
36	99,88%	4	4,54	€ 2.459,20	€ 963,69
37	99,89%	5	4,56	€ 2.471,27	€ 908,49
38	99,89%	5	4,57	€ 2.353,95	€ 965,78
39	99,89%	5	4,56	€ 2.394,59	€ 1.038,35
40	99,89%	5	4,56	€ 2.445,84	€ 1.020,75
41	99,88%	5	4,53	€ 2.427,27	€ 972,51
42	99,90%	5	4,58	€ 2.357,92	€ 900,28
43	99,87%	5	4,52	€ 2.605,78	€ 947,78
44	99,89%	5	4,55	€ 2.511,90	€ 875,33
45	99,90%	5	4,59	€ 2.305,82	€ 966,65
46	99,85%	4	4,46	€ 2.478,30	€ 2.653,95
47	99,88%	5	4,53	€ 2.417,64	€ 991,63
48	99,89%	5	4,57	€ 2.503,39	€ 923,95
49	99,89%	5	4,57	€ 2.362,82	€ 961,33
50	99,87%	4	4,52	€ 2.315,16	€ 1.007,44
51	99,87%	3	4,5	€ 2.682,81	€ 992,55
52	99,87%	2	4,52	€ 2.278,21	€ 923,20
	99,89%	**232**	**4,55**	**€ 122.193,97**	**€ 54.252,59**

-4%	FTR Index	# FTR	SQL	iCOPQ	eCOPQ
1	99,87%	1	4,5	€ 2.126,53	€ 860,91
2	99,90%	5	4,58	€ 2.145,16	€ 890,03
3	99,89%	5	4,57	€ 2.233,15	€ 1.001,55
4	99,87%	4	4,52	€ 2.490,26	€ 931,38
5	99,89%	5	4,55	€ 2.322,23	€ 1.026,39
6	99,88%	5	4,54	€ 2.230,54	€ 920,85
7	99,89%	5	4,58	€ 2.318,77	€ 882,58
8	99,88%	5	4,55	€ 2.236,58	€ 971,02
9	99,90%	5	4,59	€ 2.366,68	€ 1.000,45
10	99,89%	5	4,56	€ 2.326,67	€ 909,82
11	99,89%	4	4,56	€ 2.193,98	€ 969,77
12	99,88%	4	4,54	€ 2.385,44	€ 993,06
13	99,92%	5	4,65	€ 2.333,65	€ 1.010,58
14	99,90%	5	4,58	€ 2.376,61	€ 918,69
15	99,90%	5	4,59	€ 2.259,68	€ 975,06
16	99,88%	4	4,53	€ 2.534,58	€ 962,01
17	99,88%	4	4,53	€ 2.190,01	€ 946,60
18	99,89%	5	4,57	€ 2.277,75	€ 1.033,31
19	99,89%	5	4,55	€ 2.469,86	€ 1.174,31
20	99,90%	5	4,58	€ 2.348,75	€ 953,15
21	99,90%	4	4,58	€ 2.299,51	€ 1.220,42
22	99,89%	4	4,56	€ 2.208,27	€ 1.004,51
23	99,89%	5	4,57	€ 2.257,75	€ 1.032,60
24	99,91%	4	4,63	€ 2.215,41	€ 991,67
25	99,89%	5	4,55	€ 2.228,65	€ 996,86
26	99,89%	5	4,57	€ 2.180,23	€ 1.162,29
27	99,91%	5	4,61	€ 2.151,25	€ 1.007,91
28	99,87%	3	4,5	€ 2.313,86	€ 1.219,21
29	99,87%	4	4,51	€ 2.436,50	€ 1.139,69
30	99,87%	4	4,51	€ 2.183,46	€ 1.348,72
31	99,88%	5	4,54	€ 2.238,84	€ 1.094,06
32	99,86%	4	4,49	€ 2.505,14	€ 1.190,23
33	99,88%	4	4,53	€ 2.208,35	€ 1.032,52
34	99,88%	4	4,52	€ 2.373,34	€ 1.097,30
35	99,88%	4	4,52	€ 2.349,99	€ 1.037,47
36	99,88%	4	4,54	€ 2.438,78	€ 957,08
37	99,89%	5	4,56	€ 2.450,36	€ 904,09
38	99,89%	5	4,57	€ 2.337,74	€ 959,08
39	99,89%	5	4,56	€ 2.376,75	€ 1.028,75
40	99,89%	5	4,56	€ 2.425,95	€ 1.011,85
41	99,88%	5	4,53	€ 2.408,13	€ 965,54
42	99,90%	5	4,58	€ 2.341,55	€ 896,20
43	99,87%	5	4,52	€ 2.579,49	€ 941,81
44	99,89%	5	4,55	€ 2.489,37	€ 872,25
45	99,90%	5	4,59	€ 2.291,53	€ 959,92
46	99,85%	4	4,46	€ 2.457,11	€ 2.579,73
47	99,88%	5	4,53	€ 2.398,88	€ 983,90
48	99,89%	5	4,57	€ 2.481,20	€ 918,93
49	99,89%	5	4,57	€ 2.346,26	€ 954,81
50	99,87%	4	4,52	€ 2.300,50	€ 999,07
51	99,87%	3	4,5	€ 2.653,45	€ 984,79
52	99,87%	2	4,52	€ 2.265,02	€ 918,20
	99,89%	**232**	**4,55**	**€ 121.359,46**	**€ 53.742,99**

+5%	**FTR Index**	**# FTR**	**SQL**	**iCOPQ**	**eCOPQ**
1	99,87%	1	4,5	€ 2.143,20	€ 866,78
2	99,90%	5	4,58	€ 2.163,58	€ 898,63
3	99,89%	5	4,57	€ 2.259,82	€ 1.020,60
4	99,87%	4	4,52	€ 2.541,03	€ 943,86
5	99,89%	5	4,55	€ 2.357,25	€ 1.047,78
6	99,88%	5	4,54	€ 2.256,97	€ 932,34
7	99,89%	5	4,58	€ 2.353,46	€ 890,48
8	99,88%	5	4,55	€ 2.263,57	€ 987,21
9	99,90%	5	4,59	€ 2.405,87	€ 1.019,40
10	99,89%	5	4,56	€ 2.362,10	€ 920,27
11	99,89%	4	4,56	€ 2.216,98	€ 985,85
12	99,88%	4	4,54	€ 2.426,39	€ 1.011,31
13	99,92%	5	4,65	€ 2.369,74	€ 1.030,48
14	99,90%	5	4,58	€ 2.416,73	€ 929,98
15	99,90%	5	4,59	€ 2.288,83	€ 991,63
16	99,88%	4	4,53	€ 2.589,50	€ 977,36
17	99,88%	4	4,53	€ 2.212,64	€ 960,50
18	99,89%	5	4,57	€ 2.308,60	€ 1.055,34
19	99,89%	5	4,55	€ 2.518,72	€ 1.209,55
20	99,90%	5	4,58	€ 2.386,25	€ 967,66
21	99,90%	4	4,58	€ 2.332,40	€ 1.259,99
22	99,89%	4	4,56	€ 2.232,61	€ 1.023,84
23	99,89%	5	4,57	€ 2.286,73	€ 1.054,56
24	99,91%	4	4,63	€ 2.240,41	€ 1.009,80
25	99,89%	5	4,55	€ 2.254,90	€ 1.015,47
26	99,89%	5	4,57	€ 2.201,93	€ 1.196,42
27	99,91%	5	4,61	€ 2.170,24	€ 1.027,56
28	99,87%	3	4,5	€ 2.348,10	€ 1.258,67
29	99,87%	4	4,51	€ 2.482,23	€ 1.171,70
30	99,87%	4	4,51	€ 2.205,47	€ 1.400,32
31	99,88%	5	4,54	€ 2.266,04	€ 1.121,79
32	99,86%	4	4,49	€ 2.557,30	€ 1.226,97
33	99,88%	4	4,53	€ 2.232,70	€ 1.054,47
34	99,88%	4	4,52	€ 2.413,15	€ 1.125,33
35	99,88%	4	4,52	€ 2.387,61	€ 1.059,89
36	99,88%	4	4,54	€ 2.484,72	€ 971,96
37	99,89%	5	4,56	€ 2.497,40	€ 914,00
38	99,89%	5	4,57	€ 2.374,21	€ 974,15
39	99,89%	5	4,56	€ 2.416,89	€ 1.050,35
40	99,89%	5	4,56	€ 2.470,70	€ 1.031,87
41	99,88%	5	4,53	€ 2.451,20	€ 981,22
42	99,90%	5	4,58	€ 2.378,38	€ 905,38
43	99,87%	5	4,52	€ 2.638,63	€ 955,26
44	99,89%	5	4,55	€ 2.540,06	€ 879,18
45	99,90%	5	4,59	€ 2.323,67	€ 975,07
46	99,85%	4	4,46	€ 2.504,78	€ 2.746,74
47	99,88%	5	4,53	€ 2.441,08	€ 1.001,29
48	99,89%	5	4,57	€ 2.531,12	€ 930,24
49	99,89%	5	4,57	€ 2.383,53	€ 969,48
50	99,87%	4	4,52	€ 2.333,49	€ 1.017,89
51	99,87%	3	4,5	€ 2.719,52	€ 1.002,27
52	99,87%	2	4,52	€ 2.294,68	€ 929,44
	99,89%	**232**	**4,55**	**€ 123.237,11**	**€ 54.889,59**

G.4 Framework performance implementation long term

Baseline	FTR Index	# FTR	SQL	iCOPQ	eCOPQ
1	99,98%	3	4,99	€ 1.986,95	€ 810,17
2	99,98%	5	5,05	€ 1.992,91	€ 812,84
3	99,98%	5	5,04	€ 2.008,78	€ 827,39
4	99,98%	5	4,99	€ 2.073,41	€ 820,99
5	99,98%	5	5,02	€ 2.025,33	€ 837,64
6	99,98%	5	5,01	€ 2.013,62	€ 819,94
7	99,98%	5	5,06	€ 2.029,49	€ 813,06
8	99,98%	5	5,03	€ 2.003,90	€ 826,60
9	99,98%	5	5,05	€ 2.039,65	€ 840,00
10	99,98%	5	5,04	€ 2.025,51	€ 819,72
11	99,98%	5	5,04	€ 2.001,65	€ 828,19
12	99,98%	5	5,02	€ 2.042,13	€ 836,12
13	99,98%	5	5,11	€ 2.036,60	€ 836,25
14	99,98%	5	5,05	€ 2.043,98	€ 821,50
15	99,98%	5	5,07	€ 2.013,03	€ 824,46
16	99,98%	5	5	€ 2.055,37	€ 833,24
17	99,98%	4	5,03	€ 1.998,57	€ 825,05
18	99,98%	5	5,04	€ 2.021,61	€ 834,61
19	99,98%	5	5,04	€ 2.066,49	€ 854,75
20	99,98%	5	5,05	€ 2.039,14	€ 820,58
21	99,98%	5	5,05	€ 2.026,63	€ 866,66
22	99,98%	4	5,04	€ 2.008,53	€ 835,18
23	99,98%	5	5,04	€ 2.015,41	€ 841,96
24	99,98%	4	5,09	€ 2.009,22	€ 836,28
25	99,98%	5	5,02	€ 2.009,17	€ 840,50
26	99,98%	5	5,03	€ 2.000,42	€ 875,88
27	99,98%	5	5,08	€ 1.990,03	€ 838,86
28	99,97%	5	4,97	€ 2.030,55	€ 880,45
29	99,98%	5	4,99	€ 2.056,41	€ 871,92
30	99,98%	5	4,98	€ 2.000,73	€ 888,82
31	99,98%	5	5	€ 2.011,00	€ 859,53
32	99,97%	5	4,96	€ 2.068,72	€ 873,10
33	99,98%	5	5	€ 2.008,61	€ 842,06
34	99,98%	5	5	€ 2.046,77	€ 849,83
35	99,98%	5	4,99	€ 2.033,11	€ 845,34
36	99,98%	5	5,01	€ 2.054,16	€ 826,11
37	99,98%	5	5,03	€ 2.049,92	€ 819,36
38	99,98%	5	5,03	€ 2.037,68	€ 831,60
39	99,98%	5	5,02	€ 2.044,43	€ 836,61
40	99,98%	5	5,02	€ 2.052,06	€ 838,03
41	99,98%	5	5	€ 2.053,41	€ 824,67
42	99,98%	5	5,05	€ 2.036,50	€ 815,89
43	99,97%	5	4,98	€ 2.092,08	€ 827,70
44	99,98%	5	5,02	€ 2.072,16	€ 815,43
45	99,98%	5	5,06	€ 2.024,25	€ 826,25
46	99,97%	5	4,94	€ 2.062,13	€ 1.014,94
47	99,98%	5	4,99	€ 2.046,97	€ 828,25
48	99,98%	5	5,02	€ 2.067,47	€ 824,26
49	99,98%	5	5,03	€ 2.035,98	€ 831,33
50	99,98%	5	4,99	€ 2.022,34	€ 831,02
51	99,97%	5	4,98	€ 2.105,71	€ 828,72
52	99,98%	3	4,99	€ 2.018,43	€ 819,50
	99,98%	**253**	**5,02**	**€ 105.709,12**	**€ 43.629,14**

-4%	FTR Index	# FTR	SQL	iCOPQ	eCOPQ
1	99,98%	3	4,99	€ 1.985,42	€ 809,69
2	99,98%	5	5,05	€ 1.991,14	€ 812,26
3	99,98%	5	5,04	€ 2.006,38	€ 826,23
4	99,98%	5	4,99	€ 2.068,42	€ 820,08
5	99,98%	5	5,02	€ 2.022,26	€ 836,07
6	99,98%	5	5,01	€ 2.011,03	€ 819,07
7	99,98%	5	5,06	€ 2.026,25	€ 812,47
8	99,98%	5	5,03	€ 2.001,69	€ 825,47
9	99,98%	5	5,05	€ 2.036,01	€ 838,33
10	99,98%	5	5,04	€ 2.022,44	€ 818,86
11	99,98%	5	5,04	€ 1.999,53	€ 827,00
12	99,98%	5	5,02	€ 2.038,39	€ 834,61
13	99,98%	5	5,11	€ 2.033,09	€ 834,73
14	99,98%	5	5,05	€ 2.040,17	€ 820,57
15	99,98%	5	5,07	€ 2.010,45	€ 823,42
16	99,98%	5	5	€ 2.051,10	€ 831,85
17	99,98%	4	5,03	€ 1.996,57	€ 823,98
18	99,98%	5	5,04	€ 2.018,70	€ 833,16
19	99,98%	5	5,04	€ 2.061,78	€ 852,49
20	99,98%	5	5,05	€ 2.035,52	€ 819,69
21	99,98%	5	5,05	€ 2.023,51	€ 863,92
22	99,98%	4	5,04	€ 2.006,14	€ 833,71
23	99,98%	5	5,04	€ 2.012,74	€ 840,21
24	99,98%	4	5,09	€ 2.006,80	€ 834,76
25	99,98%	5	5,02	€ 2.006,76	€ 838,81
26	99,98%	5	5,03	€ 1.998,35	€ 872,78
27	99,98%	5	5,08	€ 1.988,38	€ 837,24
28	99,97%	5	4,97	€ 2.027,28	€ 877,16
29	99,98%	5	4,99	€ 2.052,11	€ 868,97
30	99,98%	5	4,98	€ 1.998,65	€ 885,20
31	99,98%	5	5	€ 2.008,50	€ 857,08
32	99,97%	5	4,96	€ 2.063,91	€ 870,11
33	99,98%	5	5	€ 2.006,21	€ 840,31
34	99,98%	5	5	€ 2.042,84	€ 847,77
35	99,98%	5	4,99	€ 2.029,74	€ 843,46
36	99,98%	5	5,01	€ 2.049,94	€ 825,00
37	99,98%	5	5,03	€ 2.045,87	€ 818,52
38	99,98%	5	5,03	€ 2.034,12	€ 830,26
39	99,98%	5	5,02	€ 2.040,60	€ 835,08
40	99,98%	5	5,02	€ 2.047,92	€ 836,44
41	99,98%	5	5	€ 2.049,22	€ 823,61
42	99,98%	5	5,05	€ 2.032,99	€ 815,18
43	99,97%	5	4,98	€ 2.086,34	€ 826,53
44	99,98%	5	5,02	€ 2.067,22	€ 814,75
45	99,98%	5	5,06	€ 2.021,22	€ 825,14
46	99,97%	5	4,94	€ 2.057,59	€ 1.006,27
47	99,98%	5	4,99	€ 2.043,04	€ 827,06
48	99,98%	5	5,02	€ 2.062,72	€ 823,23
49	99,98%	5	5,03	€ 2.032,49	€ 830,01
50	99,98%	5	4,99	€ 2.019,39	€ 829,71
51	99,97%	5	4,98	€ 2.099,43	€ 827,50
52	99,98%	3	4,99	€ 2.015,64	€ 818,65
	99,89%	**253**	**5,02**	**€ 105.534,00**	**€ 43.544,48**

+5%	**FTR Index**	**# FTR**	**SQL**	**iCOPQ**	**eCOPQ**
1	99,98%	3	4,99	€ 1.988,87	€ 810,76
2	99,98%	5	5,05	€ 1.995,12	€ 813,56
3	99,98%	5	5,04	€ 2.011,79	€ 828,84
4	99,98%	5	4,99	€ 2.079,65	€ 822,12
5	99,98%	5	5,02	€ 2.029,16	€ 839,61
6	99,98%	5	5,01	€ 2.016,87	€ 821,02
7	99,98%	5	5,06	€ 2.033,53	€ 813,80
8	99,98%	5	5,03	€ 2.006,66	€ 828,02
9	99,98%	5	5,05	€ 2.044,19	€ 842,08
10	99,98%	5	5,04	€ 2.029,35	€ 820,79
11	99,98%	5	5,04	€ 2.004,30	€ 829,68
12	99,98%	5	5,02	€ 2.046,80	€ 838,01
13	99,98%	5	5,11	€ 2.041,00	€ 838,14
14	99,98%	5	5,05	€ 2.048,74	€ 822,66
15	99,98%	5	5,07	€ 2.016,25	€ 825,77
16	99,98%	5	5	€ 2.060,71	€ 834,99
17	99,98%	4	5,03	€ 2.001,06	€ 826,39
18	99,98%	5	5,04	€ 2.025,26	€ 836,43
19	99,98%	5	5,04	€ 2.072,38	€ 857,57
20	99,98%	5	5,05	€ 2.043,66	€ 821,69
21	99,98%	5	5,05	€ 2.030,53	€ 870,08
22	99,98%	4	5,04	€ 2.011,52	€ 837,03
23	99,98%	5	5,04	€ 2.018,75	€ 844,14
24	99,98%	4	5,09	€ 2.012,25	€ 838,18
25	99,98%	5	5,02	€ 2.012,20	€ 842,61
26	99,98%	5	5,03	€ 2.003,00	€ 879,76
27	99,98%	5	5,08	€ 1.992,10	€ 840,89
28	99,97%	5	4,97	€ 2.034,64	€ 884,56
29	99,98%	5	4,99	€ 2.061,80	€ 875,60
30	99,98%	5	4,98	€ 2.003,33	€ 893,34
31	99,98%	5	5	€ 2.014,11	€ 862,59
32	99,97%	5	4,96	€ 2.074,72	€ 876,84
33	99,98%	5	5	€ 2.011,60	€ 844,25
34	99,98%	5	5	€ 2.051,67	€ 852,41
35	99,98%	5	4,99	€ 2.037,33	€ 847,69
36	99,98%	5	5,01	€ 2.059,44	€ 827,50
37	99,98%	5	5,03	€ 2.054,98	€ 820,41
38	99,98%	5	5,03	€ 2.042,13	€ 833,26
39	99,98%	5	5,02	€ 2.049,22	€ 838,52
40	99,98%	5	5,02	€ 2.057,23	€ 840,01
41	99,98%	5	5	€ 2.058,65	€ 825,98
42	99,98%	5	5,05	€ 2.040,89	€ 816,76
43	99,97%	5	4,98	€ 2.099,25	€ 829,17
44	99,98%	5	5,02	€ 2.078,34	€ 816,29
45	99,98%	5	5,06	€ 2.028,02	€ 827,65
46	99,97%	5	4,94	€ 2.067,80	€ 1.025,77
47	99,98%	5	4,99	€ 2.051,89	€ 829,75
48	99,98%	5	5,02	€ 2.073,41	€ 825,56
49	99,98%	5	5,03	€ 2.040,35	€ 832,98
50	99,98%	5	4,99	€ 2.026,02	€ 832,65
51	99,97%	5	4,98	€ 2.113,56	€ 830,24
52	99,98%	3	4,99	€ 2.021,92	€ 820,56
	99,98%	**253**	**5,02**	**€ 105.928,01**	**€ 43.734,97**