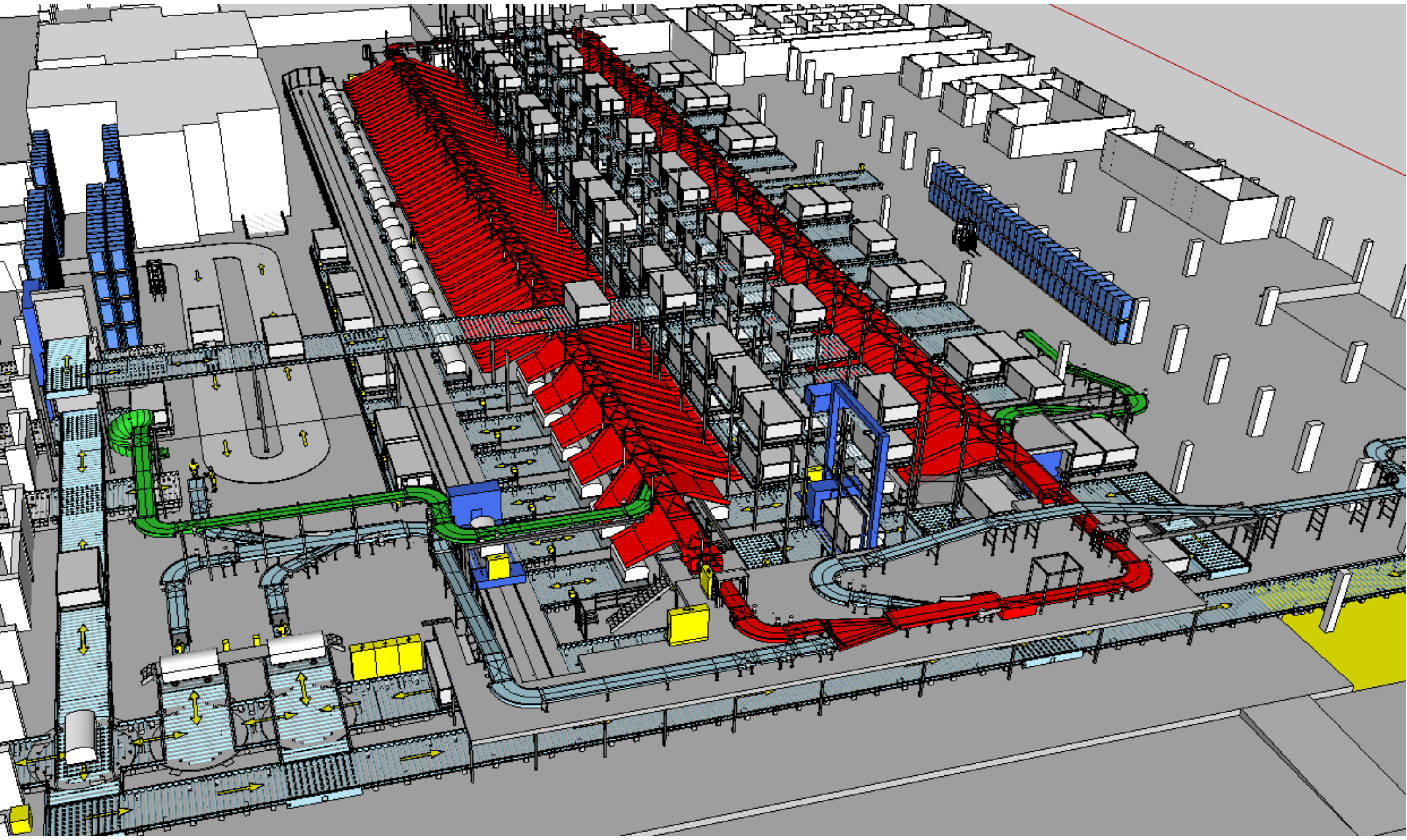
ANALYSING THE EXPECTED PERFORMANCE AND EFFECTS OF COMBINED AUTOMATED SORTING FOR AN AIR CARGO HUB ON AN OPERATIONAL LEVEL



Assessing stated specifications & functional requirements using a modelling approach in a case study at the KLM Cargo EPS department

Delft, March 2017

Author:	Koen Minnee
Student number:	1507427
University:	Delft University of Technology
Company:	KLM Cargo
Faculty:	Technology, Policy and Management
Master:	Transport, infrastructures and Logistics

Thesis assessment committee

Chair	- Prof. dr ir. A. Verbraeck	faculty TBM
Supervisor	- Ir. M. Duinkerken	faculty 3mE
Supervisor	- Dr. J. Razeai	faculty TBM
External supervisor	- H. de Groot	KLM Cargo

Key words: air cargo; sorting; discrete event simulation; automation; freight hub

Preface

When I started with my master thesis at KLM Cargo, the project A-pier team was already 2 years in the process of determining the requirements and solving operational issues during the setup of the combined system. I was being involved closely in the project from the start of the thesis and could also provide input based on my preliminary findings. Also, the opportunity to visit the factory site at Lödige in Germany and the reference visit to Hub Express at Charles de Gaulle Airport proved to be very helpful in achieving the goals of this research so I am very thankful to KLM Cargo for that.

The lack of availability of accurate data was sometimes a bit difficult during the data analysis, but by making good assumptions in consultation with experts at KLM Cargo the data analysis could be performed.

Although there was a major reorganisation within KLM Cargo, I was able to contact and meet up with the correct person eventually if I had any questions, also my supervisors at TU Delft, gave me useful feedback during the meetings to stay on course and to improve my research. All in all, I would like to thank all participants for their help and constructive thinking which made this research project possible.

As some of the data used in this study contains confidential company information, the appendices will not be available on the TU Delft repository.

Koen Minnee

March 2017, Delft

Executive summary

With the expansion of the Schiphol passenger terminal with an extra pier being planned on the KLM Cargo premises. The mail department was required to move its operations by 2017. KLM Cargo was prompted to find an alternative to continue its operations and after long negotiations and business case studies, the decision was made to build a combined automated sorter and storing system for Mail, Equation and ACT products, in the current warehouse with operational costs and surface area reduction as driving factors. The functional requirements for such a system were determined with respect to the current and a rough estimation of the future demand.

Research problem

However, as the economic lifespan of the sorting system is about 20 years it's future performance is rather uncertain as the demand patterns and growth may change depending on a large number of circumstances. It is therefore necessary for KLM to assess the performance of the system in various (potential) conditions in order to be able to anticipate for various future conditions. Also, the effects of combining the various commodities is still unknown regarding the future demand patterns and no available method to analyse the effects can be applied directly for this specific type of system.

Research goals and methods

The main goal of this research is to find and use a method to assess the expected performance of a combined automated air cargo sorting system and determine what the effects are of combining the different air cargo commodities.

In order to assess the expected performance of the system with regard to the future uncertainties a comprehensive data analysis and a (discrete-event) model study is performed, assessing multiple possible scenarios based on newly determined KPI's for this specific system. The future scenarios are based on the situation in 2035 and a distinction is made between a regular day pattern and a peak day pattern. Three models are specified based on the critical processes which will have an effect on the future KPI's and thus performance of the system. The theory of constraints is applied in order to identify possible bottlenecks and provide a guideline for solution strategies. If the performance of the system is in line with the functional requirements, stated in the RFQ document, no further actions are required. In case the performance differs from the stated performance, solution strategies are tested and implemented.

By comparing the current and the new situation, the effects of integration are determined per commodity.

Results

The operational performance of the system is proven to be according to the functional requirements in a large number of possible scenarios up to a 40% growth in 2035 with respect to the current average day demand.

During current and future peak-days the system is not able to process the offered demand, a deadlock appears during the morning as a result of high volume overlapping in- and outbound flows interfering on the roller decks.

Also in high overall demand situations (>40% growth in 2035), the system is not able to process all of the demand in the current configuration. Moreover, the space requirements for the exceptional process and extra manpower required will result in a lower overall performance of the system.

The effects of integrating the processes for each commodity are found to be as followed:

Mail: The overall operational costs are reduced and less surface area is required, although an extra exceptional handling process is required. Overall safety and ergonomics are increased. Also, the possibility to prioritize within the mail product is now an option.

Equation: Although less surface area and lower operational costs are an advantage, the lower flexibility and the increased in-and outfeed times reduce the quality of the more critical Equation product. As the cut-off time, might be increased and connectivity is reduced in some high demand and peak-scenarios. Also, additional rebooking needs to take place to pull bookings with a multiple-day dwell time in VG1 forward to prevent looping in the sorting system. This will increase the workload on the planning department.

ACT: The ACT product, is now more constrained in flexibility than in the current situation, resulting in careful planning of the in-and outfeed during high-demand scenarios and peak days. OPEX costs are reduced as a result of the automated internal transportation.

Advice for KLM Cargo

The recommendation for KLM Cargo is that the current system is performing well in the coming years with the expected demand patterns on average days. So, no further actions are required. However, during peak-days it is recommended to implement a night shift to separate the overlapping in-and outbound flows in order not to overload the ETV and internal transport system. During high-demand scenarios: over 2% growth per year. It is recommended to reconfigure the ULD routing of the internal transport system and to prioritize on belly carts. This will require extra buffering of ULDs outside in order to provide sufficient throughput capacity. It is crucial to prevent the internal transport system from clogging up as it results in the loss of throughput in all processes in the system. Try to introduce the possibility to co-load Equation and mail on more destinations. This will reduce the load on the internal transport system.

The OoG process needs to be looked at more closely in order to determine the share of Mail OoG. This share has a large impact on the handling and surface area requirements.

Recalibrate the chute allocation as often as possible in order to find the most optimal chute utilization for a certain volume-destination demand combination.

Rebook Equation consignments on earlier flights if possible and if the dwell time is longer than 1 day. This will prevent Equation to consume capacity in the storage and sorting systems and prevents looping: time-buffering and re-in feeding of the item.

Recommendations regarding the methodology used

In order to assess the future performance of similar combined air cargo sorting facilities, the specific type and lay-out of the facility is essential to determine which specific method can be used for the analysis. In the case of a more simple system, without interfering in- and outbound flows, the Theory of Constraints, or TOC in short, will provide sufficient insight in the performance regarding the majority of the KPI's, the TOC will also provide solution directions for improving the system's performance in terms of a number of the KPI's. If a more complex facility needs to be analysed, it is recommended to further analyse the system using a simulation study in order to pinpoint the constraints and to test solution strategies. The use of the TOC only is limited in terms of analysing complex input-output systems as in this study, the TOC may yield multiple bottlenecks in the system and is not able to provide insight in the effect of a certain bottleneck in terms of the spillback on the whole systems' performance.

Table of Contents

Terminology & abbreviations

AAF	type of ULD, see appendix A for dimensions
AAP	type of ULD, see appendix A for dimensions
ACT	Refrigerated container, either battery powered or dry ice see appendix A for dimensions
AKE	type of ULD, see appendix A for dimensions
AWB	Air Way Bill, acceptance document for freight
BC	or Belly carts, used by KLM to transport (bulk) belly cargo mainly for B737 aircraft and smaller
Chain	Warehouse management system used by KLM Cargo
DAP	Delivered as planned, business KPI used by KLM Cargo to measure the overall performance
DG	Dangerous goods
DIP	Diplomatic mail/equation
Dolly	Cart used to transport ULD's
DSA	Delft systems approach (Veeke, Ottjes, & Lodewijks, 2008)
EPS	Express Postal Solutions, Equation and mail operation at KLM Cargo VG1
EQ	Equation, express freight
ETV	Elevated transfer vehicle, used to transport ULD, BC to build-up positions or storage racking
EUR	Europe
FAB	Flown as booked, KPI used to measure the percentage EQ flown on the booked flight
FAP	Flown as Planned, only goes down when flown on a later flight Business KPI at KLM Cargo
ICA	Intercontinental
Lödige	Manufacturer of automated warehouse transportation equipment
LHO	Living human organs
MULAG	Diesel-powered tractor used to tow dolly's & belly carts to the platform
OoG	Out of Gauge, cargo which requires an exceptional handling process
Posisorter	Sorter system build by Vanderlande, utilizing sliders (shoes) to sort out items
RFQ	Functional requirements & specifications document, a contractual document for the system
SAL	Standard air letter, normal mail product without priority
TOC	Theory Of Constraints (Dettmer, 1997)
TRIPS	Software package used by UPU-members for track and trace of mail products
TV	Transfer vehicle, used to transport BC & ULD's to build-up positions
ULD	Unit load device, used to transport mainly mail for KLM Cargo on ICA flights.

1 Introduction

This research is performed in order to find a generic method to assess the expected operational performance of a combined automated sorting facility. This will be done by means of a case study to be conducted at KLM Cargo. The specific results and outcomes of this case study will apply to KLM Cargo. The generic results of the study and found methodology, however, can be applicable for similar combined air cargo sorting systems.

1.1 Background

Air cargo is an important driver of a country's Gross domestic product (GDP) as shown by Kasarda & Green (2005). This is also acknowledged by Harvard Professor Michael Porter in his book "The Competitive Advantages of Nations" (1990) where he describes that air cargo transportation has a large impact on the country's competitiveness. It is therefore in the interest of both Schiphol, which is government owned and air cargo facilitators to provide a competitive air cargo hub & network. However, passenger transport is also acknowledged as an important driver of the national economy (Bannò & Redondi, 2014) and therefore improvements are made to increase the connectivity and capacity for passengers. This can have conflicting consequences when the available space at an airport is limited, as is in the case of Schiphol. Schiphol plans to build a new pier south of the current passenger terminal, the so-called A-pier project to provide more airside capacity (Schiphol Group, 2016b). As the operational sorting facility of KLM Cargo is currently located at the planned location of this new passenger pier (see Figure 1), it must either cease a part of its operations or adapt in order to keep operating at a competitive level.

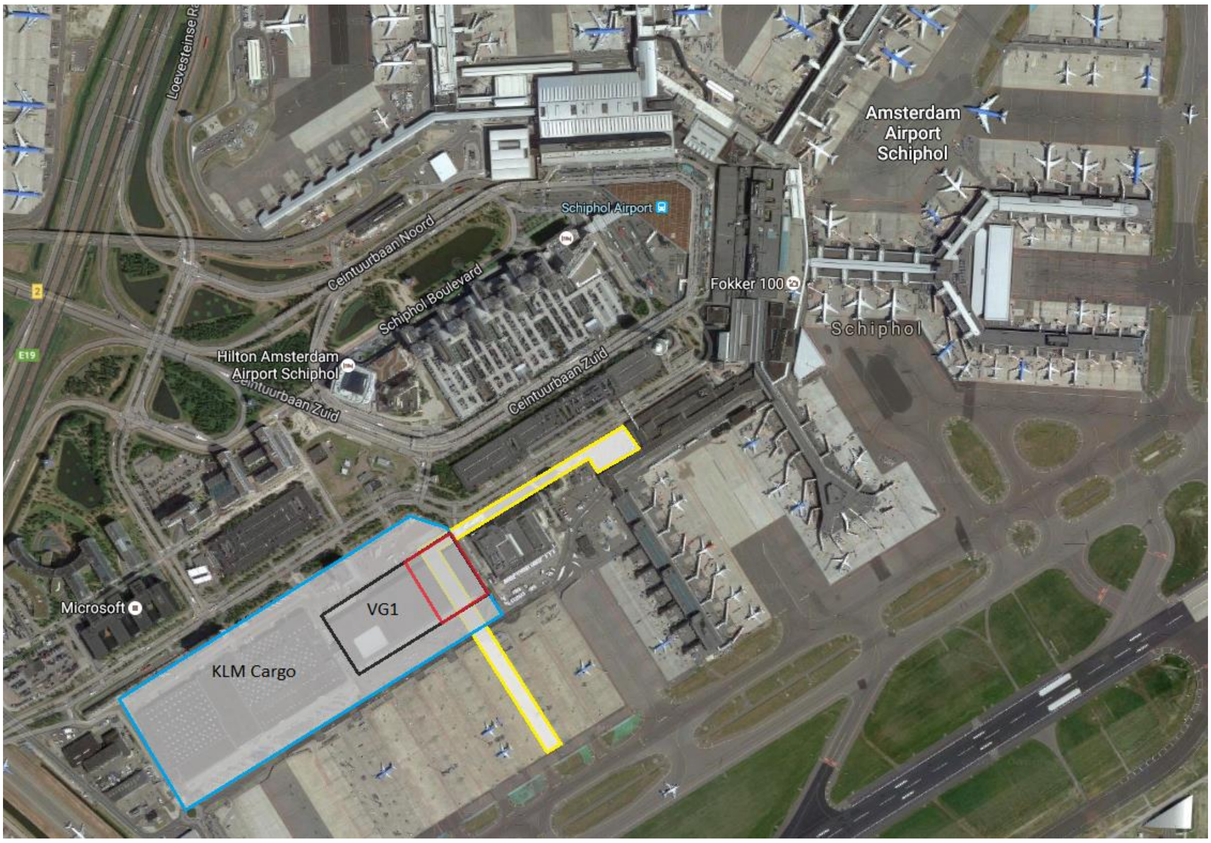


FIGURE 1 LOCATION OF VG1 (BLACK) AND EXPECTED A-PIER LAYOUT (YELLOW) (VIA GOOGLE MAPS®).

Studies are showing a varying yearly growth rate of the total volume from a meagre 0,3% by ICAO (2014),4,3% growth by Boeing (2014) to a very high estimate of nearly 20% growth by IATA (2016). It is preferred by KLM Cargo to adapt its operations to the new situation and to have a sustainable solution for the coming years. The planned construction of the A-pier will especially effect the Mail and Express cargo (Equation) departments, since approximately 1/3 of its current operational surface area will be lost. Especially in this market segment of air cargo, due to the rise of e-commerce, the largest growth is expected (IATA, 2015). As a subsidiary freight carrier of the passenger airline KLM, a so called combination carrier, KLM Cargo has the advantage that it is able to provide a large and frequent network for belly cargo (Doganis, 2010), which is cargo taken on board passenger aircraft. However, there is a large overcapacity in the air cargo market (IATA, 2015) so the margins are getting smaller and KLM Cargo has to reduce costs in order to stay competitive in the future. The large surface area required, higher requirements on throughput times and the relatively high costs of the separated manual sorting operations currently in place, actuates KLM Cargo to find a sustainable solution for the future. The most favourable option, which came forward from internal studies and negotiations with Schiphol (Capgemini, 2014) was to invest in a new automated sorting and storage system to be located in the current warehouse. This new process should combine both processes to reduce the surface area and costs at the same time (Versleijen, 2016). The idea is that the new automated sorter is able to process and store multiple types of commodities, these include: Mail, Equation, ACT (Refrigerated) containers and Out of Gauge (OoG), which consists of mail and Equation but will require an exceptional process. A joint venture of Lödige Industries and Vanderlande Industries have proposed a design in a tender procedure in 2015 and have won the tender to build the new sorter based on the functional requirements (RFQ document) stated by KLM Cargo and the industrial service provider DENC (2015). The combined automated sorting facility is expected to be fully operational in 2017.

1.2 Problem definition

In this case, a new kind of sorting system with new innovative infeed techniques is being used to combine the current processes. The infeed of belly-carts in an automated sorting and storing system is an innovation, which is unique in the world. Although the separate individual processes have been statically analysed during the design phase by Lödige, the operational performance and limitations of the system are still not fully known with regard to the future situation. For instance, the moment "double or manual handling" must take place because no destination chutes are available at that moment. This means there are not enough chutes incorporated in the design. Also, the optimal destination allocation over the day for flexible chutes is still not determined exactly. In addition to this, KLM Cargo would like to have more insight in the process and where and when possible bottlenecks might appear with the expected arrival and departure patterns. In other studies, evaluating the performance of an air cargo sorting facility, the performance is often measured mainly on process or throughput times. These Key Performance Indicators or KPI's are hard to compare directly with the operational KPI's currently used by KLM Cargo. This is due to the fact that the Mail and Equation operation at KLM Cargo is largely constrained by the flight schedule of its passenger-aircraft fleet. Therefore, KLM Cargo mainly uses operational cost-indicators indicated by the manpower utilization and the number of "Flown as planned" in the case of Equation. However, the number flown as planned is difficult to relate directly to the sorting operation alone, as it is only a small link in the logistic chain. It can better be considered as a business KPI instead of an operational KPI. Therefore, a new set of KPI's need to be determined in order to assess the operational performance of the system. This will be done in discussion with experts and by assessing relevant literature.

When there is a bottleneck, manual intervention can take place in order to solve this. However, the moment this intervention must take place is not known and this will be a consideration between costs and the number "Flown as planned". In case a deadlock appears, manual intervention must take place as soon as possible. When bottlenecks or deadlocks appear too often, i.e. the system's processing capacity is too low, the integration of the processes in a combined sorter might not have large advantages in terms of costs and capacity over the current operation and could force KLM Cargo to change the operations. On the other hand, if the sorting process is over-engineered with too high capacity and capabilities the investment costs will not weigh-up to the operational benefits. "In sorting systems, automation equipment utilization is directly related to the operating efficiency of the sorting system, and it will affect the logistics service quality further" (Liang, Liu, Wang, & Li, 2010). It is therefore important to understand whether the stated functional requirements and specifications by KLM Cargo & DENC (2015) for the automated sorter are correct to deal with various future scenario's and to provide an efficient operation.

1.3 Research questions

To define how to answer these uncertainties the following research questions are stated and answered in order during the research.

Main research question:

How can the expected operational performance of a combined automated air cargo sorting facility be assessed and what are the effects of integrating the current operations from a logistical perspective?

Sub questions:

How is the automated sorting and storage facility expected to perform in terms of KPI' in comparison to the functional requirements and the current operation?

What are the operational benefits and drawbacks of combining the mail, express and refrigerated commodities from a logistical perspective?

What are the operational constraints of the automated sorting and storage facility regarding the future arrival and departure patterns?

How can the system be configured in order to perform optimally in terms of KPI's during peak demand patterns?

1.4 Research scope

The research scope will be limited to operations within the sorting facility, a clear physical demarcation can be made on the facility itself with an in-and output from both the airside and landside. As the most relevant entities in the research are the cargo units: e.g. mail bags, boxes, etc. The research will focus on these commodities and the objects, transporters and processes they encounter during the sorting process. Irrelevant movements of personnel and movements of cargo outside the sorting facility, either on landside or airside will not be in the scope of this research. The process boundary can be set at the in-and outfeed point where the commodities arrive in belly carts, ULD's etc. at the VG1 warehouse perimeter as here the decision is made when the commodities are being fed into the system. The demarcation here is still arbitrary as the transportation department has been regarded as a buffer for the facility as there is limited storage area inside the warehouse. The demarcation at this point will be discussed further during the research.

During the analysis, supported assumptions and simplifications in the model may have to be made if accurate data is not (yet) available in order to specify the model. The physical sorting facility can largely be regarded as a "black-box" during this research. The specifications of the sorter are given and recommendations will be given based on the outcome of the model study on the sorting facility. These recommendations however, may include (minor) adjustments to the physical configuration such as the additional of extra infeed points, bypasses, the size of the racking to store special cargo and non-physical changes like optimal chute allocations, routing and the allocation of human recourses. Therefore, the assessed sorting facility could also be considered as a limited "grey-box" in this model study.

2 Literature review

Before assessing the performance of the combined automated sorting process, it is preferred to have an overview of earlier studies in this field and similar systems in place. This can help finding a good approach and methodology to answer the research questions and what the underlying factors are to automate and combine these processes. The chosen methodology, described in Chapter 3 will also be based on these findings.

2.1 Scientific relevance

From a scientific perspective, it would be interesting whether the integration of handling various air cargo flows in a combined sorting facility is advantageous from a logistic point of view. There could be a number of advantages in terms of cost, sorting times and surface area being saved but the combined handling and sorting might also have some disadvantages due to the different handling constraints and requirements of the transported commodities. The scientific relevance can also be found in the absence of a general methodology to be used to assess the expected performance for similar combined cargo hubs. It may be the case that widely used theories such as the Theory of Constraints developed by Goldrath (Dettmer, 1997) for similar input-outputs systems are not fully usable in the case of a more complex integrated input-output system with multiple interacting flows.

Analysing the performance of a combined sorting facility such as being constructed at KLM Cargo could provide more insight in these aspects. A common way to analyse the performance of sorting facilities is to use a modelling approach, as was for example demonstrated by Nsakanda, Turcotte & Diaby (2004) with a case study at Toronto Pearson. This case study, which builds forward on earlier simulation studies and applications, showed that a modelling and simulation approach can provide insight in the performance of an air cargo sorting facility assuming only 1 type of commodity. Another more recent simulation study by Ou, Zhou, & Li (2007) demonstrates the applicability of simulation in order to optimize operations in an automated air cargo facility. In 2009 a master thesis study was performed at KLM Cargo (van Amstel, 2009) with regard to the proposed combining of the two processes, this yielded interesting results with regard to the effects of combining the Equation and Mail commodities. However, the specific manual system proposed at that time is completely different from the new system, so a number of the conclusions drawn in 2009 are not relevant for this study. However, the methodology used provides a guideline for this study as it covers a major part of the research questions.

The proposed research study builds forward on these studies and could provide a better understanding of the more complex process in combined sorting facilities with multiple types of commodities going in and out of the system at an operational level. Eventually, this leads to the conclusion whether integrating the separate sorting processes into a combined sorting process provides advantages from a logistical perspective. In addition, it will provide insight in whether the available theories and methods in literature are suitable for analysing similar complex air cargo sorting hubs.

2.2 Societal relevance

The societal benefits are gained in having found a good method to test the functional requirements of similar sorting facilities. As the automation in sorting is getting more common, margins in freight transport are getting smaller and space at preferred logistic locations such as airports and large cities is getting scarce. The need to find the optimal balance between investment costs, capacity and surface area used is therefore more important than before. By understanding where the operational limitations can be expected in the sorting process, measures can be taken in advance before the system becomes fully operational in terms of control and minor reconfigurations; saving costs on interventions or major reconfigurations and avoiding operational downtime. Also during operation, the model can give an indication how to allocate resources optimally and when backup plans needs to be implemented when unexpected peak-loads occur. Furthermore, as Liang et al. (2010) described, an optimal utilization of the system is also crucial for an efficient operation. This will also be taken into account during the analysis.

All this together can result in both lower throughput times, lower operational costs and thus lower transport costs per unit transported. Eventually increasing the competitive position of the company and indirectly, the economic development of the region it is located in (Kasarda & Green, 2005). Although there is a direct loss of employment in operational fte at KLM Cargo due to the automation of the system, on the long term there will be an overall improvement of the competitiveness of the region, presumably resulting in the creation of new employment opportunities. Moreover, at KLM Cargo, there will be a large improvement on ergonomics and safety after implementation of the new system, resulting in a lower sick-call and accidents.

2.3 Similar process in place

As this specific fully combined automated process being assessed is one of a kind in the world, there are no existing 1-on-1 examples of the system in place. However, since the system is built up from various components which are being used in around the world. Assessing the performance and experience of a similar system gives an indication of the way how a combined process will perform and where potential operational limitations are expected.

An example of combined sorting can be found at the other hub used by Air France-KLM Cargo, this facility called SoDeXi (Société pour le Développement du Fret Express Internationalis) located at Charles de Gaulle airport, Paris. This facility is operational since 2015 and has proven that combining the processes has advantages in terms of surface area saved and reduced costs in comparison to a full manual operation.

FIGURE 2 COMBINED SORTING AT THE SODEXI HUB, PARIS (AIR CARGO NEWS, 2015)

From experience, also drawbacks of combining these two processes became apparent. Combining two different products into a single standardised process for both reduces flexibility and can have negative effects on the quality of one of the product types. As all cargo, both mail and equation, is now being loaded FiFo on the ULD's where co-loading is possible, the flown as planned (FAP) criteria for Equation becomes effected. If a mail bag has occupied the volume booked for an Equation product, the equation product becomes not FAP, the quality of the whole operation is degraded. The average weekly FAP of Hub Express is around 82% versus 97% of VG1 at KLM Cargo (AF-KLM Cargo, 2016b). It must be mentioned that this difference cannot be fully accredited to the sorting and handling process alone, therefore it cannot be clearly stated that the lower FAP is only caused by the co-loading of equation and mail but there is a causality. Combining both processes might therefore not have the desired effects, especially for Equation. Although costs and manpower are reduced, the quality of the express product becomes lower.

The difference with the SoDeXi system and the new integrated sorter, is that SoDeXi only handles ULD’s. This is due to the current fleet composition of Air France. The narrow-body A320’s have the capability to transport ULD’s (AKE-sized) in their belly cargo hold (Airbus, 2016). This is not possible with the current Boeing 737 fleet of KLM on the European destinations (Boeing Commercial Airplanes, 2013). The infeed of belly carts in addition to ULD’s provides an extra handling constraint for new system to be assessed. As can be seen in the figure above, the system is also semi-automated, as only the sorting is automated. The internal transport, in- and outfeed, of the ULD’s is still a manual process using castor-decks to reduce effort. This system is considered to have of a more flexible capacity in the favour of higher operational cost. The exceptional processes are also fully manual, since it is impossible to drive a forklift truck over the castor decks.

A comprehensive report of the reference visit and meeting with the project manager can be found in Appendix D.

FIGURE 3 DESTINATION CHUTE ULD BUILD UP WITH CARGO AT SODEXI HUB, PARIS

3 Methodology

From the literature reviews, earlier studies give an indication of methods to be used in both the analysis and model study. The framework in Figure 4 bellow gives an overview of the research approach and steps taken. It is based on the Step-by-step plan for discrete modelling by Verbraeck & Valentin (2006) but adjusted for this specific modelling situation where the current situation is not applicable in the future and the future alternative has been chosen already:

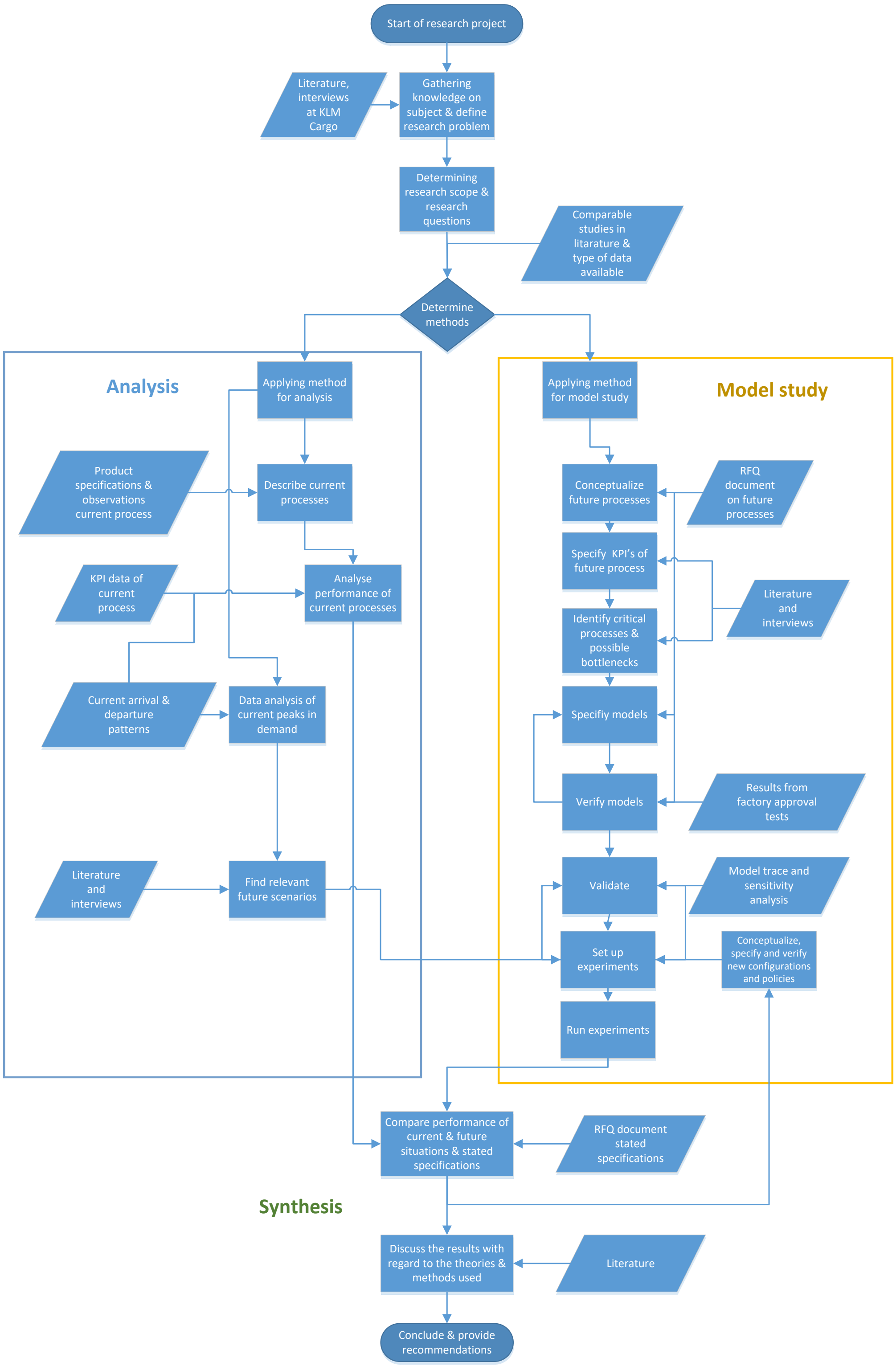


FIGURE 4 RESEARCH APPROACH FRAMEWORK FOR THE ANALYSIS AND MODELLING STUDY AT VG1

3.1 Analysis

First, in order to define the scope and to get a structured mapping and overview of the system a method should be chosen suitable for similar systems. The Delft Systems Approach or DSA (Veeke et al., 2008) is a method used to simplify an industrial input-output model and to provide a structured analysis and demarcation of the system. The main process of sorting, which is being analysed can be regarded as an input-output process see Figure 5 , making it suitable for a method such as the DSA.

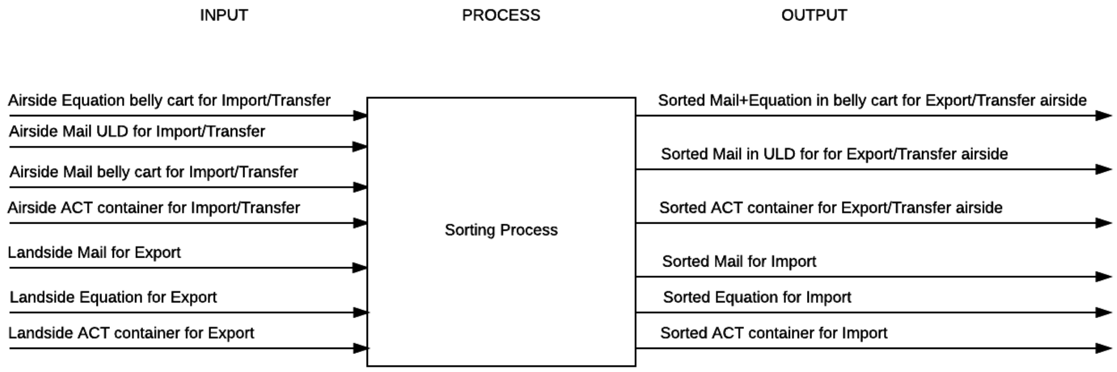


FIGURE 5 INPUT-OUTPUT PROCESS (I/O) AT VG1 (Veeke et al., 2008)

This model can be further improved, including the performance with for instance the Process – Performance or PROPER model, one of the models used in the DSA. After this analysis of the process using the data available at KLM Cargo, literature and knowledge obtained by interviews, a conceptual model is made using a systems-engineering method such as IDEF0 and Flowcharts. This forms the basis for further analysis: the model study. From literature, interviews and by assessing similar integrated systems, a number of logistical effects of combining the processes can be determined.

After analysing the process, a data analysis is performed on the demand patterns of the main commodities in order to assess potential crucial situations and to provide base-input variables for the model. These input variables can later be varied over a to be determined bandwidth: for example, [-10% to +10%] or other variations can be implemented to represent various future scenarios for the experiments in the model study. Besides the input variables, it is important how the current KPI's from KLM Cargo can be operationalized in measurable output variables for the new system in the model study. More on the data analysis and KPI's can be found in the corresponding paragraphs.

3.2 Model study

First, in order to conceptualize the critical processes based on the expected future scenarios, the Key performance indicators of the new system need to be determined. As the new system is unique these KPI's are determined in conjunction with KLM Cargo and literature. Next, there are a couple of options to continue the analysis in order to find the critical processes based on the KPI's: a static model based on mathematical queuing theory can provide a static insight in expected waiting times at various stations in the process (Kirmani, Viswanadham, & Narahari, 1993). In addition, there is another method to find constraints in a certain system: the Theory of Constraints designed by Goldratt (Dettmer, 1997). This is a relative simple and fast method to identify bottlenecks in a certain processing system. The most applicable for an in-and outfeed process is in this case the Theory of Constraints, or TOC, developed by Goldratt. The TOC provides a stepwise approach how to identify and solve constraining processes in a logistical system. Dettmer (1997) has further specified the use of the TOC in a systems approach for input-output systems, which will be applied to find the expected constraints in the integrated sorting system given the uncertainties of the future demand (patterns).

Steps in the TOC:

1) Identify the system constraint
2) Decide how to exploit the constraint
3) Subordinate everything else
4) Elevate the constraint
5) Go back to step 1, do the cycle again in order to find the new constraint until demand equals system capacity

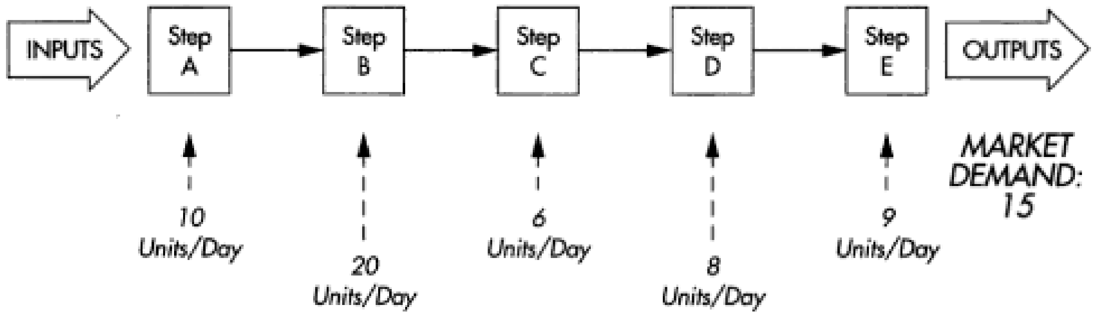


FIGURE 6 AN EXAMPLE OF HOW TO APPLY THE THEORY OF CONSTRAINTS IN A PRODUCTION LINE INPUT-OUTPUT SYSTEM (STEP 1: IDENTIFYING THE CONSTRAINT)(Dettmer, 1997)

However, due to the time-dependant nature of the various processes and arrival patterns over time, this method is limited as it only provides the location of the constraints and how to solve them in the system and not the operational performance output data required in this study. Also, the complex nature of the new input-output system could provide difficulties pinpointing the exact bottleneck over time.

Discrete event simulation modelling is an option to model and analyse the operational performance of the sorting process and is able to locate the bottlenecks, as it does offer the possibility to include stochastic variances over time and to run replications to perform sensitivity analysis and experiments. A model study by Masel & Goldsmith (1997) in this field has proven the use of simulation models in air cargo sorting. However, this study was limited to the configuration, testing and to the handling of a parcel sorting process. Another more recent model study by Nsakanda et al. (2004) shows the benefits of simulation models in a more complex sorting environment in a case study at Toronto Pearson airport. It demonstrates the use of simulation as an evaluation method for similar facilities. The study however, considers only one commodity: general cargo. The proposed study will comprehend modelling of a combined sorting and storage process for commodities as equation, mail, out of gauge (OoG), refrigerated goods in containers (ACT) and infeed by belly carts and ULD's adding additional constraints on handling. Gijs van Amstel has actually performed a thesis study (van Amstel, 2009) into the integration of the Equation and mail processes at KLM Cargo back in 2009, this was however with a less automated system and has not been worked out in this form. However, this study showed that modelling and simulation provides a very useful tool in analysing the effects of combining the different commodities at VG1. Also, the use of more recent simulation tools gives more potential to provide insights on a more operational level. The disadvantage of this method is that it requires (a lot of) accurate data and knowledge of the process, which takes considerably more time, depending on the level of detail. For this case though, it could be a more suitable method to answer the research questions. The discrete event modelling method is therefore preferred over the other models, though the amount of time required for the specification of model should be in balance with the level of detail and the required aspects of the model.

As detailed specification of the whole process in one model could be difficult regarding the large number of constraints regarding the commodities are present, various sub-models of crucial processes could be modelled separately in order to test the performance of the combined sorter. This reduces the time required for specification and for running the experiments but the input variables of the separate models should be chosen with regard to the output of the other models in order to get a representative model of the entire process. Ou et al. (2007) has made several sub-models in order to simplify the system and to achieve the goals of the simulation study. This model-framework is seen below in Figure 7.

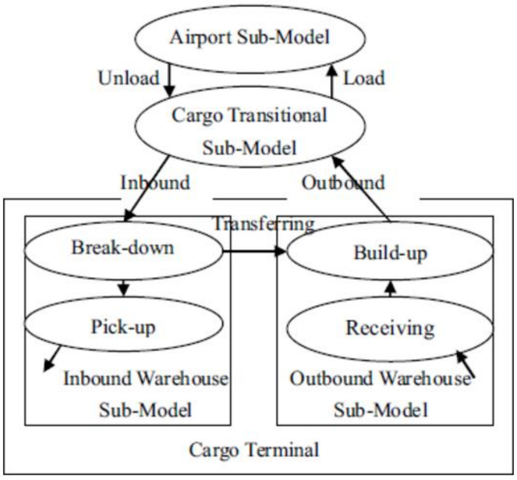


FIGURE 7 MODEL-FRAMEWORK OF AIR CARGO SORTING SYSTEM IN VARIOUS SUB-MODELS, LARGELY APPLICABLE AT THE KLM CARGO CASE. (Ou et al., 2007)

In the KLM Cargo case, the Airport sub-model represents the hourly demand and the transitional sub-model is represented by a delay in the KLM case. The pick-up and receiving processes are the Import/Export processes.

During the model study, the possible bottlenecks of the new system need to be determined. In order to do so, the performance indicators of the current process as in addition to new Key Performance Indicators (KPI's) are used to determine where potential conflicts and bottlenecks might start to appear. These new KPI's are based on the current KPI's, literature, RFQ document and interviews with experts. The bottlenecks and critical processes are then determined using the theory of constraints (TOC).

The level of detail and specification should be in balance with the required functionality of the model. As mentioned earlier, the conceptual models obtained from the initial analysis provide the basis for the specification of a discrete simulation models (R. G. Sargent, 2009). After specification of the models, the models are verified with the known data, specified and verified again in an iterative process (R. Sargent, 2000). After verification, the models can be used to answer the research questions and to provide recommendations for improvements.

Exact validation of the simulation models can take place after the system has been built and in operation, this is due in 2017. Another method used to validate the model is by face validation (R. G. Sargent, 2009) Experts from KLM Cargo and Lödige are able to judge the model on functionality and realism based on their experience with the operational processes and design of the system. In addition, a sensitivity analysis and model trace are used to provide validation of the model.

3.3 Synthesis

After the validation of the model, the model is suitable to be used as a basis for experiments. The data analysis performed earlier now provides the input variables for the parameters. The base scenario can be compared with the performance of the current situation, as well as a peak scenario. This provides a benchmark to measure the initial performance. The future scenarios can now be assessed based on the new KPI's and with the stated performance in the RFQ document. The comparison provides information on what the logistical effects of the new integrated system will be on the different products and where the limitations of the system can be found. In addition to this, the model can be used a tool on how to configure the system most optimal in order to mitigate the effects of combining the processes. A new configuration can now be tested based on the KPI's resulting in the most suitable configuration of the sorting facility during critical demand periods. Finally, the research questions can now be answered and a recommendation for reconfigurations can be given to KLM Cargo. In addition, a recommendation can be made regarding the used scientific methods and how these methods could be used in the future when assessing similar air cargo hubs.

4 Analysis

In order to determine the drawbacks and benefits of an integrated sorting and storing facility, first the current situation needs to be analysed. This provides a benchmark for the new situation. As the business case studies by DENC (DENC, 2015) and KLM Cargo (Capgemini, 2014) have already proven that there will be an improvement in terms of operational costs and the surface area. It is however, not clear how large this improvement will be in terms of costs and what the effects for the different commodities will be from a logistical perspective.

Therefore, the current system is analysed first, using the data available, the Delft Systems Approach (Veeke et al., 2008), interviews and observations of the operation. Various techniques such as flowcharts and IDEF0 will be used to visualize the process and to analyse the data. After assessing the current situation, the performance will be analysed based on the current operational KPI's. After this, the current demand patterns will be assessed and analysed for potential critical situations. Finally, possible scenario's will be determined and selected for the model study based on the arrival and departure data, literature and interviews with experts.

This will later form the basis of the model and the experiments.

4.1 Current situation at KLM Cargo VG1

In the current situation at VG1, the processes for different commodities are separated. This is either in VG1 in the case of mail and equation or VG2&3 for the ACT operation. The operation is manually operated, only at the mail operation a simple conveyor belt system is in place for transporting the mail bags to the carousels. This system is often called the "potato belt" by employees due to the simplicity of the system.

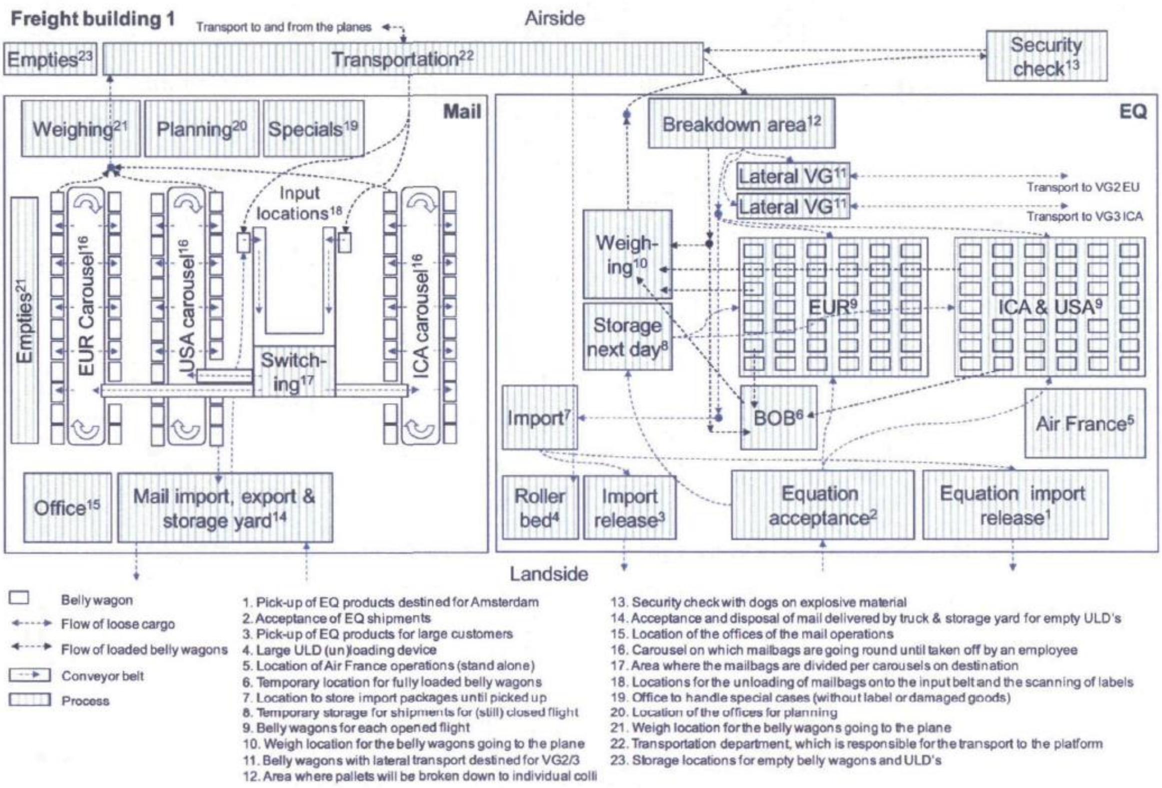


FIGURE 8 SCHEMATIC OVERVIEW OF THE CURRENT OPERATIONS IN VG1, NOTE: THE EQ OPERATION HAS BEEN MOVED TEMPORARILY IN ORDER TO CREATE SURFACE AREA FOR THE NEW COMBINED SORTER (van Amstel, 2009)

The current operation is relatively flexible in terms of capacity since this largely depends on the available manpower. Moreover, the handling of Out of Gauge(OoG) items is generally not considered as a separate process in the current situation, although it does exist in small numbers in the mail handling process.

4.1.1 Sorting & storage system

The sorting and storing of mail and equation can be regarded as a complex system with a large collection of elements and interactions between these elements. There is also an interaction with the "environment" which can be described as systems outside of our scope: Transportation departments on the air and landsides. In this paragraph, a number of relevant methods from the Delft Systems Approach or DSA (Veeke et al., 2008) will be used to analyse the current system.

Aspect- and subsystems

The DSA states that the system can be differentiated further into either so-called aspect systems and subsystems (de Leeuw, 2000).

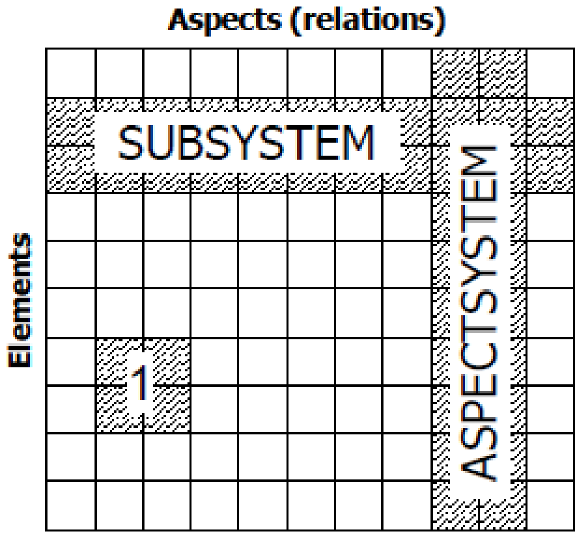


FIGURE 9 SUBSYSTEMS AND ASPECTSYSTEMS (Veeke et al., 2008)

The subsystems can be seen as the process for 1 of the type of the commodities being processed in the system. The commodity involves a large number of relationships within a limited number of elements. The elements involve among other things the storage, transport and handling of the commodity. For example, the sorting, transporting and storing of mail can be regarded as the subsystem of the sorting and storing system in VG1.

The aspect systems can be regarded as part of the separate systems within VG1 covering all elements but with limited relations among other things: the human resources being allocated, the transportation of goods, the breakdown and build-up system of all cargo, storage system etc.

Both the subsystems, aspectsystems and the interrelations will be assessed during the analysis; although they will not always be referred to in that manner.

System control

The DSA provides an extensive description of various control systems. In this case, the system is controlled using feed forward control. Based on the measurements at the input of the system, the system control is triggered if the expected demand (standard) is not in line with the actual demand measured. This causes a deviation of the standard and actuates the control to intervene. This generally means a higher or lower number of flexible human resources is called in to assist in the executing process.

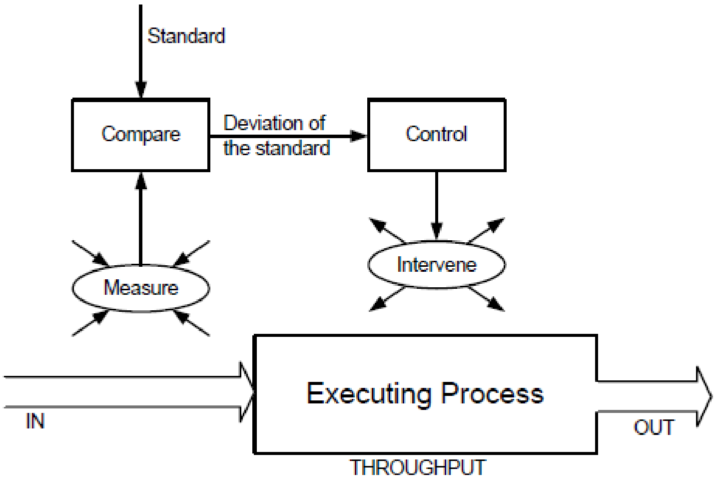


FIGURE 10 FEED FORWARD CONTROL (Veeke et al., 2008)

The current feed-forward control however, is not considered to be very responsive to the actual demand due to fixed rosters, shifts and other resource constraints as found in a research on human resource planning at VG1 (Klein Douwel, 2015). In the future situation, a more dynamic control is being considered to allocate resources more efficiently.

Scope

As described in the introduction (Chapter 1) the scope of the system being analysed is the physical demarcation of the building walls. However, just outside the boundary there is an important process subsystem, which determines the input of the main process inside the building: the transportation department. The transportation department functions as a buffer for the transfer and import cargo at VG1. Since there is no area available to handle and buffer all incoming cargo at the same time inside the building, the cargo is held at the transportation department until the breakdown stations are available. Although this sub-system is not analysed specifically, it is necessary to mention it as it might become of significance in the future situation. And, also regarding the new integrated system where the buffer is largely internally located, there will still be a buffer function available at transportation. The input variables available at KLM Cargo, such as the arrival and departure times of the aircraft, are therefore not to be used directly as the input variables of the model. There should be a built-in delay to represent the Transportation process.

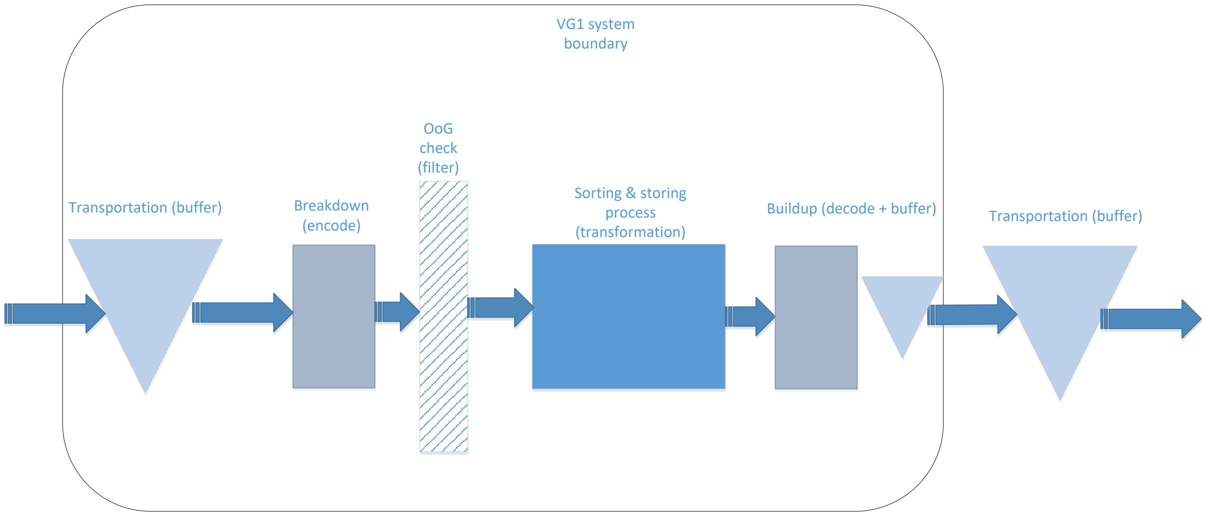


FIGURE 11 SYSTEM BOUNDARY AND BUFFER FUNCTIONS OUTSIDE VG1

Process and Performance

Continuing the analysis, the DSA mentions the construction of the so-called Process Performance or PROPER model in order to map the flows of “products”, “orders” and “resources”. These are transformed in the model. This transformation is controlled based on standards and results, however in the system at VG1, this is not the case. As the control is merely based on expectations of cargo (Transport requests, short term), the cargo demand (long term) and resource utilization (Manpower & Energy), standards and not on output results. The PROPER model is therefore not to be used in the original format, but needs to be adapted to the system at VG1:

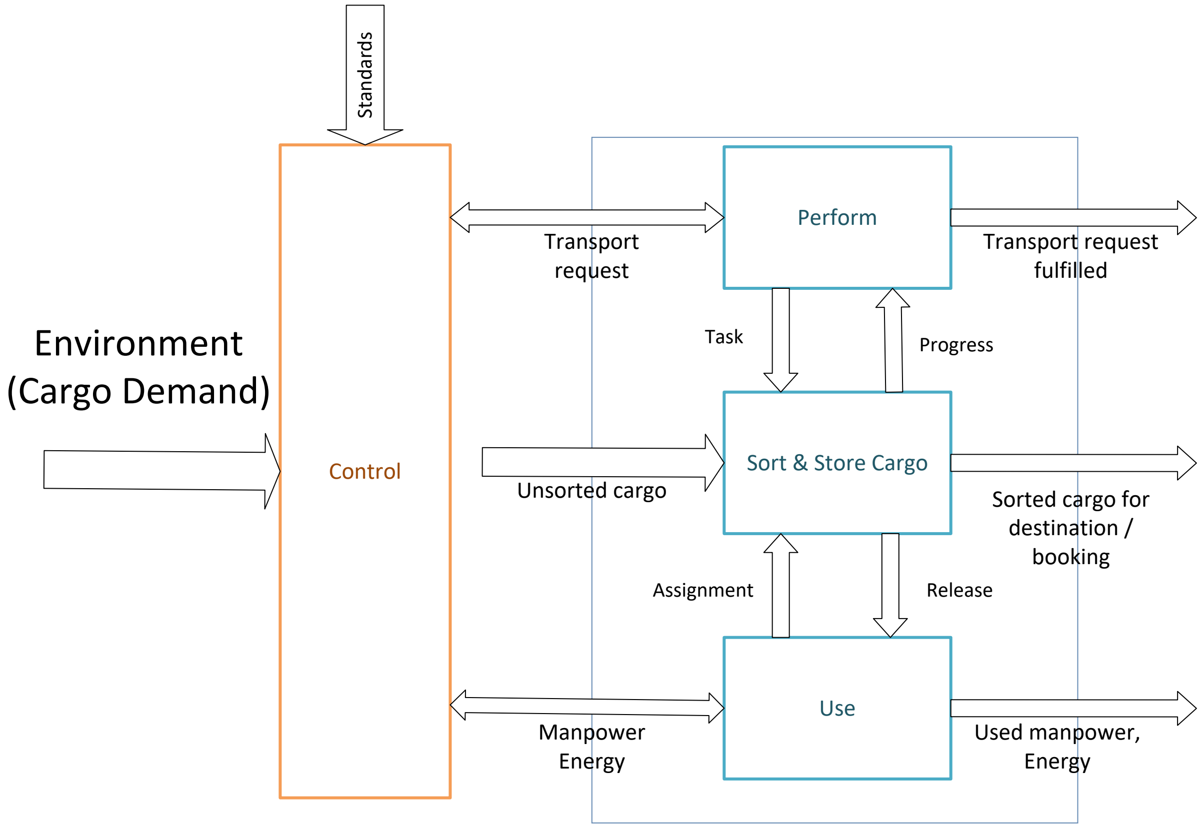


FIGURE 12 PROPER MODEL OF THE SYSTEM AT VG1

The performance of the system is currently measured based on the amount of orders being handled per hour against the lowest costs (resources utilized). This comes generally down to the effectivity, productivity and utilization of the individual handlers in the warehouse. From experience, there are some standards in place for the productivity of the various tasks to be performed by the operators. Veeke et al. (2008) defines the performance of a process as followed: “The *performance* delivered is then the ratio of the actual productivity to the productivity set as being standard.”

$$Performance = Effectiveness_{actual} * Efficiency$$

The performance formula can be now implemented for the KLM Cargo case

The effectiveness is hereby the number of units, or colli, handled of the total to be handled in an “acceptable” time frame for Mail and Flown as planned (FAP) for Equation products. The efficiency is the ratio of the amount of resources utilized per handled colli. In this case, generally, the human resources utilized in the observed time-period over the standard productivity.

The performance reports retrieved from the KLM database provide the number of FTE’s per cost position and the number of colli handled per week, see Appendix B. Assumptions can now be made for the average efficiency per day and per hour. The effectiveness is retrieved as well, in terms of backlog and Flown as Planned. The effectiveness, however is assumed to be 1 assuming that all commodities are handled on time within the warehouse in the current situation. As in peak demand periods the “flexible” operation allows for extra employees to be employed to process the demand, no impact on the effectiveness is assumed.

$$Effectiveness_{actual} = \frac{Colli\ flown\ as\ Planned(FAP)in\ VG1}{Total\ colli\ handled} = 1$$

As a result of this, the FAP, is not fully applicable for measuring the operational performance within VG1. This is because FAP can have many root causes not in the operational scope of VG1. Delays in the incoming flight or at the landside transportation have a much larger impact on the FAP indicator and therefore it is assumed that the actual *Effectiveness* is equal to 1 in the performance determination.

To determine the efficiency of the daily operation, or per hour, the productivity standard needs to be determined. This can be used as a benchmark for the efficiency. The standard is set by taken the highest number of colli handled against the lowest FTE utilized in the measured time-period:

$$Productivity_{standard} = \frac{Maximum\ number\ of\ colli\ handled}{Lowest\ FTE\ utilized}$$

The efficiency is then benchmarked based on the standard productivity. The efficiency is calculated by dividing the actual productivity by the standard productivity. Where the actual productivity is the productivity in that week, day or hour divided by the operational FTE utilized in that period.

$$Efficiency_{actual} = \frac{Productivity_{actual}}{Productivity_{standard}}$$

Now the performance can be calculated by multiplying the effectiveness with the efficiency. This number represents the operational performance in relation to the standard, or average performance benchmark.

The current operational reports, see Appendix B provide the average hourly productivity per week, these give an indication of the efficiency and resource planning on a weekly basis. In the table below, the performance of the operation in several weeks in 2015 is calculated, assuming a *FAP* (EQ) *or flown within acceptable limit* (Mail) of 100%.

TABLE 1 PERFORMANCE CALCULATION OF THE CURRENT SITUATION IN VG1

	Productivity standard (highest productivity in time-period)	**19,6**	**Colli/fte/hour**	
Week	*Effectiveness: assumed 1 within VG1 in current situation*	*colli/fte/hour (Actual productivity)*	*Efficiency*	*Performance*
19	100%	19,0	97%	97%
20	100%	14,8	75%	75%
21	100%	18,4	94%	94%
22	100%	15,9	81%	81%
23	100%	15,2	78%	78%
24	100%	14,9	76%	76%
25	100%	19,6	100%	100%
26	100%	17,3	88%	88%

*assumed to be 100% for the internal operation at VG1

4.2 General process in current situation

As already described, the general process in VG1 can be characterized as an input output system with a transformation process in between. This process can further be decomposed using various techniques to show the decision points, sequences, controls, resources and process times. There are three general process-flows for the various commodities to be assessed: Import, Export and Transit. In this paragraph, the main commodities: mail & equation, will be assessed. The size of the current operation amounts to around 5.5 million items processed per year. Of which approximately 80% of the volume consists of mail and 20% equation (AF-KLM Cargo, 2016b). For equation, there is also a small lateral flow in- and outbound for heavy equation and other special products.

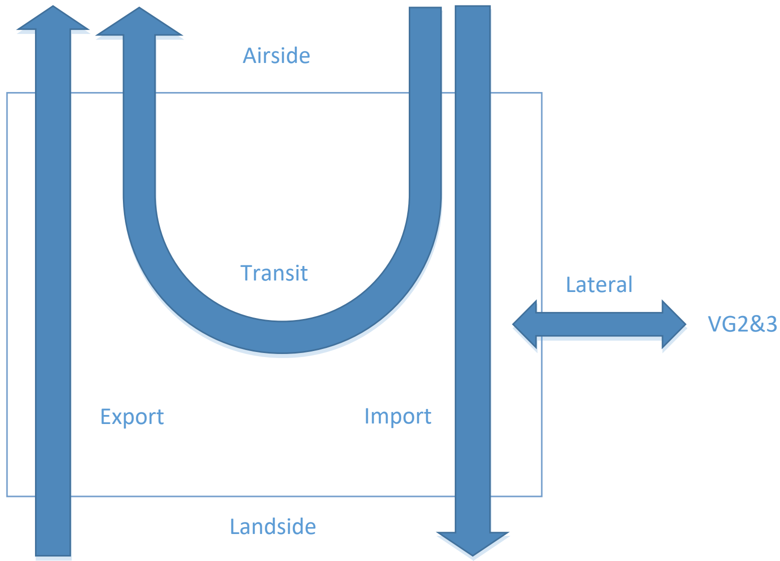


FIGURE 13 GENERAL PROCESS FLOWS IN VG1

Flowchart

The flowchart method is used to visualize decisions, elements and process flows in a comprehensive diagram. In Appendix B, the flowchart of the general process can be found with all decision points in the process. All decision points in the process flow will be analysed in order to compare these to the new situation later. This provides insight in whether the logistical decision points are relevant for the logistical effects on the commodities. In Chapter 5, the flowchart method will also be used to describe critical process decisions on a more detailed level. The main characteristic in the current situation is that the current flows are fully separated at entering the warehouse and are reunited again at the transportation department. The employees are therefore not trained to handle both processes but either mail or equation.

IDEF0

The IDEF0-diagram or SADT diagram is used to visualize the processes, to understand the control mechanisms and support elements involved. The diagram is build-up in hierarchy to be decomposed in the individual processes towards the level of detail desired for the analysis. The processes are described based on observations of the current process and on descriptions by employees. The first levels (A0 and A1) can be found in Appendix B.

Block diagram

In order to visualize the process-times in a comprehensive manner, a so-called block diagram is used to get a good overview of the relative process times of the separate processes.

In the new situation, a combined in and outfeed will be used for both the belly carts and ULD's. As stated in the problem definition, there is still no full understanding of what will happen if these streams interfere. Looking at the in- and outfeed times of the current situation relative to the new situation provides an indication of the performance of the system and how the operational controller needs to plan the in-and outfeed.

4.3 Description of the current process at KLM Cargo per commodity type

In order to assess the performance of the new combined system, it is important to assess the current handling and quality of the process per commodity type. Due to the combining of the processes, some product-specific aspects of the current process are improved and others are degraded in the new situation.

The current processes vary quite a lot per commodity, also within the type of commodity, there are sub-categories. The main types can be characterised as followed:

TABLE 2 OVERVIEW MAIN TYPES OF COMMODITIES & CHARACTERISTICS (UPU, 2013a) (AF-KLM Cargo, 2016a)

Type	*Sub-types*	*Main characteristics*
Mail (FiFo planning)	1st class	Prio mail, registered letters
	EMS	Special mail, parcels
	DIP	Diplomatic mail
	SAL	Less prio, standard 2nd class mail
Equation (First flight, Booking)	M21 (XPS)	Regular EQ, max 32 kg, cut-off time 90 minutes. First flight out
	M25 (XPH)	Heavy EQ, no weight, limitations, cut-off time 180 minutes on booked flight
	Courier	Courier consignments
	DIP	Diplomatic equation
	LHO	Living Human Organs
OoG (under EQ or mail)	DG, Specials	Dangerous goods, specials in EQ, laterally transported to VG2&3
	Large dimension mail/repairs	Exceptions in mail process
ACT (VG2&3)	Reefer	Needs to be charged on the grid
	Dry Ice	Needs dry ice refill

4.3.1 Mail products

As the mail market is generally still regulated in most countries. The mail products and handling requirements are largely subject to regulations, postal charges and standards stated by the Universal Postal Union or UPU (UPU, 2013a). The UPU also classifies the types of mail mentioned in the introduction and what the handling standards of these types are.

- The 1st class mail, or prio-mail, can be considered as mail with a high priority to be delivered as soon as possible on the destination. These include registered letters and similar types of mail.
- EMS can be considered as the non-letter mail products, mainly parcels. In the last years, there has been an increase in this type of products coming through the operation. Although the exact numbers are not known as no accurate date is available in the Warehouse management system (Chain).
- DIP mail, is the diplomatic mail for the embassies, which is a small exceptional process in the current handling process. The DIP mail is handled separately for certain countries due to security matters, such as the US embassy.
- SAL mail is the standard air letter, or second class mail. There is no priority for this mail and therefore the mail can be used as a filler-up of cargo holds in the passenger-planes if there is still capacity available. This type is mainly characterized by large mail bags and mail boxes.

Handling process

Although there are clear distinctions made in the categories of mail, the handling in the current process is largely the same. The Prio and SAL mail are handled according to the same First in First out principle, because the current handling process and IT-support system, TRIPS, does not allow for exceptional handling of all separate categories. Distinctions in the order of handling are now made based on the postal client, large volume clients, such as China Post are now given priority over smaller clients. By not distinguishing in handling processes for mail in the current process, the quality of the overall product goes down. When the new system is becoming operational, the consideration is made whether to change this to improve the quality of the mail product. In appendix B, a detailed description of the current process is given and shown in the form of a IDEF0 diagram.

In addition to the IDEF0, a block diagram is given to show the various process times in succession.

4.3.2 Equation products

The EQ products are differentiated by AF-KLM Cargo (2016) into several categories: regular Equation, heavy equation, Courier consignments, DIP and LHO. The products have different tariffs but are merely handled in the same way. Some products with a dangerous or cooled content, see OoG products, are handled in VG2&3. The specific facilities for storing these products are available in these warehouses: Cooling facilities, secured storage etc. See appendix A for the brochure on equation products.

- Regular Equation or XPS is a product which can be booked by a client up to 90 minutes before departure. The regular equation products are may only contain a limited type of items and is constrained to a certain size and weight. See the figure below for more characteristics of XPS equation.
- Equation heavy or XPH can be booked on the same routes but is not highly constrained in terms of size and weight. The Equation heavy product has a larger cut-off time and transit time due to the more comprehensive and difficult handling process. The restrictions depend merely on the aircraft cargo door sizes and maximum payload distribution. Large consignments are handled in VG2 & 3 as general cargo. Also, some special cargo (cooled products etc.) needs to be booked as Equation Heavy and will be handled as OoG (see OoG).
- Courier consignments are single consignments being delivered or picked up by the courier service. These are generally integrators such as DHL or TNT.
- DIP equation is the express version of the DIP mail for embassies and other diplomatic organisations.
- LHO equation is a very special product, which requires accurate planning and high priority handling. The living human organs need to be delivered Just in Time (JIT) and require a very careful handling in a conditioned environment.

Handling of EQ

Equation in general, or EQ, is the express cargo product of KLM Cargo. It differs from mail due to the fact that the EQ products are flown on a booking or first flight principle instead of a First in First out (FiFo) principle. The type of equation being transported varies largely as the product is less constrained to regulations as the mail products. Equation products, depending on the qualification Heavy and light, can be brought in either 180 minutes for heavy equation or 90 minutes prior departure time. This is called the cut-off time. Also, the transit times are twice as high for equation heavy products. So, the product is less fast as the regular equation. This is also seen in the pricing of the product. Regular equation generally has a higher tariff than equation heavy, although more handling is required for equation heavy. It is therefore common for shippers to book small consignments without priority as heavy equation due to the lower tariffs. The handling and decision sequences of Equation are explained and visualised in a Flowchart and IDEF0 diagram in Appendix A.

4.3.3 OoG products

Regarding the mail, a small exceptional process is required to sort out the products. There is a trend in the mail to send more irregular items using regular postal services. According to Bram Talahatu, business specialist Express postal solutions (EPS) at KLM Cargo, KLM Cargo receives an increasing amount of irregular mail items. Postal items are subject to international regulations and standards stated by the Universal Postal Union (UPU, 2013a). These regulations also include the maximal weight and dimensions of the items. However, it is not uncommon that larger and heavier mail bags in excess of 30 kilograms are being received from large volume destinations such as China. Most of these bags are currently being handled the same way other bags are handled. This has resulted in an increase in complaints from the employees due to back-injuries. Mail items which cannot be put onto the belt for sorting are being transported manually to the destination belly carts.

Another exceptional process, which is also present at SoDeXi Hub Express, is the repair process. This normally comprehends, manually entering the label number into the TRIPS system or printing a new UPU label for the mail bag. In some cases, the mailbag or parcel is damaged and needs actual repair on site before being handled. The amount of mail items requiring a repair varies from day to day between 2-3 % of the total volume but on rainy days, the amount of repairs can add up to 5% according to Bram Talahatu.

There is no actual data available on odd-sized unconveyable mail items, so this share needs to be determined based on observations or on interviews with operators.

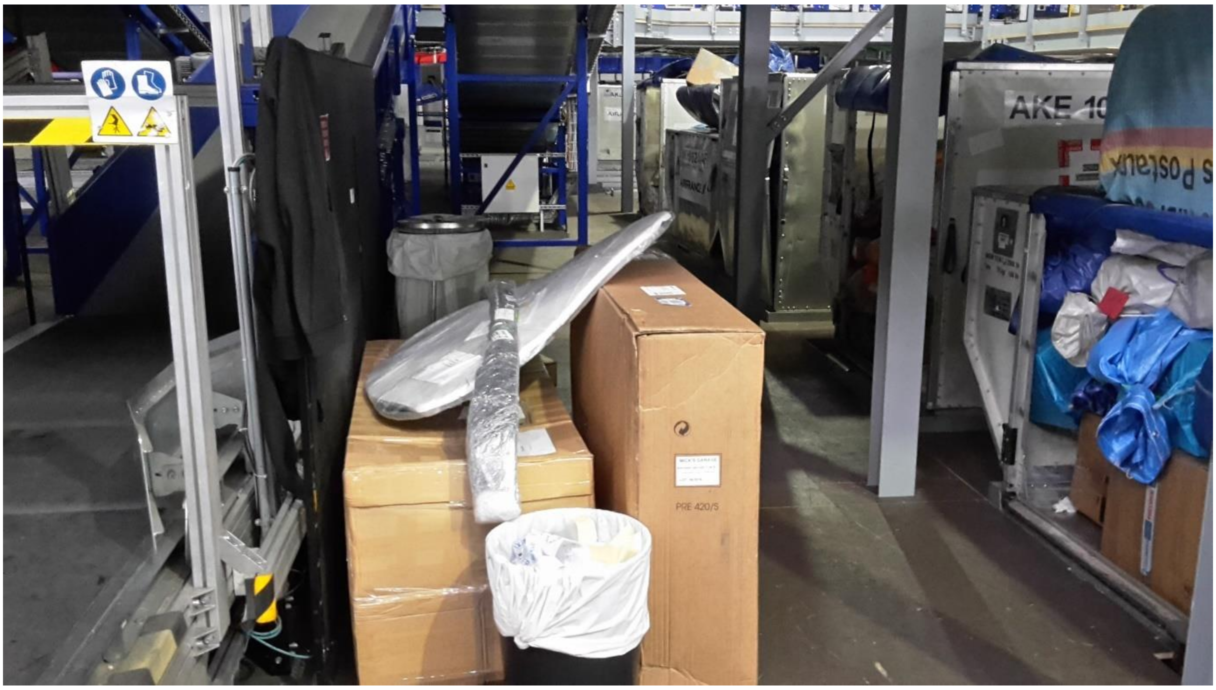


FIGURE 14 OOG AT HUB-EXPRESS, PARIS CDG

Looking at equation, Out of Gauge (OoG) products are mostly handled the same way as regular products in the current situation. For Equation, there is no exceptional process, since the OoG is already manually being handled with a high level of flexibility in terms of weight, dimensions and content. The warehouse operator is able to handle all types of products in the same way as regular products. The products (both DG & large dimensions) are brought in by a Belly carts and are broken down (taken off from the belly carts) using a forklift-truck. The items are then brought to import, put on a belly carts for lateral transport in the case of DG or on the belly carts for the corresponding booked flight.

4.3.4 ACT products

The ACT (air conditioned) products are a special form of Air cargo with a high number of constraints in handling. The ACT containers are currently handled in VG2&3. In the new combined situation, the ACT containers will be handled in VG1 to utilize the system's capacity and available surface area more optimal. Although the expected arrivals of ACT containers is low relatively to the ULDs and belly carts: 5 ACT/hour versus +/- 30 units per hour (Vanderlande & Lödige, 2016). The containers are, however, constrained in handling and the ACT's require a higher priority setting over the regular ULD's and belly carts. Since the ACT containers carry refrigerated goods such as medicines, they require regular recharging in case of battery-powered ACT's or a refill with Dry ice. The time spend at the outdoor transportation buffer is therefore limited to 90 minutes maximum. Either inbound or outbound. The peaks in arrival and departure of ACT products might overlap with the peaks of Equation and Mail. The ACT containers are therefore taken into account in the analysis, especially during in- and outfeed.

FIGURE 15 ACTIVE ACT CONTAINER WITH GRID CONNECTOR (Envirotainer, 2016)

4.4 Data analysis on demand patterns at KLM Cargo VG1

In this paragraph, the currently available data is analysed and used to get an overview of the various peak-patterns. After analysing the current demand patterns, a prediction in made on the future demand in terms of ULD vs belly carts split, growth and patterns. These will eventually result in several scenarios to be tested in the model.

4.4.1 Arrival & departure patterns at Schiphol Airport

The current arrival and departure patterns of the commodities are largely correlated to the wave patterns of the airport. These patterns are present at international hub-airports over the world but may differ in the exact times, number of waves and size. As operations at Schiphol are largely restricted to day-time operations only, the wave pattern has been adjusted to this.

Since KLM is the flag carrier at Schiphol airport, these patterns are largely overlapping the daily demand pattern in VG1. The split belly cart versus ULD being handled is also largely dependent on the type of aircraft landing and departing from Schiphol airport. The wide-body aircraft, which are able to hold ULDs in their holds are mostly ICA flights and the EUR flights mainly utilize belly carts.

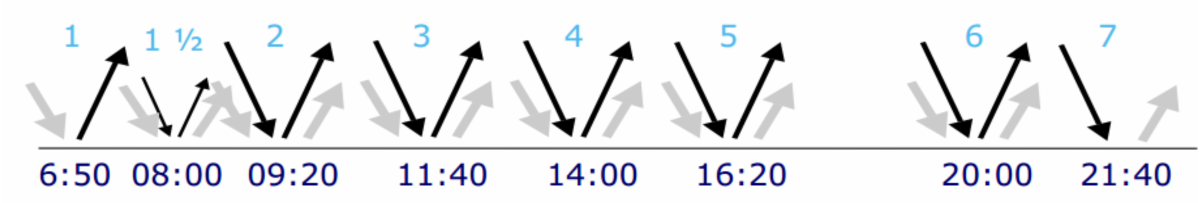


FIGURE 16 DAILY TRANSFER WAVE PATTERN AT SCHIPHOL AIRPORT VIA (Royal Dutch Virtual, 2016)

The various commodities do have another demand pattern, in order to analyse the effects of these patterns on the performance on the sorting and storage system, it is necessary to have a good understanding of the various demand levels and where overlapping peaks might present undesired effects during operation. From data warehouse (DWH) the arrival and departure data is retrieved. This data is from the last year and can be filtered to a daily level in order to use the data as an input for the base model and as a basis for future scenarios. Since for equation, the times retrieved from data warehouse represent the departure and arrival times of the flights. The time at transportation, approximately 90 minutes, need to be added and subtracted respectively to obtain the actual arrival and departure times at VG1. For mail, the recorded times represent the moment of breakdown at the infeed belt obtained from TRIPS and data from the analysis by Lödige and Vanderlande. This is therefore assumed to be the moment mail enters VG1. In the end, the patterns of an average day and a peak day obtained from both mail and equation will be combined.

Equation

First, the demand pattern of equation is analysed on both colli and consignment, or airwaybill, level. The first is more relevant for the handling process and the second more for the in-and outfeed process. Lödige and Vanderlande have estimated, that based on their own data analysis (Vanderlande & Lödige, 2016) which is also based on data provided by KLM Cargo, on average approximately 5,8 pieces per cart are being transported. Additionally, 95% of these flights are estimated to have only one cart. For flight with more carts, an average of 21,5 pieces per cart are estimated. This means that in 5% of the flights there is a high volume to be expected in terms of equation. The yearly pattern over the day can be found in appendix E.

Daily pattern equation

The average daily pattern is obtained by dividing the year patterns by the number of days in the dataset retrieved from Data Warehouse, approximately 1 year. The found numbers will be assumed to be a daily pattern. One actual day is chosen to represent a "peak day" pattern. This is the day in the year with the highest number of consignments handled. On an average day, the following inbound-outbound patterns can be identified:

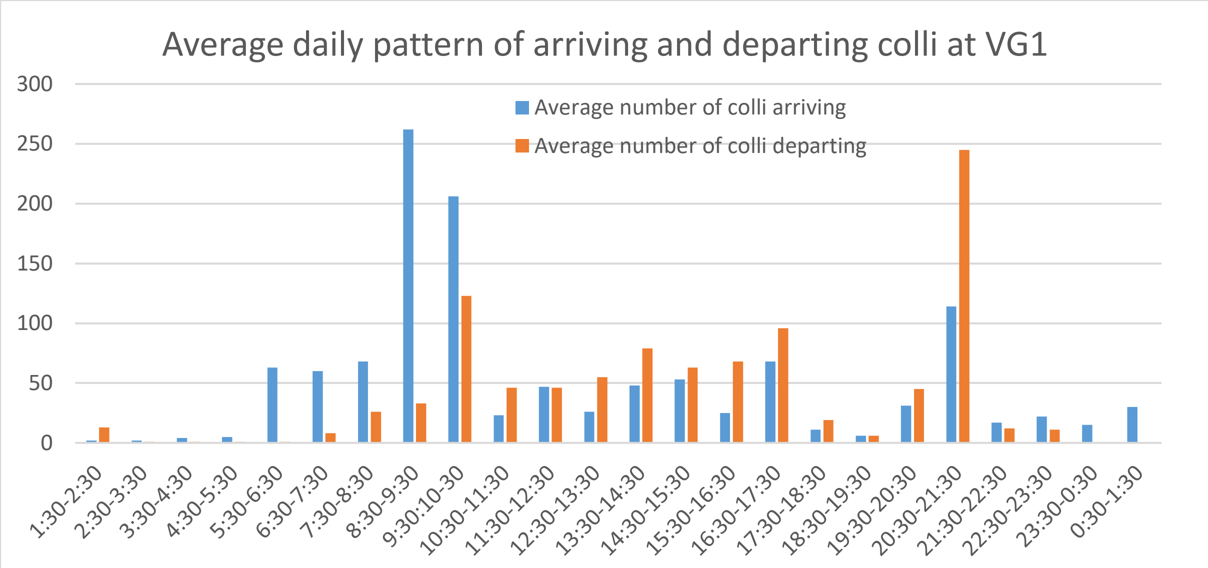


FIGURE 17 AVERAGE NUMBER OF COLLI ARRIVING PER HOUR AT VG1

Figure 17 above shows that in some time-windows, there is an interference with the inbound and outbound flows. In particular, during the morning peak and the evening peak. The infeed and outfeed of the belly carts is considered to be a critical process in the system as there is no redundancy for this particular process. Also in terms of capacity this process might be identified as a bottleneck. In the model study, among others, this process is therefore analysed further. This will be done by using the results obtained from the data analysis as an input for the model.

Belly carts Equation

The number of colli provides an indication of the number of belly carts and ULD going in and out of the warehouse. As mentioned earlier, an average load of 5.8 colli per belly carts for 95% the belly carts is estimated by Lödige and Vanderlande (2016). Assuming this to be correct, an average number of inbound and outbound carts can be derived over time. The estimated number of belly carts can be found in appendix E. The graph in appendix E, **Error! Reference source not found.**, shows that according to this analysis and assumptions at peak moments during the average day; 60 belly carts need to be fed-in-and -out of the system in an hour for equation. This seems not to be correct as the RFQ document only assumes 20 handlings per hour at peak days for the combined operation. The discrepancy can partially be explained by the assumption of 5.8 colli per belly carts. If there is a specific flight with multiple consignments consisting of one or few colli, these are still transported on 1 belly cart. The same holds for the large consignments with a high number of colli. As in 5% of the flights the average number of colli per car is estimated to be around 21.5. It is, however hard to identify which specific flights have these high number of colli per car. A quick scan of several random days provides a plausible explanation for the high peaks. It appears that on these moments a high number of small consignments (40), 1 collo per consignment, is structurally arriving on a flight from HAM (Hamburg) each day at VG1 between 8:30 and 9:30. In addition, a high number of colli (40) in one consignment from EDI (Edinburgh) with cooled products arrives each day. The same holds for the departing consignments. A specific flight to SVO (Moscow) has a very large number of bookings with a single collo (31). And two consignments to BCN (Barcelona) with a high number of colli (75 in total).

With the current assumptions, these typical flights will overestimate the number of belly carts required. It is therefore more reliable to use the daily flight schedule as a basis to determine the number of belly carts and ULD required. Since it may be assumed that for 95% of the flights only 1 belly cart is used (Vanderlande & Lödige, 2016). The number of belly carts can be estimated more concise. The analysis of the number of colli per hour is still useful for other analysis, such as the productivity analysis. In appendix E the daily demand patterns and the movements of belly carts can be found for both the average day and a peak day.

Mail
The mail patters are harder to retrieve in comparison to equation as the mail planning system, TRIPS, only provides allotments. These allotments are basically the volume reserved on a certain flight for mail. The allotments are reserved based on the expected demand and historic demand each half year. The Data Warehouse only provides the number of pieces scanned at the infeed point of the conveyor belt on an hourly level during the day. A distinction is made in Import, Export and Transit mail. Transit is only scanned once at entry, but it is unknown when the transit mail will leave the warehouse. There are two months of mail data available for the analysis, one regular month (October 2016) and one peak month (December 2015). This data was not considered to be very useful for analysis of the outgoing flight patterns due to the large deviation in the dwell-times (Vanderlande & Lödige, 2016).

Assumptions & analysis
Lödige and Vanderlande have performed a data analysis based on their observations and more specific data and this information is found to be more useful for the full demand analysis. Although Vanderlande and Lödige did make some crucial assumptions in their data analysis. For instance, Vanderlande and Lödige assumed 35 mail pieces in one transport unit (ULD of Belly carts). However, this is a rough estimation as noticed from personal observations and from the duty managers. The average number of pieces per cart/ ULD is known to have a large variation although certain large volume destinations are expected to have a full AKE, AAF or AAP container. But the overall average of 35 pieces per transport unit is a fair assumption according to Bram Talahatu and Peter Schut, respectively business specialist and duty manager at EPS. This number will therefore be assumed for further analysis. The number of incoming ULDs and belly carts vary a lot as well although it generally follows the demand in piece level. The split Belly carts versus ULD entering and exiting VG1 largely depends on the origin: ICA or EUR. This has also been acknowledged by Vanderlande and Lödige (2016). In order to achieve the same results as for the equation analysis, a different approach is required due to the absence of accurate data for the required results. The following approach as can be seen in Table 3 has been used to obtain the desired results.

TABLE 3 MAIL DATA ANALYSIS APPROACH

	Number of pieces	Transport units	Belly carts	ULDs
Inbound average	Based on average incoming mail from TRIPS data in December (above year average)	Assumed 35 pieces per transport unit	Based on flight schedule split EUR vs ICA and data from Lödige % multiplied with Transport units	Based on flight schedule split EUR vs ICA and data from Lödige % multiplied with Transport units
Inbound peak	Known from Lödige	Assumed 35 pieces per transport unit	Same as above	Same as above
Outbound average	Assumed 35 pieces per transport unit	Known from Lödige analysis used average December data, assumed 35 per unit as well	Same as above	Same as above
Outbound peak	Known from Lödige	Assumed 35 pieces per transport unit	Same as above	Same as above

The results of the data analysis for mail can be found in Appendix E.

Combined situation
In order to get a complete understanding of the in- and outfeed of the transport units, and especially the belly carts. As for the ULD, the combined situation represents generally the graphs in Appendix E with regard to the current ULD patterns. The demand patterns of both mail and equation are combined for both an average day and a peak day.

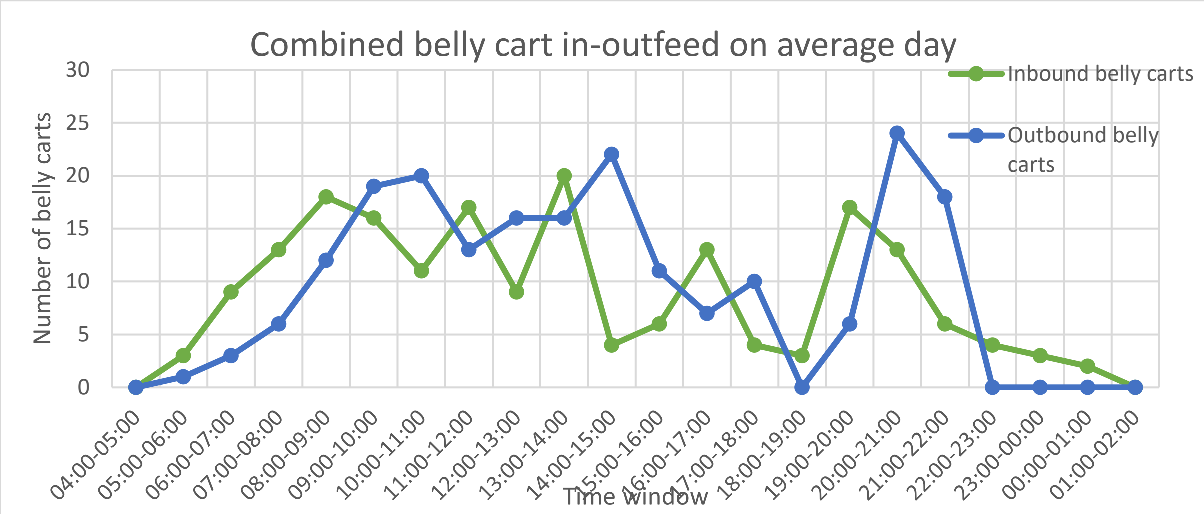


FIGURE 18 COMBINED BELLY CART IN- AND OUTFEED ON AN AVERAGE DAY

Assessing the graph in Figure 18 the contours of the pattern are still largely determined by the mail demand as it represents 80% of the volume. The overall amount of belly carts is a higher and the time-window where carts are fed into the system is longer. The same potential problems are apparent in this situation as with the mail only operation. When the demand peaks are in the vicinity of each other and are overlapping partially, this might pose operational difficulties at the in- and outfeed point and must further be examined in the model study.

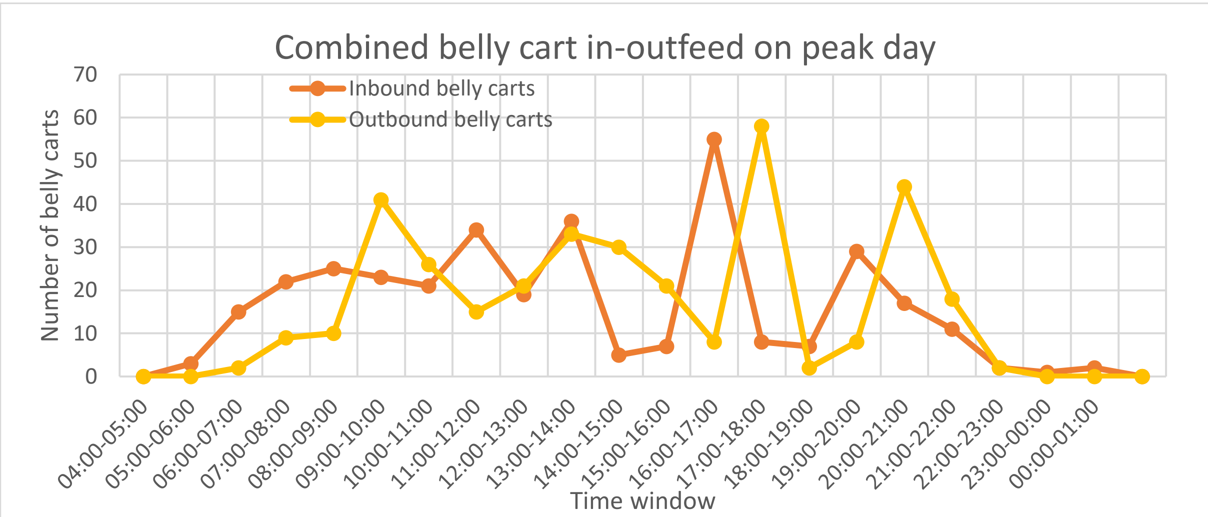


FIGURE 19 COMBINED BELLY CART IN- AND OUTFEED ON A PEAK DAY

During a peak day, the situation with the belly cart in- and outfeed becomes more critical in a combined situation. Especially with the overlapping in and outbound peaks in the afternoon. This situation therefore requires further analysis during the model study.

Conclusions on current demand pattern analysis

The above analysis shows are when the operations are combined, very high peak demands are overlapping during peak days. It is expected and assumed that these Christmas-peak demand rates are also present in the future, with even higher volumes. In the current situation, the available surface area in the warehouse and outside is used to buffer mail during the Christmas peak in some cases for weeks. In the future situation, the buffer-space is more constrained and to the storage racking. Especially on these days it is therefore expected that peak-shaving is required in order to prevent waiting times and especially with an exceptionally high peak demand regarding time-critical ACT containers planning will become crucial.

It is expected that in the near future the daily demand pattern will not change significantly, however in the coming years an extra inbound-outbound wave might be added when the new A-pier allows for more aircraft to be serviced. These specific scenarios will be determined in the next paragraph in conjunction with experts and based on generally assumed predictions of the air freight market.

4.4.2 Data analysis of the future situation

In the future, or integrated situation the demand patterns might differ as the market circumstances change. In order to determine the scenarios for the analysis, several methods can be used (Börjeson, Höjer, Dreborg, Ekvall, & Finnveden, 2006). First a time horizon or time path needs to be set. The estimated time horizon is 2030 -2035. As not only the (economic) life expectancy of the sorter system is expected to be around 15 to 20 years, it also depends on the expected further expansion of the Schiphol passenger terminal. This means that the system must be broken down and re-assembled at another location. This can be an opportunity to expand or implement major reconfigurations into the system suitable for the demand at that future moment. In the assessed system, only small physical adjustments can be made due to the building constraints.

Scenario selection

As the volume is merely based on the mail demand, it is preferred to look at the past developments in the mail market in order to estimate a scenario for 2030-2035. This would lead to *exploring* scenarios. However, changes in the network could lead to other changes rather than volume changes, for example the addition of new routes and destination or fleet composition changes. This is more a *what if?* scenario, which is a predictive scenario. This can lead to a shift in the transport vehicles used: Belly cart versus ULD. In addition, if the trend in parcel delivery is in the current direction, there can be changes expected in the ratio equation/ mail and OoG. The selection of the scenarios and the quantitative bandwidth of these scenarios are to be determined in conjunction with various experts in the company.

Growth scenarios

Some scenarios estimated are based in a multiplier of the current demand pattern. Hereby the assumption is made that the daily patterns and peak-shapes remain the same. At the 10th World Cargo Symposium in Berlin IATA predicts a large growth in the volume of parcels, especially in the at the Asia-Europa routes (IATA, 2016). In the figure below this trend is visible. In business case studies performed by Capgemini (2014) in advance of the decision to the tender procedure for integrating the processes, specific growth predictions are made for KLM Cargo at that moment based on the past developments and expectations in the future with an overall growth of approximately 2% per year. Although there is a large global growth present in the last years, KLM Cargo does not seem to benefit from this global growth in the last years: 2015-2016. Bram Talahatu and Norman Aipassa confirm this and there can be various causes of this or combination, such as less focus on sales and customer relation management, no good distinction between mail products or pulling forward of transfer bookings has allowed new competitors with better service and product distinction to initiate services on parts of the network. It is therefore especially hard to make long term predecitions on the expected growth, as the stagnation in the last years was not foreseen. An number of explorative growth scenario's should therefore be made within a bandwith of stagnation [0.5%/year and and the IATA prediction: 10% per year overall]

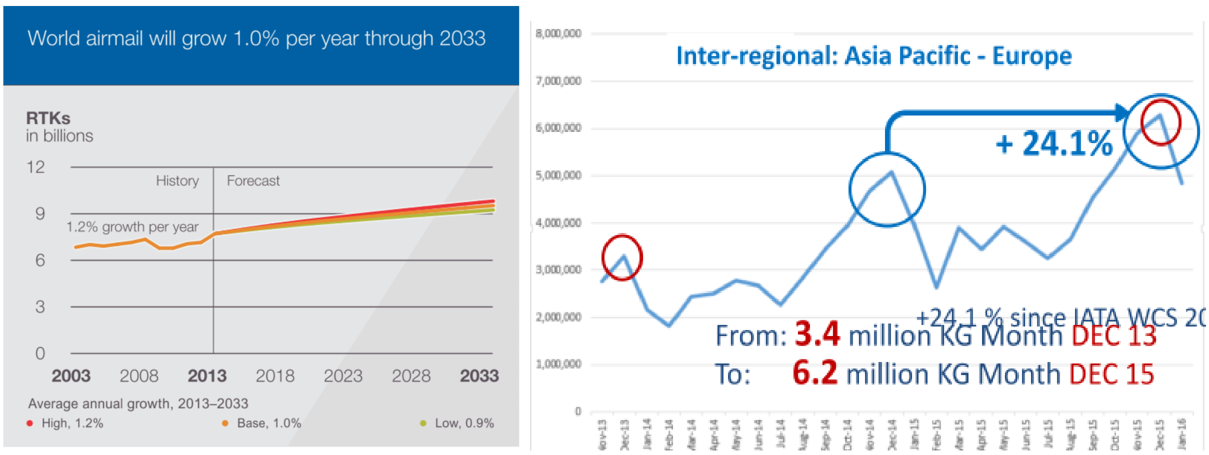


FIGURE 20 BOEING & IATA ESTIMATE GROWTH SCENARIOS (Boeing, 2014), (IATA, 2015)

More destinations

The addition of new destinations largely depends on the development of the passenger transport network. As mentioned by Bas Coenen, head of network development of AF-KLM Cargo, KLM Cargo has no influence on the development of the network, apart from the full-freighter and little on the 747-combi fleet. As the largest volumes for VG1 are being transported in the bellies of full-pax. passenger-aircraft it is necessary to look at the developments in this network. It is however, hard to predict what the developments in this market will be, as this can change a lot depending on the market demand. There is however, a trend, which is also based on the fleet expansion that on average 1 to 2 destinations are opened extra each year on top of the closing and reopening of routes. Nevertheless, this does not directly mean that these flights will be carrying belly cargo as in the last year mainly previous not flown seasonal European leisure-routes are opened, which tend not to create a large cargo/mail volume demand. The expectation is therefore that the number of new cargo routes will lack behind the number of passenger routes being opened and that this will not increase significantly over the coming years. Therefore, it is assumed that on average every 5 years an extra route, op top of reopening or closing, is opened which will also generate a certain cargo/mail volume. In addition, as the largest volume handled is the parcel/postal product, there is not a large increase expected in new customers at outer stations and especially not on European stations as this market is largely covered already.

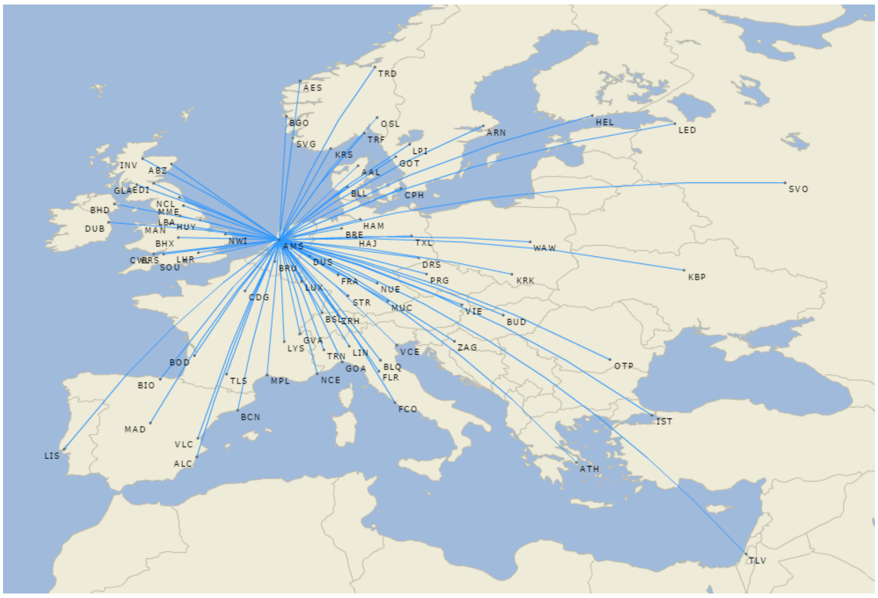


FIGURE 21 CURRENT EUROPEAN NETWORK SERVED BY KLM

New alternative parcel services on network

In the last years, new innovative parcel services have opened on the network utilising the baggage holds in the belly of aircraft departing from Schiphol (WBS, 2016). These companies such as Worldwide Baggage Services (WBS) utilize the now, still available overcapacity of the baggage handling system at Schiphol airport to sort-out the parcels for the specific flights as “unaccompanied baggage” (Schiphol, 2016). The expectation is that these services will reduce the incoming equation in VG1, as the freight building is now -bypassed by the Baggage handling system and the companies promise higher speed, service and flexibility. As the freight is still transported by KLM, there can be a win-win situation in this case as the baggage handling system is able to provide relief at the peak moments during the day but still generate some revenue for KLM. However, as the capacity of the baggage handling system is more constrained in the future due to capacity, this cargo will eventually be handled by KLM Cargo again. Also, if the experience with the new innovative concept proves not to provide the extra service and flexibility it promised, customers will return to KLM Cargo. Some scenarios are therefore chosen that in the coming years (0-20) an overall reduction in the number of equation parcels takes place with either 1% or 3% per year.

Transfer wave changes

In the meeting with Bas Coenen, head of network development, the topic on new transfer waves was discussed as well. Especially with the additional aircraft handling and turnaround capacity becoming available when the A-pier is present. As the fleet and network of KLM will not increase rapidly in size itself, this will not directly affect the growth of cargo demand. However, KLM expects that there is a possibility that one extra wave is added in between the large morning and evening waves, which are heavily constrained due to the time-zones. An extra wave provides a more spreaded demand pattern over the day, which may reduce the effort of planning the in- and outfeed of transport units in VG1 during the day. Although the large morning and evening peaks will not be affected due to the new wave, this can still provide a reduction in the planning effort over the day and allow for better planning of these peak-moments as well. Bas also mentioned that it is far more likely a wave is added to the current 7.5 waves than that a wave will be reduced. It is also not considered to be likely that new waves will start during the night hours, as these are still heavily regulated by the government due to imposed noise constraints around Schiphol. A scenario is therefore created that one extra demand wave will be added to the current 7.5 inbound-outbound waves in between the morning and evening peaks. Spreading the demand of the inter-peak period.

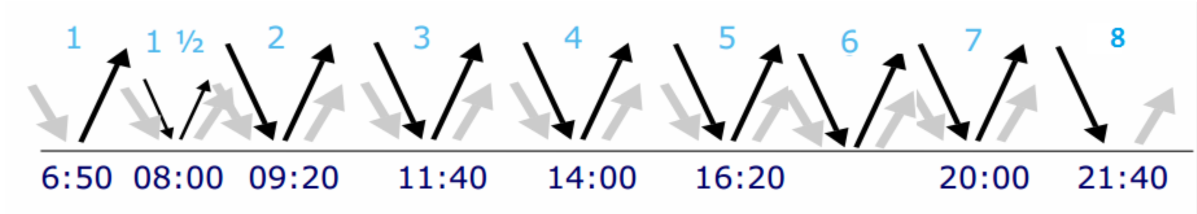


FIGURE 22 EXTRA TRANSFER WAVE ADDED BETWEEN MORNING AND EVENING PEAKS

Fleet changes

As the type of aircraft determines the type of transport unit entering VG1 as described in the demand analysis, it can be very useful to include a future scenario where the consistency of the fleet changes. The current fleet (KLM Fleet Development & Aircraft Trading, 2016) consists of a high number of Boeing 737 aircraft and Embraer aircraft for the short to medium haul European destinations. These aircraft require belly carts to handle the belly cargo as the lower decks are to small to fit ULD's. On the ICA destinations, a larger variety of models is used, including the Combi-aircraft which are able to transport larger AAF or Horsetrailer, containers in addition to the AKE, see Appendix A for more information. As these aircraft will be phased-out I the coming years, more smaller containers (AKE) will be coming in during the peak moments of the day, increasing the load on the internal transportation system, on the other hand, the service, or breakdown time per container is reduced. An increase in ULD handlings for ICA flights is expected in the coming years until the phasing-out of the combi-aircraft is completed. It is expected that from now on every year a combi-aircraft is phased out, increasing the number of ULDs to be handled on these specific routes by a factor 2 increasing the number of ULDs by 10%.

FIGURE 23 B747-400M COMBI-AIRCRAFT CURRENTLY IN USE AT KLM BUT WILL BE REPLACED IN THE COMING YEARS

The topic on fleet changes was also discussed with Bas Coenen, he assures that there will be no change in the European fleet from 737 to comparable aircraft such as the A320 due to the constant renewal of these aircraft and the maintenance being optimized for this type of aircraft. Also, the strategic decision has been made that Air France will keep acquiring Airbus aircraft and KLM Boeing aircraft, in order not to fully rely on only 1 manufacturer. As the A320 aircraft is able to hold ULD's, the scenario of a high increase in ULD's over the whole day and a large decrease in Belly Carts is not considered to be plausible in the timeframe until 2030-2035.

UPU regulations change
Although the postal market is generally considered to be a conservative market, as it is centrally regulated by the Universal Postal Union or UPU. As the transition from letter mail to parcels is expected to continue and health and safety regulations for employees are getting a higher priority over the world, regulations might change in the coming decades. If the current maximum weight described in article RL 122 (UPU, 2013a) of 30 kilograms of the postal bag or parcel is reduced, this can have an impact on the handling and process in VG1. Stricter regulations will improve ergonomics but also increase the number of total handlings as the volume is now spread into more bags. On the other hand, the number of OoG handlings, which are more labour intensive will decrease. It is therefore a useful scenario to consider in the analysis. As a possible scenario, a decrease in maximum weight is imposed to 25 kg. Another scenario is that UPU decides to loosens the constraints on dimensions stated in article RC 115 (UPU, 2013b) of the parcels due to the rise of E-commerce it is plausible and already noticed by KLM Cargo, that more types of goods are being transported via air-mail and therefore a scenario of an increase of 10% in dimension is estimated. This will increase the amount of OoG required to be handled, as the new automated system is specified for the current dimensions and therefore expected to decrease overall performance in terms of costs and system throughput capacity.

4.4.3 Future scenarios

The scenarios and the corresponding quantitative input of the models to be examined are:

TABLE 4 SCENARIO SPECIFICATION

Type of scenario	Specification for input
No change current average day	0-scenario as in 2015-2016
Peak day	Current peak-day
Growth	0,5% growth per year (Current stagnation) (10% in 2035)
	2% growth per year (Capgemini) (40% in 2035) (base scenario)
	5% growth per year (100% in 2035)
	10% growth per year (200% in 2035)
Extra destinations	1 per 2 years (10 in 2035)
	1 per 5 years (4 in 2035)
Competition (assuming 2% overall growth/y)	-1% equation up to 2035 per year (-20% in 2035)
	-3% equation up to 2035 per year (-60% in 2035)
Extra capacity on Schiphol, Transfer wave (assuming 2% overall growth/y)	+1 Extra wave (averaging out peaks between morning and evening)
Fleet replacement (assuming 2% overall growth/y)	+1% number of ULD per year until 2025 (+10% ULD in 2035)
UPU postal regulations (assuming 2% overall growth/y)	Max weight is 25KG -5% OoG in mail
	Increased dimensions, +5% OoG in mail

The majority of these scenarios are translated into factors and multiplied with regard to the current arrival and departure patterns. In the transfer wave scenario, the peaks are averaged out between the morning and evening peaks. In the case of the extra destinations being added the patterns are not altered. As it is not predictable how the extra destinations will specifically affect the demand patterns.

It may be assumed that the current transfer wave peak-patterns will not change dramatically as the time-slots KLM has obtained historically will not be interchanged likely. The destinations can change though, which can result in higher or lower individual peaks in the pattern, this scenario has not been taken into consideration due to the high uncertainty and complex specification: which peak is higher/lower. The potential effect though, is still partially covered by the other scenarios.

If the system will not be able to process the demand in a number of the scenarios, alternative configurations and policies are introduced and the performance is measured based on the to be determined KPI's.

General use of the future scenarios

The scenarios found are KLM Cargo specific, especially the quantitative specifications. However, the general scenarios can be applicable to similar air cargo hubs, although different quantitative specifications are expected here or additional location-specific scenarios might be added.

5 Model study on integrated process at VG1

The integrated sorting facility has been chosen based on a long and extensive business case study, negotiations and tender procedure. It was found to be the most favourable option for KLM Cargo in terms of operational costs and expected operational performance. As described in the problem description, the operational performance is still not fully known as the design is merely based on static calculations of separate processes and do not consider variances in the processing times over the day, also logistical effects of combining the processes is still not fully understood. In order to measure the performance, new KPI's must be determined in consideration with KLM Cargo for testing the new system. Among others, these KPI's are used to determine the processes to be critical for the performance of the system. In this chapter, these critical processes are determined and a detailed conceptualization of the processes is done in preparation for specifying and verifying the processes in Chapter 6.

5.1 Description of future situation, system & general process

The integration of various processes and automation of the internal transport leads generally to lower costs and a less surface area requirements. It may be assumed that the planned system fits inside the building constraints and its basic functionality is good. In Figure 24 below, the new integrated system is shown. The top of the figure represents the airside and the bottom, the landside.

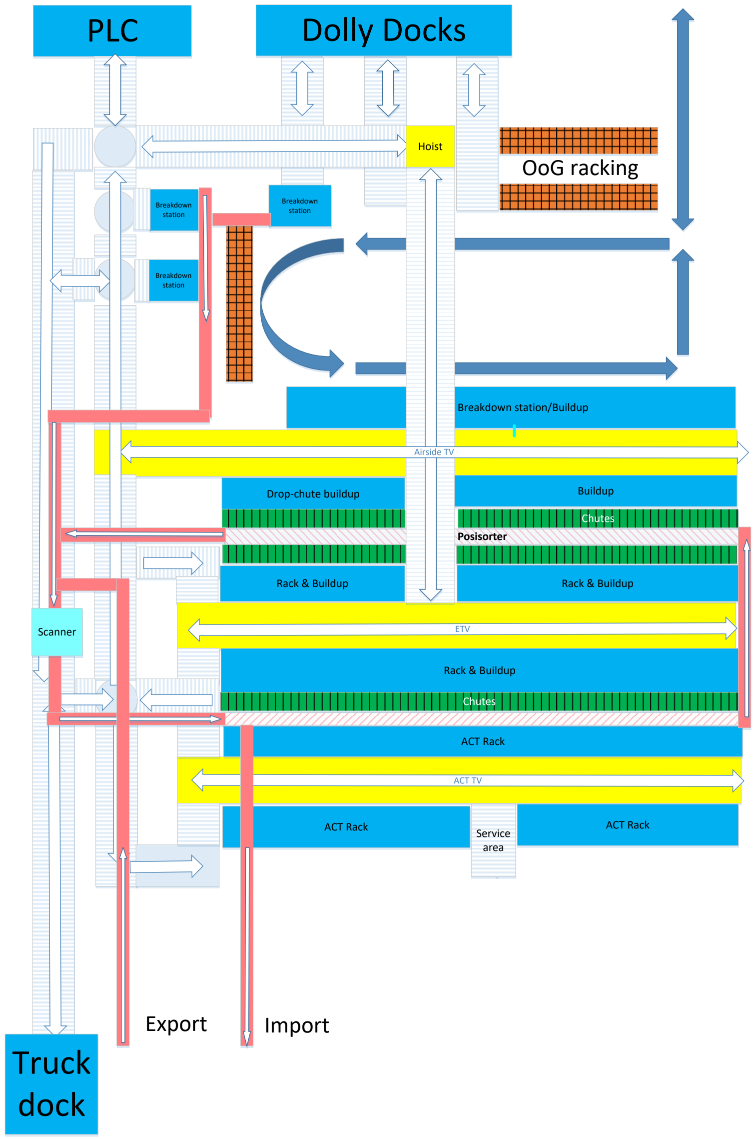


FIGURE 24 SCHEMATIC OVERVIEW OF THE SORTING AND INTERNAL TRANSPORT SYSTEMS, NOT DRAWN ON SCALE

In general, the system has two main functions as in the current situation: the storing and sorting of air cargo. The fully automated internal transport system must transport the transport units, either Belly carts, ULDs or ACTs to the breakdown or storage positions (ACT). The Belly carts and ULDs are broken down at the breakdown station and the cargo is put on the conveyor belt by a handler to be sorted out automatically over the destination chutes by the Posisorter system.

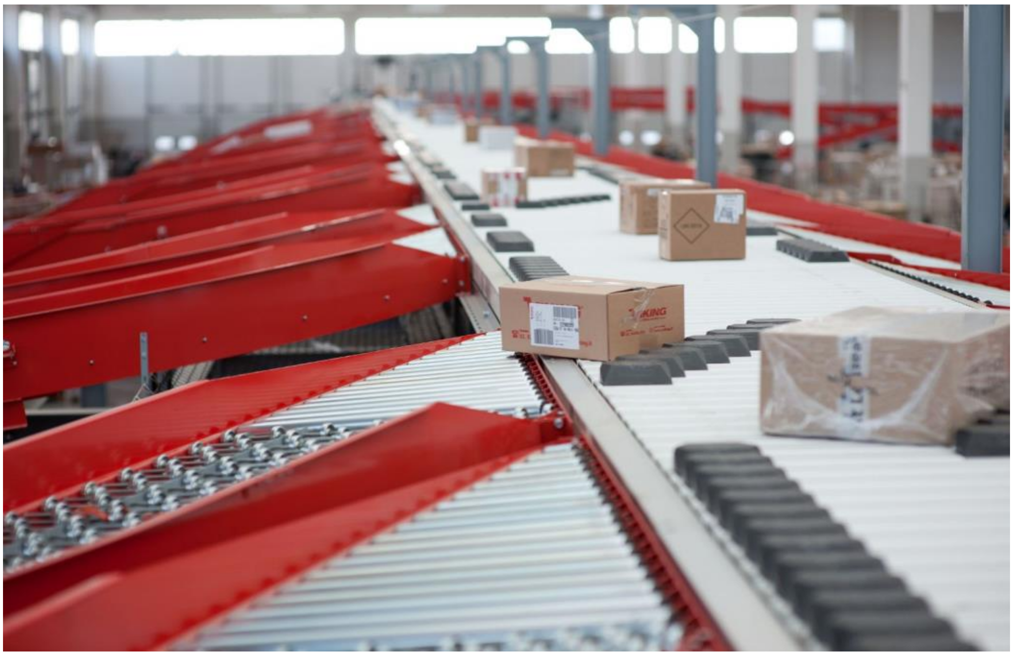


FIGURE 25 VANDERLANDE POSISORTER OR SHOE-SORTER VIA WWW.POSTALTECHNOLOGYINTERNATIONAL.COM (2016)

When the cargo is sorted out in the various chutes on either type of cargo per destination or on flight, a handler will build-up all the empty transport unit standing by the build-up station. When the transport unit is full, the handler will send away the unit to airside transportation for weighing and transport to the aircraft.

FIGURE 26 CHUTE WITH BUILD-UP POSITION AT HUB-EXPRESS, PARIS

The general process is visualized in a decision flowchart and an IDEF0 diagram which can be found in Appendix C.

5.2 Functional requirements & new key performance indicators

The functional requirements and the new Key performance indicators (KPI's) have a strong relationship as the performance of the system can now be assessed and compared to the stated specifications and functional requirements. Since the contract obliges the contractor to design a system which is able to function in future up to 2030-2040, it is necessary to assess how the system will perform on an operational level in various future scenario's which affect the in- and output of the system. The new KPI's allow for this comparison in addition to a comparison to the current system.

5.2.1 Functional requirements and sorter specifications

The functional requirements of the new integrated sorting facility have been determined based on input from KLM and in conjunction with Lödige and DENC. In the RFQ document all requirements are stated which are contractually binding (DENC, 2015). As the proposed system will have to be able to function in the coming years with the number of fte stated in the document, as well as the stated travel times through the system and a large number of other variables, it is crucial to test the most relevant functional requirements in the model under various future circumstances or scenarios.

The most relevant functional requirements to be assessed are:

Sorter system capacity
KLM Cargo and DENC have determined that based on the expected combined quantities of cargo the system must be able to handle. The number of items to be sorted per hour is approximately 2.300 items. Whether this number is reached is largely depending on the type of products being fed-in the system. Parcels do not need any manual scanning at the infeed, as the label is readable with the automated scanner. If all items were parcels, the 2.300 per hour is reached with 2 infeed points. The postal bags do require manual scanning and thus the estimated infeed-time is longer. The approximate infeed-rate is about 575 per hour, per infeed point if all bags need to be scanned. There are no direct issues expected here, as the system is technically able to sort-out 5.000 items per hour.

Buffer capacity
The total capacity amounts to 212 carts/ULDs in the whole system. In the storage racking, 79 x 10ft storage racking is present, these positions can take 2 x 5ft units (AKE/Belly cart). The buffer racking is expected to have sufficient capacity in the current situation as the in-outfeed balance of transport units on an average day is around 0 and the inflow peaks do not exceed 56 units. In the future, however, temporary peak fluctuations in the infeed might cause a lack of storage capacity. This will result in the requirement to store transport units outside in order to leave sufficient capacity for the full transport units, limiting the capacity on the roller decks. The required outside buffer will therefore also be taken into account.

(E)TV moving capacity
The estimated moving capacity is estimated to be 35 cycles per hour. This is based on the processing capability of the whole sorting & storing system. In reality, the (E)TV moving capacity can be higher, if the cycles are short.

Chute capacity
There are 61 double chutes in total, of which are 54 destination chutes and 7 drop sorting chutes. Additionally, there is a conveyor for equation with destination AMS (import) and an extra belt for last-minute build-up of partially filled ULDs at the dolly docks. Each chute has a size of approximately 6 x 2,1 m (L x W) and is estimated to hold up to 19 items per chute, either equation or mail and 37 items per destination. This allows for prioritization per destination. The expected filling rate is 75% per destination. The configuration and allocation algorithm is to be determined by KLM Cargo, since there are not enough chutes to serve all destinations permanently. If an item cannot be sorted out directly if the flight is still closed, the items are allocated to an overflow chute for the specific time-window.

Turning table capacity
Although, not specifically named in the document, the assumption is made based on an estimated average 1 unit every 10 seconds: 4 seconds (un)loading, 6 seconds turning. Assuming a throughput capacity of 6 units/minute. As turning only must take place at for the infeed of belly carts and the potential outfeed of ULD's, this average throughput is acknowledged by Lödige at the Factory approval test.

In/outfeed capacity
As mentioned earlier, this has not been stated directly but the requirement is states that the systems needs to have a handling capacity of 35 units per hour of the combined in-and outfeed of transport units. The in- and outfeed of a belly cart at the palletizing system is 55 seconds for infeed and 35 seconds for outfeed.

Travel times in the system
The travel times within the system are written down in the specifications, these are of importance when compared to the modelled travel times, for planning the in-and outfeed of transport units. The speed of the roller decks is approximately 0.3 meter per second. The speed of the (E)TV is approximately 2 meters per second.

OoG handling
The RFQ document states only 1 person is required to operate the forklift truck on average periods in order to handle the OoG products, on peak days, the OoG handling requires 3 operators on forklifts to do all handlings. The required storage area is not mentioned in the document, as it needs to be determined. No specific handling times for OoG are given.

5.2.2 Key Performance Indicators
The key performance indicators have been determined in conjunction with experts at KLM Cargo and literature. In a meeting with Michiel van der Eijk and Harry de Groot, see appendix D for a summary, the future KPI's are discussed since with a new automated system other factors such as utilization and capacity (constraints) are having a larger impact on the overall performance, as these can also influence the current performance indicators such as FAP and manpower utilization than with the more flexible manual current situation. From the discussion and literature, a number of KPI's came forward which are relevant for measuring the performance of the system.

1) Costs, here variable costs are taken and energy costs are not taken into account as this depends on a large number of external factors over time and the energy usage is considered to be nearly constant over the day as the automated sorter is in full operation during the day.
    I. Manpower used (OPEX)
    II. Utilization per workstation (%)
    III. Cost/item (Volume / OPEX)
2) Utilization of the system (Liang et al., 2010):
    I. Chute utilization (% filled)
    II. ETV average scheduled utilization (%)
    III. Rack utilization [%]
3) System processing capacity, Throughput
    I. Average volume / hour processed over the day
4) Throughput time over the day, in- and outfeed times most relevant due to high dwell times, EQ and ACT are time-critical products so the maximum in-outfeed time is important for the operational performance.
    I. Average In- & outfeed time per belly cart [min]
    II. Average In & outfeed time per ULD [min]
    III. Average in-& outfeed time EQ [min]
    IV. Maximum in-outfeed time EQ [min]
    V. Maximum in/outfeed time ACT [min]
5) Extra surface area required
    I. OoG handling area
    II. Outside buffer

A number of the KPI's are more constraint parameters, as there is a certain value which cannot be exceeded. For example, the surface area and throughput times are currently limited due to the warehouse-building constraints and the cut-off times in place. The costs and utilization are considered not the main requirements of the system but should be optimized, in addition these indicators will have an effect on the most critical indicator: the throughput. As this will be the most constraining in terms of the main function of the system.

The Flown as Planned, or FAP, which is an important business KPI in the air cargo business has not explicitly taken into the set of operational performance indicators since a large number of other factors may influence this KPI, such as late arrivals etc. From experience, this has been the main cause of a lower FAP at KLM Cargo. This does not mean, however that in the new situation, the FAP may change due to poor planning of the in- and outfeed process. For the various products, the KPI's have a different priority in the final assessment. Equation has an important time-factor but for mail, the capacity and costs are more relevant.

In order to achieve the most optimal operation there is an optimal balance in cost versus capacity, as the system must have the following characteristics:

- Lowest costs (OPEX)
- Highest utilization
- Sufficient capacity: in other words, demand equals system capacity
- Lowest throughput time
- Lowest surface area

General use of the found KPI's
The found KPI's for the KLM Cargo system can be applied to similar systems, although, depending on the physical lay-out, the priority of the individual KPI's may differ, at the SoDeXi hub, the throughput time is not considered to be a critical KPI as the system is more flexible in terms of internal transportation. Also, the available surface area was not as constrained as in the KLM Cargo case. The focus-KPI's should therefore be determined per specific sorting system.

5.3 Description of the integrated processes per commodity type

As the new integrated system combines the currently separated flows, a standardization in handling takes place for the commodities. This homogenization has effect on the flexibility and the quality of the various products as the handling times are now standardized but the in- and outfeed is constrained more than in the current situation due to queuing on the roller decks and the transport vehicles.

5.3.1 Mail products

The mail products are handled almost fully automatically in the new system. In addition, the new system offers the opportunity to store and buffer mail products at various locations within VG1. These can either be the destination chutes, overflow buffer chutes, stored in the belly cart or ULD inside the racking. As the sorting of mail products is based on destination, the chutes are allocated in such a way the large volume mail destinations can be sorted -out right away in the fixed chutes. Mail items with a closed destination are sorted out in the buffer-chutes, or bulk chutes. These consolidate all mail items in a belly cart and if full or after a certain time-period, the belly cart is broken down again into the system, sorting all items again. As an extra product-differentiation, the possibility to sort and separate priority mail items from standard mail may also be used. This increases the quality of the mail product. There is, however, a constant consideration to be made whether to open chutes for this prioritization or to open chutes to sort-out directly for a destination as there is a shortage of chutes.

5.3.2 Handling of EQ products

As mentioned earlier, the EQ products are now handled the same way as the mail products. There are only a few distinctions regarding the priority of building up the items. The destination-chutes are therefore divided into two compartments: One for mail, one for equation. The operators' task is to first load all equation into the belly cart or ULD, then check whether co-loading is possible and if so, load the mail into the same transport unit. If co-loading is not possible, due to restrictions at the outer stations regarding mixed cargo, the transport unit is send away to transportation and an empty unit is retrieved from storage to be loaded with mail. It is also possible that the mail will be handled first and send away before the cut-off time of equation. This will enable the handler to fill a new transport unit with Equation at the cut-off time or before.

5.3.3 Handling of OoG products

In the new situation, a large number of EQ products will now be sorted using the automated sorter. For the greater share of the products, this can be done without any problems. However, with the introduction of the sorter, new constraints are introduced regarding the dimensions, weight, contents and other characteristics of the EQ products. It is important to prevent certain product from entering the automated sorting process, as it may result in blockages or dangerous situations. In the current situation, these products where handled the same way as the regular EQ. This process is described in paragraph 4.1.1.3. All constraints for automated sorting of EQ and mail are described extensively in the RFQ document (DENC, 2015). The most important constraints to be taken into account are:

- Dimensions: Min [150 x 100 x 20 mm]; Max [1500 x 800 x 800 mm] (L x W x H)
- Weight: Min [0,5 kg]; Max [35 kg]
- Content: No Dangerous Goods (DG), cooled products, human remains

In the new sorter system, these products are initially fed into the system while they are still in the Belly carts/ULD. At the breakdown, the breakdown employee initially determines whether the product is sortable or not, based on the above constraints. If the product is considered not sortable, the EQ and mail remains in the belly carts or ULD and is transported to the OoG breakdown station. If the operator makes a misjudgement on the constraints, there a back-up in the form of an automated dimension, weight and label scanner to scan all passing items. In the image below a similar system can be seen.

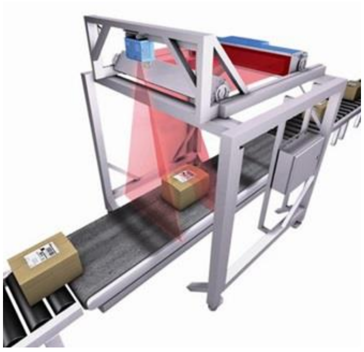


FIGURE 27 AUTOMATED (VOLUME)SCANNING AND WEIGHING OF ITEMS

If the scanner determines the item is OoG, the belt is stopped and the item is removed manually. The EQ inside the ULD/Belly carts is then brought to the OoG breakdown station, where a distinction is made between dangerous goods (DG), cooled, human remains etc. and "regular" OoG items. The DG and other irregular products are build up in a belly cart and laterally transported to either the cooler or VG2&3. The regular OoG items are stored in the OoG racking.

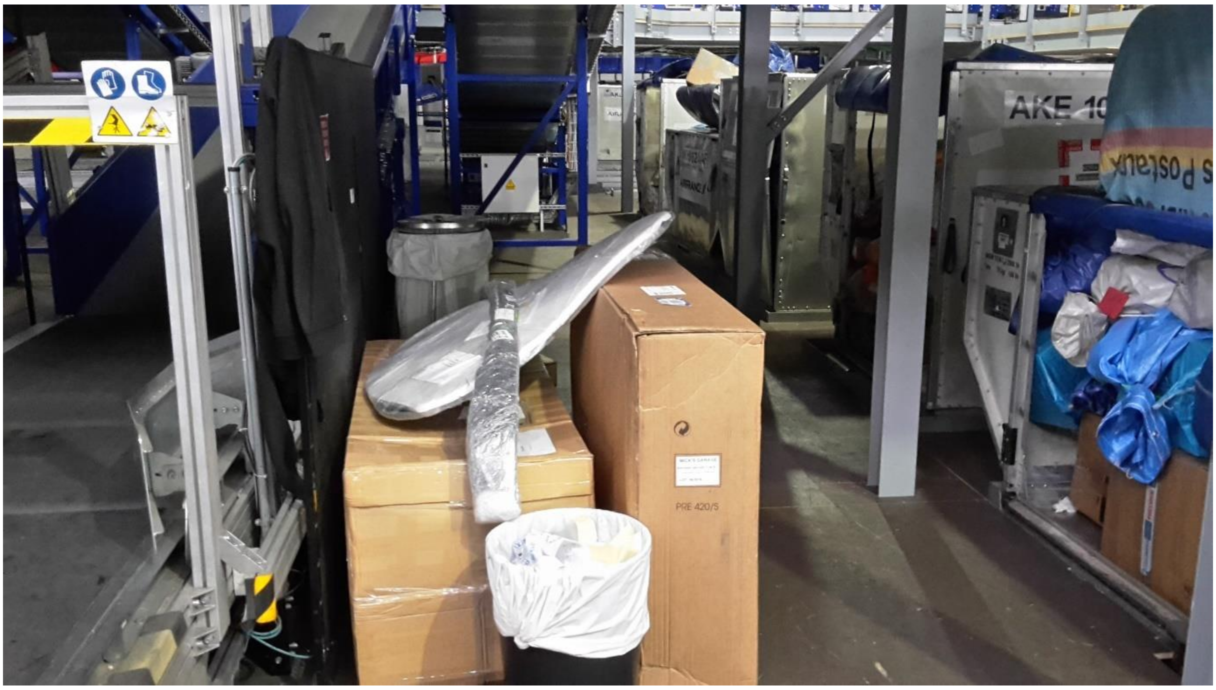


FIGURE 28 OOG STORAGE NEXT TO INFEED POINT AT HUB-EXPRESS, PARIS CDG

After the items have been stored in the storage racks using a forklift truck, the items are retrieved from the racking based on their booking before the departure cut-off. The items are transported to the belly carts or ULD with the corresponding booked flight. Finally, belly carts and ULDs are transported to the weighing station and to transportation to be loaded onto the flight. Export OoG is directly stacked on the rack or transported to the booked belly carts/ULD. In appendix C, a flowchart of the OoG handling process can be found.

As the handling of OoG goods requires relatively more manpower and surface area than automated sorting, it is important to understand how large the share of OoG items is to be expected. This determines the cost-efficiency of the new system and the usage of scarce surface area available in VG1. As there is currently not an exceptional process for handling these items, apart from Dangerous goods e.g. no exact data is known about the share of OoG products to be handled in the future. Therefore, the specification of the sorter is mainly based on rough estimations based on current data, experience and on standards for similar systems in place. So, a more elaborate data analysis of the current data and measurements of the dimensions should be performed in order to determine the share of OoG handling and the size of the storage racking.

5.3.4 Handling of ACT products

The ACT products are in general handled in the same way as other ULD's. However, since these are time-sensitive and require regular servicing, the priority given, for handling these ACT containers is very high. Although the number of ACT containers is relatively low compared to the Mail units: 2 versus 27 per hour at peak times. The handling constraints are, however, critical for these products and there are overlapping peaks according to Vanderlande & Lödige (2016). Moreover, the ACT containers often weigh more than 3.000 kilograms, constraining the in-and outfeed to the lower roller decks. It is therefore crucial to plan the in- and outfeed of the ACT containers well. The ACT containers are not allowed to wait outside on the platform in the transportation buffer due to product safety regulations and therefore require a Just-in-time in-and outfeed. The ACT containers have their own dedicated storage racking with grid connection in order to charge the batteries. There is also a servicing (refill) area for dry-ice containers being served by a manual TV. This service roller deck may also be used to discharge ACT containers in peak-times as an extra outfeed-option, but this is not preferred as transportation needs to make a detour around VG1 and the surface area on landside is limited for manoeuvring. The in- and outfeed times are therefore a critical performance indicator for this product.

General application of the handling processes

The handling of the various commodities is bounded to a number of constraints, being determined by the general conditions of the carriers and the Universal postal Union in the case of mail. The specific handling process itself varies between the different cargo hubs but is generally similar in terms of products handled and the general flows. System-specific handling constraints regarding dimensions and weight, such as the OoG handling process can differ per used system.

5.4 Identification of critical processes

Based on the KPI's stated for the new system, the performance-critical processes now have to be identified. In literature, a number of methods are provided for identifying the critical processes in a project or production line in terms of throughput. The most applicable for an in-and outfeed process is in this case the Theory of Constraints, or TOC, developed by Goldratt.

As the throughput capacity and the in-outfeed times are important performance indicators, the internal transport system is analysed first. When the TOC is applied to the in- and outfeed process of the handling system in VG1, the following expected constraints (encircled) are found:

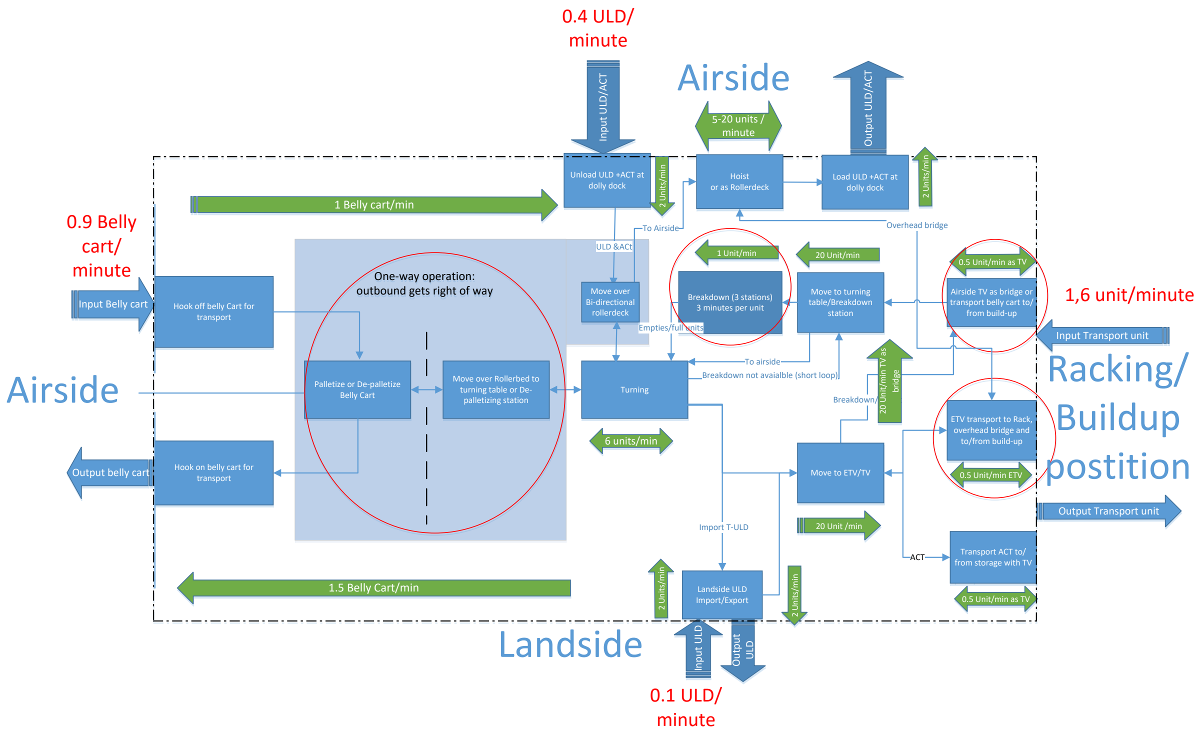


FIGURE 29 THROUGHPUT CRITICAL PROCESSES (ENCIRCLED) IDENTIFIED IN THE INTERNAL TRANSPORT SYSTEM BY APPLYING THE TOC TO THE SYSTEM IN VG1

As can be seen, for both the in- and outbound processes, different bottlenecks are identified. Concerning the inbound process only, the ETV is the process with the lowest capacity encountered. However, if the outfeed-stream is taken into account as well, additional potential constraints start to appear at for example the PLC system, as the PLC serves both flows. Also, at the breakdown points, a bottleneck might appear if there is a high volume of traffic interfering with the inbound transport units requiring breakdown. Also, the potential spillback might have a large effect on the overall systems performance and capacity, which cannot be assessed directly using the TOC. Depending on the time of the day, the theoretical bottleneck might shift or imply multiple bottlenecks at the same time. This is in contradiction to the principles of the TOC, which states that only 1 bottleneck can be identified in a particular system. The application of the TOC to a more complex system with multiple variable flows with bottlenecks which may influence the processes upstream is therefore limited. In order to pinpoint the actual operational bottleneck in a complex system with contraflows over the day it is therefore necessary to further analyse the internal transport system in a simulation study.

Cost of the process & surface area
As the current system's cost/capacity performance mainly depends on the efficiency of the allocation of human recourses with the varying demand. In the future system, the cost factor in the operation becomes smaller relative to the performance or throughput of the system. The operational costs, are in general one of the main arguments to opt for an automated system, as it reduces the amount of human resources required to run the operation. In this case, this is also one of the main reasons the choice was made for an automated integrated system besides from the surface area reduction. The costs are, however, still an important factor in the operational performance of the integrated system. In order to identify the crucial process affecting the operating costs of the system, the process with the highest non-fixed operating costs needs to be located, as this varies over the day, depending on the demand. The TOC also states that Operating expenses (OE) can be a constraint as well. Identifying the process with the highest Operating expenses expected is therefore necessary, this will be done by means of interviews.

In addition, it is necessary to reason back from the newly determined KPI's in order to find critical processes in terms of these KPI's as they will determine the performance of the new system. The TOC already covers the constraints in terms of (internal transport) or throughput capacity, in-and outfeed times which are related and the costs. But there is another performance-critical process, which cannot be found directly using the TOC. But has to be analysed as it has an impact on the performance of the system.

Utilization of the system
The utilization of the (automated) system needs to be as high as possible in order to keep manual processes to a minimum. On the other hand, the required utilization of human recourses should be optimal, just below 80 percent in order to prevent queuing. An optimal chute allocation/utilization is an important factor to achieve this, as this determines the amount of double-handlings required. The buffer-racking should be utilized as well, in order to spread the work-load over the day. In conjunction with this, the optimal utilization of the ETV is crucial to achieve this. The utilization has the underlying effect of affecting the overall throughput and the costs of the system. The utilization should therefore be as high as possible for automated systems but without causing the function-critical KPI's as the throughput times and capacity to deteriorate.

General application of the critical process determination
The critical process determination can be performed for similar systems with an automated internal transfer system in the case of the Theory of constraints. As a matter of fact, if the system becomes less complex, the TOC can be applied more easily and could also provide a direct solution to possible constraints. If more system-specific performance indicators are present it is favourable to consult experts on possible constraints in the system in order not to overlook these constraining processes.

5.4.1 Internal transport of transport units
As the TOC has shown already, there are some critical points where, based on the current peak demands as described in paragraph 4.4.1, capacity issues might occur. The point where belly carts are fed into the system can be considered as critical point in the system, as it has no redundancy, the same holds for the (E)TV. Furthermore, the in-and outfeed is a one-way type system; so, either in- or outfeed can take place one at a time. Also, the interference with ULDs on the roller deck might cause capacity issues. It is therefore necessary to assess the whole internal transport process using the TOC in order to find other possible constraints in the system.

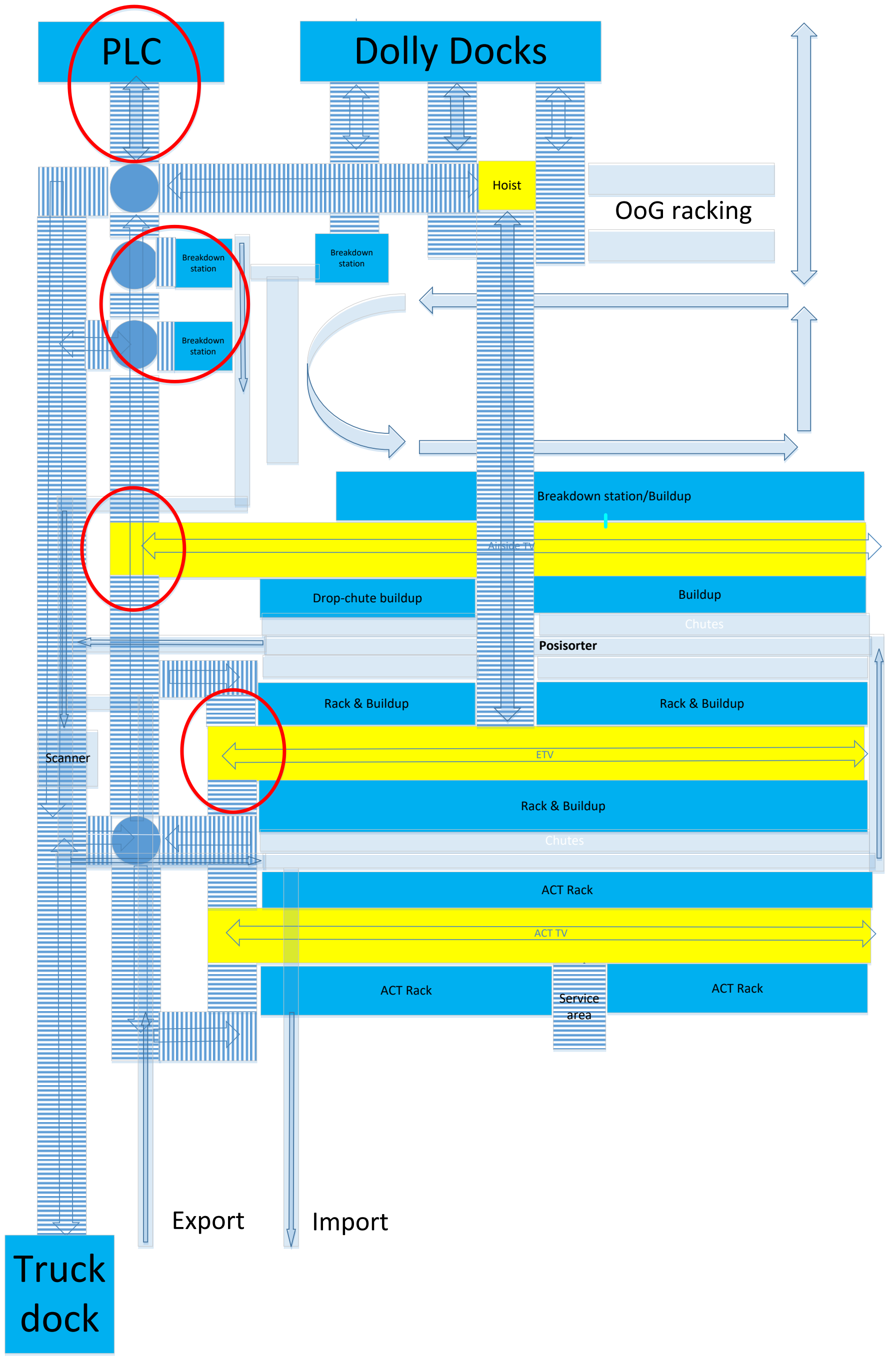


FIGURE 30 INTERNAL TRANSPORT SYSTEM: ROLLER DECKS, TRANSFER VEHICLES, HOIST, PLC, DOLLY DOCKS, AND BUILD-UP/BREAKDOWN STATIONS, POINTS OF CONSTRAIN ARE ENCIRCLED

Th TOC is used in order to locate the capacity constraints, or bottlenecks in the whole transport system. In the schematic figure in Figure 29 and Figure 30 critical processes are encircled as these are the processes with the lowest throughput first encountered from the possible input flows. The throughput capacities of the various processes have been obtained from the RFQ document (DENC, 2015). In the modelling study, the in-and outfeed process is tested using the various scenario inputs as experiments in order to determine at which moment the system cannot process the demand, in other words: where are the constraints of the system and how do the various scenarios effect the relevant KPI's applicable in the internal transport process.

5.4.2 OoG handling process

The OoG-handling is considered to be the most labour intensive process as it depends largely on the type of input there is. From the data analysis in the previous chapter, interviews and reference visit. The share of OoG can vary largely depending on for example the weather conditions or the origin of the mail/equation. In order to handle this type of items within the business constraints regarding among others the FAP being used by KLM Cargo a sufficient number of employees and storage positions need to be available for processing the OoG items accordingly. The OoG handling process is also found to have a large impact on the surface area usage, although the volumes are relatively small (10% EQ & 3% Mail) compared to the total processed volume per day. This area can otherwise be used to store or buffer other commodities and should therefore be analysed as well.

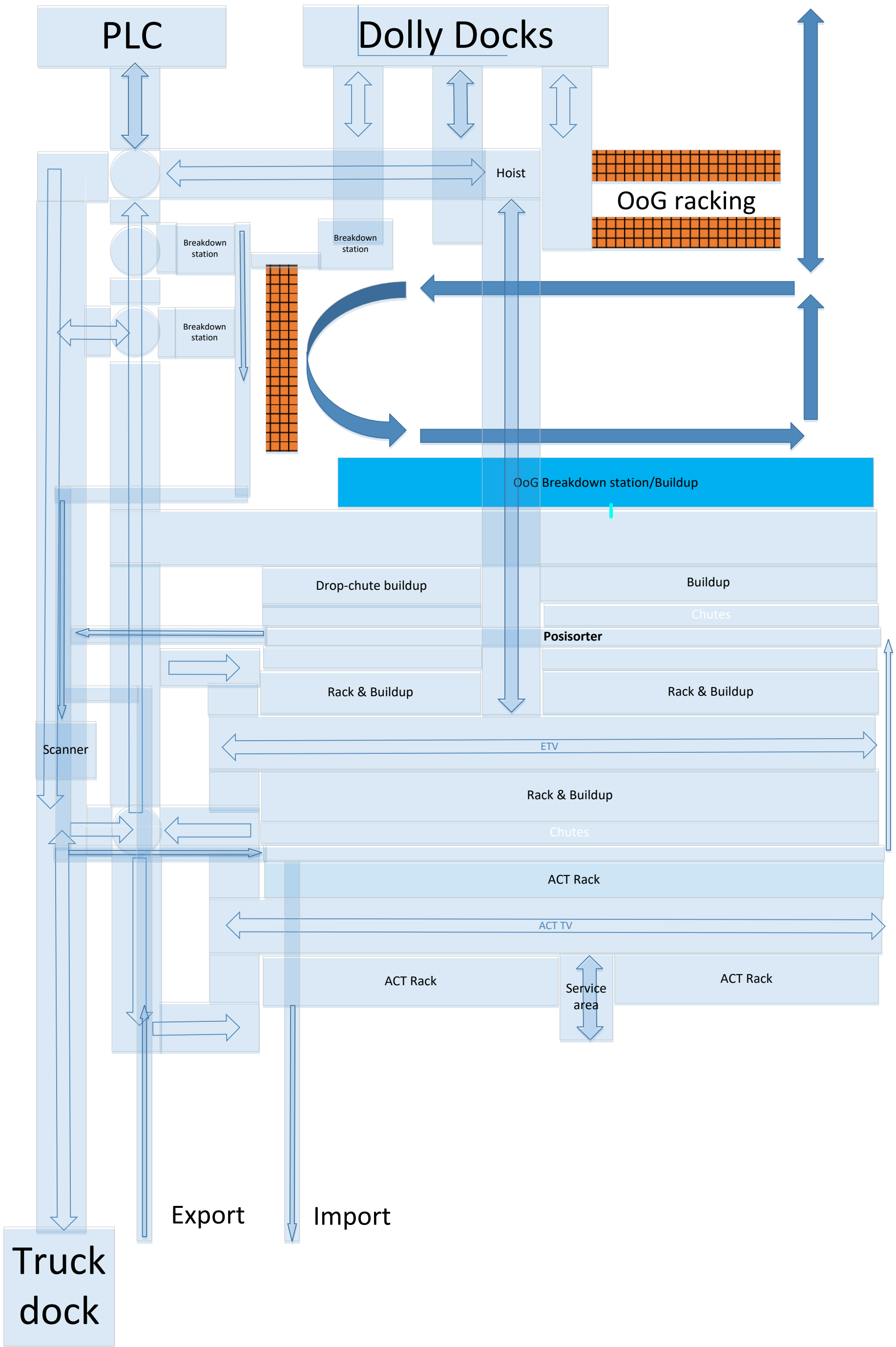


FIGURE 31 THE EXCEPTIONAL PROCESS OR OOG HANDLING PROCESS IS HIGHLIGHTED: OOG RACKING, BREAKDOWN/BUILD UP AND FORKLIFT MOVEMENTS

5.4.3 Chute allocation/utilization process

The chutes are an essential part of the sorter system as this is one of the places where value is added to the process inside VG1. By sorting out the items on flights/destinations, the chutes provide a buffer for the employees to build up the belly carts & ULDs when required. This increases the resource utilization over time in comparison to the current system. However, due to the limitation of surface area, some considerations need to be made with regard to the usage of the chutes. There are several options to be considered with regard to the utilization of these chutes. These will be discussed later in this paragraph.

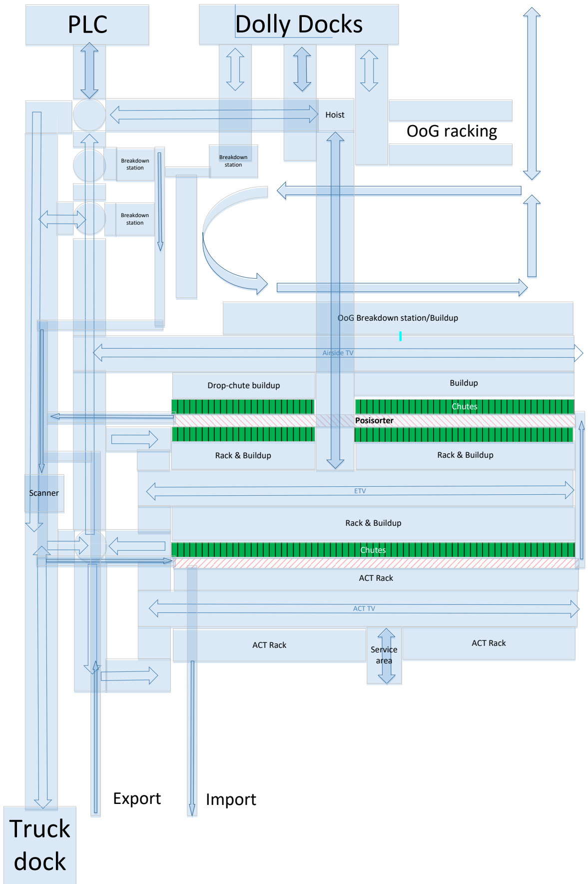


FIGURE 32 CHUTE AND POSISORTER ARRANGEMENTS ARE HIGHLIGHTED

Chutes

KLM Cargo and its strategic partners have a large number of destinations in its network flying from Schiphol, the amount of different cargo-destinations flown at in a week on average is 118 destinations. These are the combined destinations for mail and equation. However, there are only 54 destination-chutes available at the same time each divided in 2 compartments for equation and mail products. In addition to the divided-chutes there are 7 so called batch chutes available. These can be used for either flights with a mail-only destination, or as an overflow buffer-chute if the destination-chute has not yet been opened or is full. These chutes need to be emptied over time and refed manually into the sorting system or automatically stored in the racking. The chutes are designed by Vanderlande as part of the Posisorter® sorting system. They have been designed based on the specifications and requirements stated in the RFQ document (DENC, 2015) The destination-chutes are designed as such that the items are not tumbled or damaged during the sorting operation. This makes it possible to sort out fragile goods and “keep upright” products. However, the batch chutes are not suitable for these products as there is a free-fall drop from approximately 1 meter into the belly carts. Fragile goods which are typically found under equation, may not be allowed to use these chutes. Possibly constraining the use of the batch chutes for mail products only. The chutes are also expected to be steep enough so no bags or parcels will stop moving before reaching the end of the chute.

Allocation of chutes

For a number of destinations, the flight frequency is such that the destinations are permanently allocated to a certain "fixed" chute. These also include the large volume destinations. The total of fixed chute arrangements amount to 30. This leaves only 24 flexible chutes to be allocated for smaller volume destinations. The initial allocation algorithm proposed by Vanderlande & Lödige (2016) based on three time-windows is considered not to provide sufficient chutes for the various types of commodities: Mail and Equation in the second time-window. It is therefore necessary to consider a new allocation algorithm to provide enough chutes. Another algorithm needs to be assessed based on a fixed time before the flight departure (SDT). In order to, achieve maximum utilization and lowest costs, the items sorted directly should be as high as possible. This will reduce the manual and non-value adding process of re-infeeding overflowed items and time-buffered items.

5.4.4 Summary of critical process identification and connection with KPI's

The processes found to be critical in determining the performance of the system are to be conceptualized in the next paragraph. A brief summary of the measurement goals of the different models can be found below:

TABLE 5 OVERVIEW OF MODELS AND CORRESPONDING KPI'S AND THE SCENARIOS WHICH WILL USED TO AFFECT THE INPUT OF THE CORRESPONDING MODELS: AM -> ALL MODELS, TM -> TRANSPORT MODEL. OOG-> OOG MODEL

	KPIs				
Scenarios	*Costs*	*Utilization*	*Processing capacity*	*Throughput times*	*Surface area required*
A) Average Day current	AM	AM	TM	TM	OoG +TM
B) Peak day current	AM	AM	TM	TM	OoG +TM
C) 0,5% growth/y (Current)	AM	AM	TM	TM	OoG +TM
D) 2% growth/y (Capgemini)	AM	AM	TM	TM	OoG +TM
E) 5% growth/y	AM	AM	TM	TM	OoG +TM
F) 10% growth/y	AM	AM	TM	TM	OoG +TM
G) Wave_added_avg 2%	TM	TM	TM	TM	TM
H) Wave_added_peak 2%	TM	TM	TM	TM	TM
I) Competition EQ high avg day (2%/year growth)	AM	AM	TM	TM	OoG +TM
J) Competition EQ low avg day (assumed overall 2%/year growth)	AM	AM	TM	TM	OoG +TM
K) Fleet replacement_no more combi's	TM	TM	TM	TM	TM
L) UPU postal regulations less restriction (dimension)	AM	AM	TM	TM	OoG +TM
M) UPU postal regulations more restriction(weight)	AM	AM	TM	TM	OoG +TM
N) Extra destinations +4	Chute model	Chute model	none	none	none
O) Extra destinations +10	Chute model	Chute model	none	none	none

5.5 Conceptualization of critical processes in integrated situation

In order to conceptualize the critical processes of the integrated situation, first the level of detail and the aggregate level of the analysis needs to be determined. As the data, available from KLM Cargo is only accurate on an hourly basis, the accuracy and usability of the model is therefore limited to this time step. During conceptualization, some detailed aspects and sequences of certain sub-processes are therefore not conceptualized in the models.

For example, in the internal transportation model, the amount of ULDs and Belly carts being pulled by the Spijkstaal or MULAG from and to the transportation department is highly variable between 1 and 6. However, no data is available on this and for the performance indicators of the model, it is not considered relevant as the transportation time from the outside transport buffer to the infeed point is very small: <1 minute. In the next paragraphs, among the conceptualization, the considerations and limitations of each model are discussed.

5.5.1 In- & outfeed of transport units

The in- & outfeed processes of transport units are largely automated processes, from the moment the transport units are transferred into the system by either the PLC system, a dolly dock or the trucking dock. The transport through the system is performed by either powered roller decks or a (Elevated) Transfer Vehicle.

FIGURE 33 ROLLER DECKS AND ETV (LÖDIGE, 2016)

The system is designed as such that the roller decks are controlled independently, creating a discrete conveying system. This offers the possibility to queue transport units on the roller decks, creating a temporary buffer for the cycled, transfer processes. This possibility, does however create potential capacity issues in the system. As the routing within the system is such that the same roller decks transport ULDs and Belly carts with other internal destinations. As most of the roller decks are bi-directional, the routing is not straightforward as there are a number of options to choose for different transport units. These decisions are made by a human controller, who has an overview of the cargo to be expected and decides based on experience with the system what is the most favourable routing for a certain transport unit. This is, however difficult to model in a deterministic discrete event model. A balance between the level of detail, validity and usability of the model needs to be found. Since KLM Cargo does not yet have a strict routing protocol for the controller for all possible situations, as this will be based on the testing and experience with the system over the years, it has been decided in consideration with KLM Cargo and Lödige to specify the model with a base routing, expected to be used in > 70% of the operational time. Another peak-hour configuration will be tested for comparison, but this will be mentioned later. The ability to pre-build and anticipate for cargo in the coming week is not considered in this base model, as the scope is only set for 24 hours and build-up for the next morning will already occur in the evening. In Figure 34 the base-routing is given for the transport units in a schematic way, in the model itself, a distinction is made in the routing for ULDs and Belly carts as well. These distinctions will further be explained in the modelling logic paragraph in Chapter 6. The palletizing system (PLC) is also limited in the amount of successive in-and outfeeds it can process. Due to the limited stack of only 6 pallets, the system must be refilled with a new stack, in case only infeed takes place. These stacks are either available next to the PLC system or in the rack. When there is excessive outfeed of Belly carts superseding 6 pallets, the pallets must be stored in the system. Since it is hard to estimate the possibility that this will happen due to the level of aggregate data available per hour, it is not valid to model this process specifically. Instead this probability is accounted for in the process time for the PLC system.

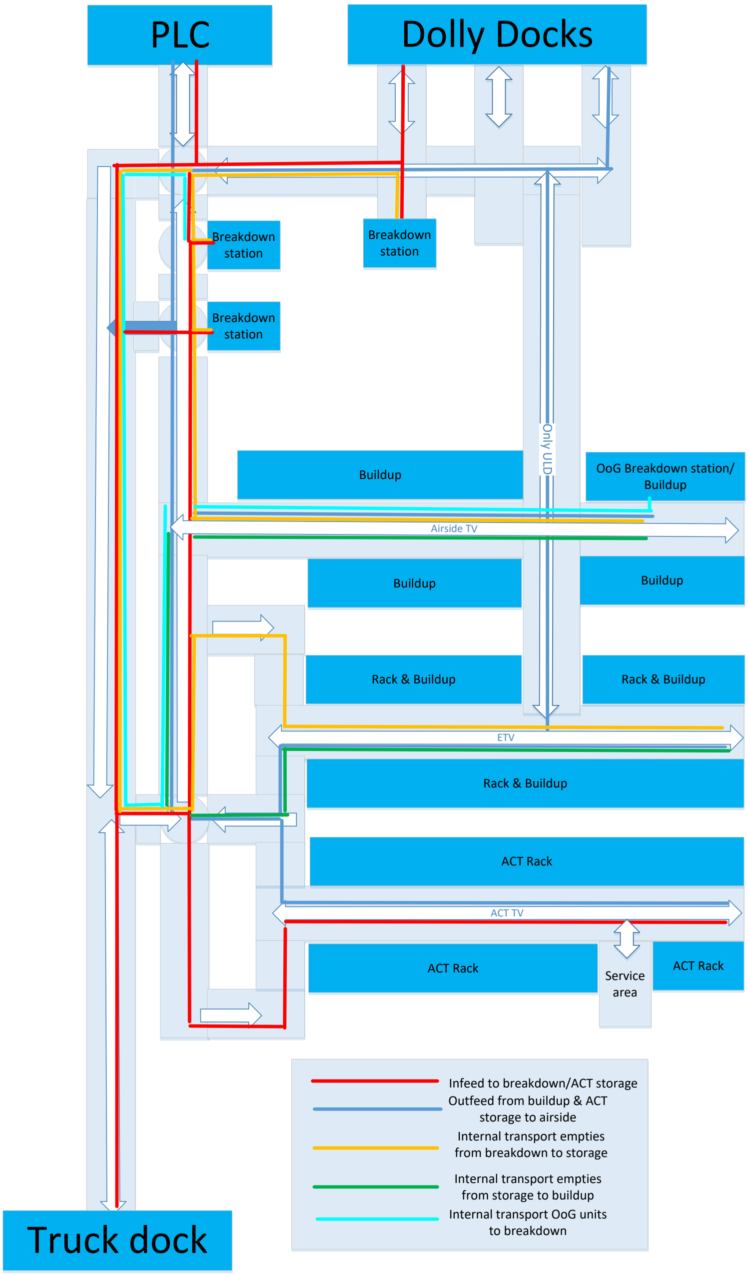


FIGURE 34 STANDARD OR BASE ROUTING OF TRANSPORT UNITS IN THE SYSTEM

5.6.3 Exceptional OoG handling process

In order to analyse the exceptional process of handling OoG, the available data of the cargo currently transported needs to be analysed. It consists of three parts:

1) Determining the share of OoG being transported
2) Determining the required surface area for handling & storage
3) Determining the human resources required

Share of OoG

The share of OoG being transported can be determined by filtering available data based on the conveyability requirements stated in the RFQ document (DENC, 2015). The data being analysed consists of all bookings Equation & Dangerous goods. The dataset contains information on scheduled arrival & departure times, the number of colli on a booking and the weight of the booking. Also, the Origin and Destination AWB code is available. By filtering the data on either Dangerous goods and weight per colli, the share of OoG freight is determined as followed:

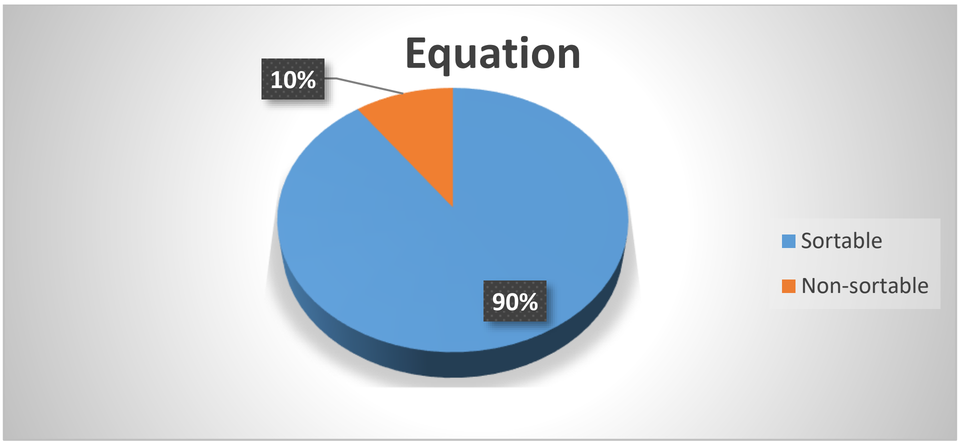


FIGURE 35 SHARE OF SORTABLE EQUATION

Unfortunately, the available data does not include a specification for oversized items. These items are currently handled the same way as other EQ items and are therefore not specifically registered. In 2014, some measurements (see Appendix E) were performed on the dimensions of EQ products being broken down in VG1. Form these measurements, it became apparent that about 4% of the EQ products can be considered Out of Gauge in terms of dimensions based on the RFQ document. Lödige has performed some analysis on the type of EQ shipments (Vanderlande & Lödige, 2016) . In this analysis, a distinction was made between mini (<40 pieces counted as 1 <30kg) and midi shipments (>40 pieces counted as 1 piece >30kg). There is a comparable ratio to be found here as with the heavy Equation. It is however not known how large the correlation between weight and dimensions is for these products, since both aspects are not measured at the same time. A fishing rod, for instance, has an Out of Gauge dimension but the weight does not exceed 35 kg. A certain spare part made out of high density steel can have a small dimension, but a very high specific weight. The oversized items are incorporated in the mail percentage as a conservative 3% is assumed here.

Mail OoG

Mail is, as mentioned earlier, restricted in size and weight to the UPU regulations. However, these regulations are not followed strictly by a large number of out-stations, resulting in Odd-sized mail entering VG1 on a daily basis. There is no hard data on the share of OoG being handled by the mail department so these are merely based on estimated guesses by the handlers and shift leaders. It is estimated that around 2-3% of the volume is not sortable with the Posisorter due to volume constraints. Furthermore, there is a category of non-scanable, or repair items, to be processed and relabelled. Loïc L'higuinen, project manager at Sodexi Hub Express, mentioned that the number of non-scanables varies depending on the weather and the origin, varying from 2-5%. Rain causes a sharp increase on the number of repairs being sorted out. These repairs will be sorted out in the hospital chute and repaired by the employee, re-infeeding them into the sorting system. These items are not taken into account in the OoG analysis, as the items are able to be sorted by the machine in the end but the process should be bear in mind in case there is bad-weather day, in terms of the human resources requirement. A conservative 3% percentage is assumed regarding the oversized mail.

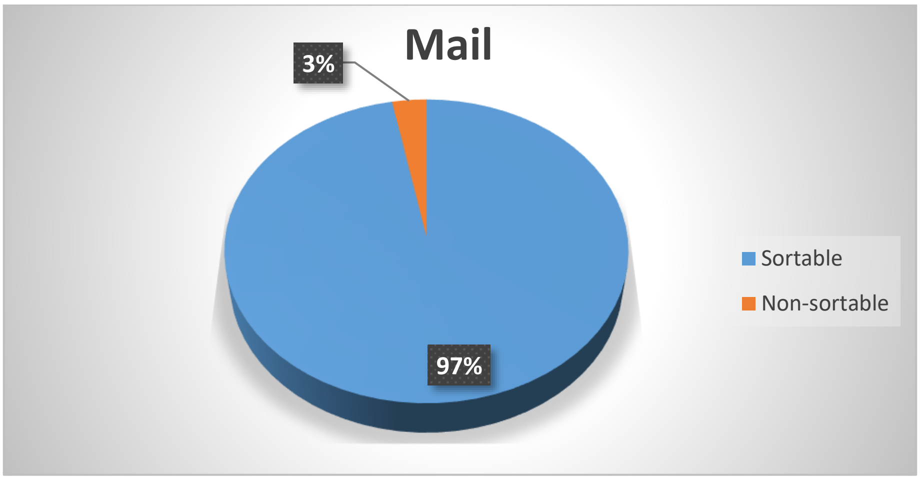


FIGURE 36 SHARE OF SORTABLE MAIL

Required surface area for handling and storage of OoG

The next step is to determine the surface area required for handling and storage of OoG. This can be done by assuming the storage area, which is basically a racking with positions for OoG, as an input output system of its own. The difference between the arrival times and departure times, also known as the dwell time, determines the time required per item in de storage area. In order to determine a suitable capacity and size for the storage area, it is necessary to estimate the maximum area required, so an average dwell time is not suitable to determine the size of the rack. By using a small-scale modelling and simulation study, the rack input-output system can be modelled over time.

FIGURE 37 SIMPLIFIED INPUT-OUTPUT MODEL OF OOG HANDLING PROCESS

As an input, it is necessary to find a balance between the significance and the size of the model. Therefore, a sample is found in the dataset. This sample represents the number of items processed quite well: student T-test score of 0.96. Also the weight distribution was compared with the population, this gave a student T-test score of 0.70. (see Appendix E). This sample is now used to provide the Equation arrival rates for the model.
Concerning the mail, as the data is limited and for consistency the average daily and the peak day rates per hour are taken and repeated over the day.

Required (human) resources

The resources required can be determined by analysing the utilization of the forklift used for input of the rack if the forklift utilization is higher than approximately 80%, queuing starts to appear. This is not possible in reality and therefore an additional forklift is required in this case. By determining the number of forklifts which will provide a lower utilization rate than 80% under the given demand scenario, the required resources can be determined.

5.6.4 Chute utilization and allocation

The chute utilization and allocation is an essential part of the performance of the sorting system. There is a balance between the number of handlings and thus costs and the capacity of the system. Since the capacity of the sorting system and the number of chutes is constrained to a total of 54 double make-up positions for EQ and Mail, an optimization based on the expected volumes per destination can be made. The allocation has been made such that large volume/demand destinations and destinations with more than 1 flight per day are always opened so the cargo can be sorted directly as long as the chute is not full. The number of “permanent destination” chutes is 14. For the rest of the flights, a decision rule is in place to open a chute based on the Standard Departure Time (SDT- X hours).

TABLE 6 TYPE AND NUMBER OF CHUTES

Chute type	#
Permanent destination double chute (EQ+MAIL)	14
Batching double or single drop chute	depends on volume threshold [KG] for combining. If only mail, a drop chute can be used instead
Time window double buffer chute	depends on STD – X hours
Repair double chute	1
Overflow double chute	1
Lateral double chute	1
Flexible destination double chutes	37 – [Number of batch chutes + Time-buffer chutes]
Drop chutes [Mail only]	*7*
Total	54 + *7*

In order to do this, a static model is build to represent the peak day flight demand, see the schedule in Appendix F, where the allocation becomes critical. Various chute allocation algorithms have been tested in conjunction with Ton Hendriks, Equation engineer at AF-KLM Cargo in order to find the most optimal decision rule to open a specific chute based on the historical demand in order to sort out as much items as possible directly. In Appendix F, a number of these chute requirement calculations are given based on different SDT- X hour decision rules. There is a balance between the number required time-buffers and the amount of flexible chutes.

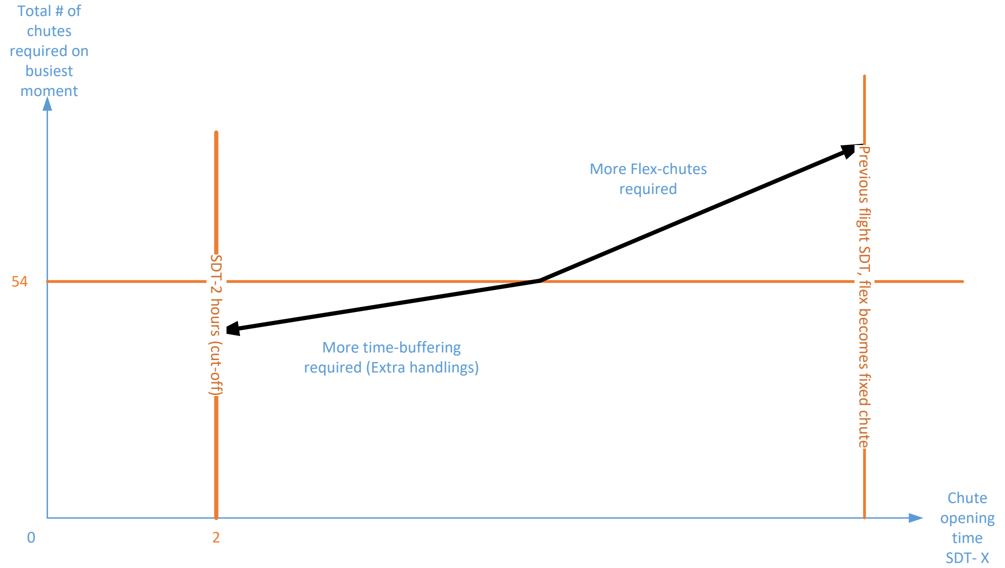


FIGURE 38 CONSIDERATION BETWEEN TIME-BUFFERING AND CAPACITY CONSTRAINT

On an average day, there are sufficient chutes available to sort out all items on destination/ flight. At the busiest day, however, the number of flights exceed the number of chutes available in certain time windows. In order to still sort out the items on destination, a decision rule is implemented if the predicted cargo volume is under a certain threshold the destinations are combined (batched) in 1 chute. The handler then needs to build up each cart or ULD separately. And sent the Belly cart or ULD away when finished.

General use of the conceptualization for similar systems

The conceptualization is quite system-specific as it depends largely on the physical lay-out of the system and how the routing is determined and should therefore be performed per system. The general methods and tools, such as flowcharts and IDEF0 diagrams, can be applied for similar systems though. As they provide a good overview of the complex processes and how to eventually specify the models.

6 Modelling of integrated processes

The modelling of the performance-critical processes found and conceptualized in chapter 5 is performed in separate sub-models in order to simplify the modelling process and increase the clarity of the models for their specific use.

In paragraph 6.1 the following models will be specified based on the conceptualization:

1. The internal transport, or Transport model
2. The exceptional process, or OoG model
3. The chute allocation, or utilization model

In the next paragraphs, the model verification and validation is performed per model. After this, the simulation experiments are performed per model. Finally, the results and the responses on the KPIs of the simulation experiments are given.

6.1 Model specification

The models are specified according to the stated specifications in the RFQ document (DENC, 2015) and if there is no specific data (yet) available on the process, measurements are performed and if necessary information is asked from experts currently implementing the system. The specification will take place in a cyclic process with verification and validation until a satisfactory level of usability is reached in order to answer the research questions. In this paragraph the model specification will be described per model regarding the following aspects:

Model inputs
As a model input, the results from the data analysis found in chapter 4 are combined with the future scenarios estimated in chapter 5. The inputs are assigned to the entity "sources" where the input is created. These sources create a number of entities per hour based on the time-varying arrival rates which are found in the scenario-analysis. The input is created on the point, which is relevant for the model study. The OoG handling and the chute utilization processes have a system boundary at the point of infeed of the item or breakdown of the item at the breakdown station. The ULD in- and outfeed process input is created at either the airside, landside or build-up areas. For an overview of the model input specification, see Appendix F. The scenarios will create a specific variation in the inputs for the model.

Entities
In this model study, the model entities represent either the transport units in the transport model, Out of Gauge items in the OoG model or regular mail and equation items in the OoG model. The model entities are being created based on the input and transported through the model represent the discrete events on which, among others, the performance of the system is measured on. The average travel time a certain entity through the system and the maximum travel time of a certain entity are an important performance indicator of the system. For each model the entities used are different, these will be discussed next. An overview is provided in Appendix F.

Processes
The various process-times and characteristics to be implemented in the model, are mostly found in the RFQ document. The processes or processing times are a very important feature of the model, as they determine the flow rate of the entities being transported through the model and therefore have a large impact on the performance of the system. Again, in the case of the three models, different processes are modelled.

Routing logic
The routing logic determines how the entities flow through the models from the input to the output. During this process a number of decision-points determine the routing. In the transport model, the routing is more complex than in the OoG

6.1.1 Transport model specification

The transport model specification is performed in iteration with the verification until the model is of such level of detail that it is sufficient to use for experiments. The specification consists of 3 main parts, determining the model input, entities and processes.

Model inputs for the transport model

In the Transport model the input for the model is largely depending on the type of scenarios being used. Nearly all scenarios will affect the inputs of this model and with that, the performance of the system. A proper quantification of the scenarios into actual input data is therefore crucial. The input is provided by the data analysis, put into rate tables with a time-windows of 1 hour and is varied using rate-factors in the case of growth scenarios. In the case of other scenarios, the rate-tables are adjusted for the correct scenarios or policies.

Entities in the transport model

In the transport unit in-and-outfeed model a large number of different entities is used in order to model various transport processes in the system, although in reality these entities are physically only three types of transport units.

FIGURE 39 TWO TYPES OF ENTITIES USED IN THE TRANSPORT MODEL: BELLY CART & ULD

As the known input data only provides generic departure and arrival rates for the mail and equation, the dwell times of the individual entities are unknown. Moreover, the mail and equation is separated from a specific transport unit and combined again in another transport unit. It is therefore hard to specify the entire process and use less entities during specification. In addition, as the model models only 1 day, the system is already filled with entities.

Processes in the transport model

In the transport model, the most relevant processes for determining the performance of the system are specified. Some transport processes, which are considered less relevant for the performance of the system are not taken into account. The process times of the palletizing system, or PLC system are based on the statements in the RFQ document. However, as is often the case in human controlled processes, the process time is not deterministic as these depend on a number of factors such as operator experience. Measurements are therefore performed at the Factory approval test (FAT) session at the Lödige factory in order to find a realistic process time distribution for the model specification. The other process times, vary in according to a distribution within a certain bandwidth. According to Peter Schut, duty manager EPS, and the measurements performed in the current operation provide a distribution of the various processing times. The motivation for the various distributions and assumptions are discussed in Appendix F. Below in Table 7 a summary of the process times used for model specification is shown.

TABLE 7 PROCESS TIMES AND DISTRIBUTIONS USED FOR TRANSPORT MODEL SPECIFICATION

Process	Fixed	Dist. Type	Distribution		
Breakdown belly cart/ULD station		Triangular	Min 1 m	Mode 4 m	Max 6 m
Breakdown ULD station		Triangular	Min 1 m	Mode 4 m	Max 10 m
Dolly dock/truck dock in/outfeed		Triangular	Min 20 s	Mode 30 s	Max 45 s
PLC infeed (Palletizing)		Discrete prob.	55 s (83%)	85 s (17%)	
PLC outfeed (de-Palletizing)		Discrete prob.	35 s (83%)	65 s (17%)	
Roller deck speed	0.3 m/s				
(E)TV transfer time from loading point to Rack and vice versa		Triangular	Min 10 s	Mode 20 s	Max 50 s
(E)TV internal transfer: rack to build-up/bridge		Uniform	Min 5 s		Max 25 s
Hoist speed	8 s				
Load/Unload (E)TV, Hoist & for TV roller deck bridging	4 s				
Transportation to/from outside buffer including weighing for outfeed	1m				

In the model, the distances are modelled on scale for the roller-deck transportation. The capacities of the roller decks are based on the drawings as well. For the Transfer vehicles, a variable time-path is specified to provide an accurate process-cycle time during operation.

Routing logic

In the transport model, the routing of the various entities is based on the data provided by Lödige in the RFQ document (DENC, 2015) and on a number of considered assumptions. As mentioned earlier, the routing is based on a minimal viable solution and models the base behaviour of the system providing a standard routing logic. Lödige states that this routing logic is sufficient to keep the system running in the minimal viable solution described in the RFQ document. On peak days Lödige estimates that the capacity will be insufficient and a control room operator will have to override or to plan (days) ahead with the in-and outfeed to provide sufficient capacity. Also, the individual routing of the transport units within the system can be changed by the operator instantly. This ad-hoc behaviour and decision making is hard to specify in the model, as is it human judgement.

Another assumption is made that, from a start point, all Belly carts and ULD's require breakdown when being fed into the system. However, if the breakdown station is occupied, a distinction is made between the Belly carts without and the belly carts with Equation. As the belly cart with Equation is possibly critical for making a connection, this unit must be broken down. Other ULD's and Belly carts will first be routed to the breakdown station for a breakdown but will be routed to the racking for later breakdown if the station is occupied. The belly carts containing equation will make a short loop for another attempt, in order not to block the roller deck. As the analysis in Chapter 4 has shown, it may be assumed that all Equation is carried on a belly cart and will therefore be

It is further assumed that the build-up will take place 3 hours prior closing time of the chute, so empty units need to be transported from the racking to the build-up locations. The routing is based largely on a one-directional loop as much as possible. At some points, due to the lack of surface area, a bi-directional flow is implemented, where transport units must wait before another unit has passed. The traffic management is based on a basic prioritization, which is based on the type of transport unit and its destination, otherwise it is first come first served.

TABLE 8 PRIORITIZATION TRANSPORT UNITS IN BASE MODEL

Priority setting	Direction	
Transport units	*Inbound/To rack*	*Outbound/build-up*
ULD	1	3
Belly Cart	1	3
Belly Cart with EQ	2	4
OoG unit	1	3/4
Empty transport unit	1	2
ACT	4	5
T-ULD	N/A	3

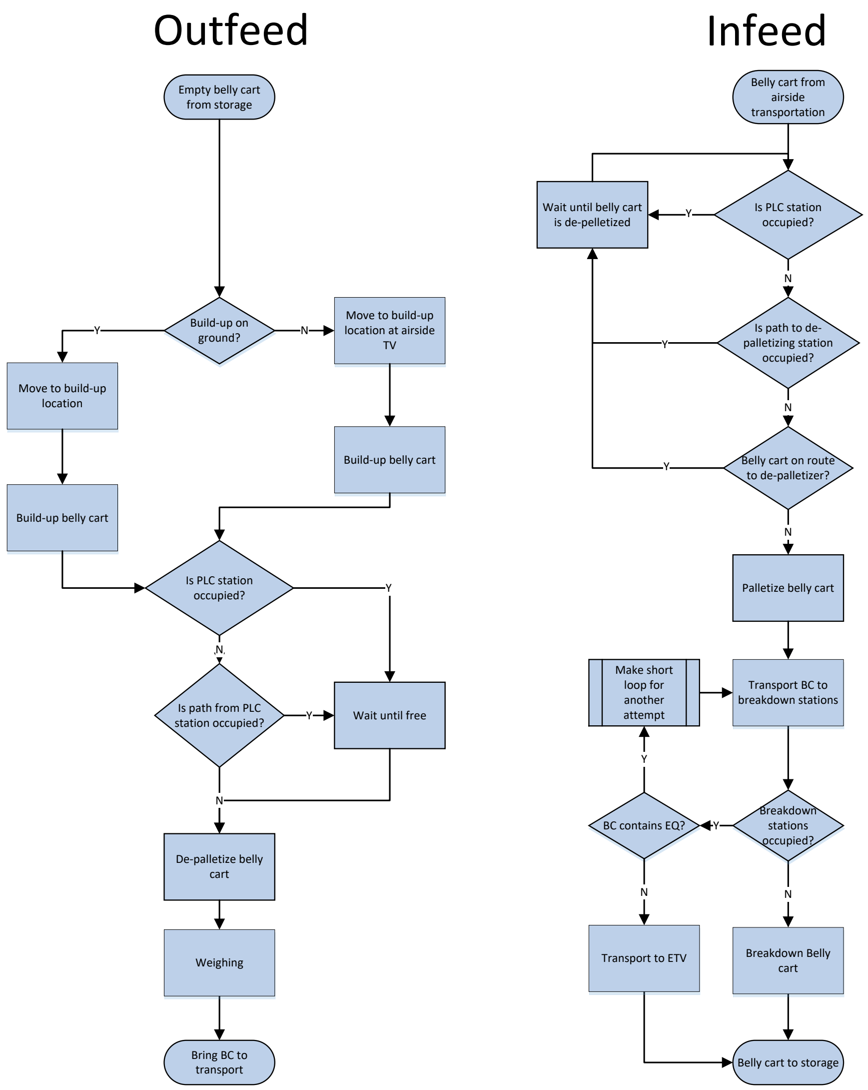


FIGURE 40 DECISION FLOWCHART OF THE IN- AND OUTFEED OF BELLY CARTS IN THE INTERNAL TRANSPORT MODEL

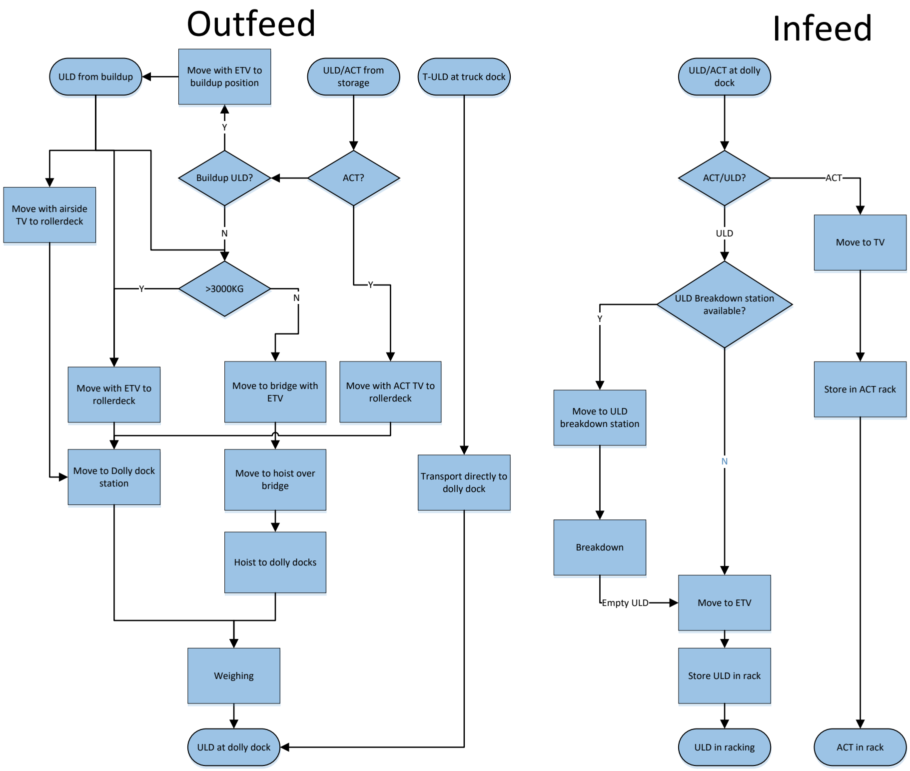


FIGURE 41 DECISION FLOWCHART OF THE IN- AND OUTFEED OF ULDS IN THE BASE INTERNAL TRANSPORT MODEL

Implementing in SIMIO

The above-mentioned specification aspects can be implemented in SIMIO discrete simulation software without any large adaptions. Due to the large number of available options and features in SIMIO such as rate-tables, decision trees and drag & drop modelling features, the specification is relatively simple if done correctly although some experience is required to find some of the options and do the specification.

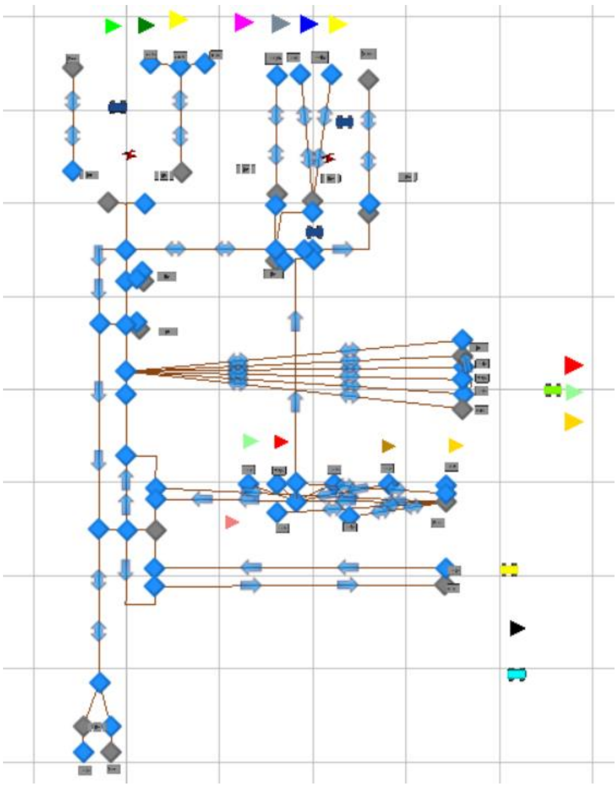


FIGURE 42 MODEL SPECIFICATION AND IMPLEMENTATION IN SIMIO AS SHOWN IN THE "FACILITY" VIEW.

6.1.2 OoG model specification

The specification of the OoG model is performed in another way as with the transport model, in this case the input of the model and the process time (dwell time) of the rack is crucial to determine the required KPI's of surface area required and the required FTE.

Inputs

The OoG model uses another input as the transport model. As the scope of this model is different, the input data changes as well. In order to determine the required racking and resource utilization, the simulation scope needs to be larger than 24 hours as the dwell time distribution determines the size of the racking. A sample is therefore taken from 1 year of equation consignments to find a representative sample size, based on the weight and a compensation is made for the overlap with dimensions. For mail, there is no accurate data available on the amount of OoG, so an assumption is made based on the average daily rate.

Entities

The OoG process has other entities in the model, these include Dangerous goods, Out of dimension Equation, too heavy mail bags and heavy equation. Here the entities do represent the physical items being handled and stored in VG1.

Processes

The OoG model consists of only a couple of processes, the storing of the OoG item and the temporary storage of Dangerous goods in belly carts for lateral transport. The storing of OoG is modelled as the processing time of the racking. Each individual entity gets an assigned process time on entering the rack based on the dwell time distribution estimated in Appendix F.

Regarding the DG, the dwell time distribution is similar to the OoG, however the DG is constrained on storage time due to safety regulations. The DG can be stored temporarily for transit, but this must be within 24 hours from arrival time. After this, the DG has to be transported laterally to VG2 & 3 for longer storage.

Routing logic

The Out of gauge model is based on a simple one-way routing from the OoG breakdown station, to the Rack and to the OoG build-up position, or lateral transport to VG 2&3. The transport is performed by a forklift truck. A detailed flowchart can be found below:

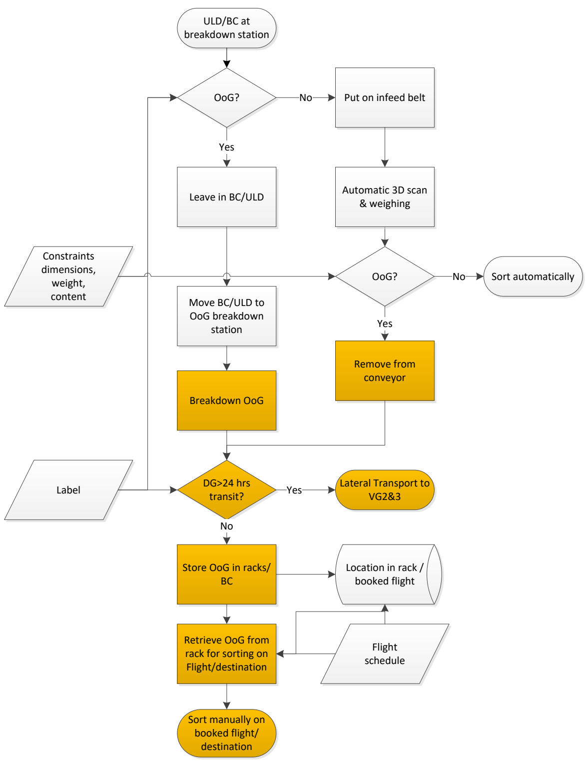


FIGURE 43 DECISION FLOWCHART OOG PROCESS, COLOURED PROCESSES ARE MODELLED

Implementing in SIMIO

The implementation, is again relatively simple due to the extensive modelling features available in SIMIO, only modelling the storing process-distribution was relatively cumbersome due to the multiple discrete-distributions to be specified for this specific process.

6.1.3 Chute utilization model specification

The chute utilization model is specified using the data of only 1 specific busy day in terms of destinations. As every day

Model inputs

The inputs are the flight arrival and departure data for this specific day. In addition, the volume per flight /mail or equation is given. Other inputs are the constraints of the chutes: fixed (23) & flexible + drop chutes (6).

Routing logic

Not directly applicable for the static model, but the chute allocation decision algorithm is shown in the flowchart below.

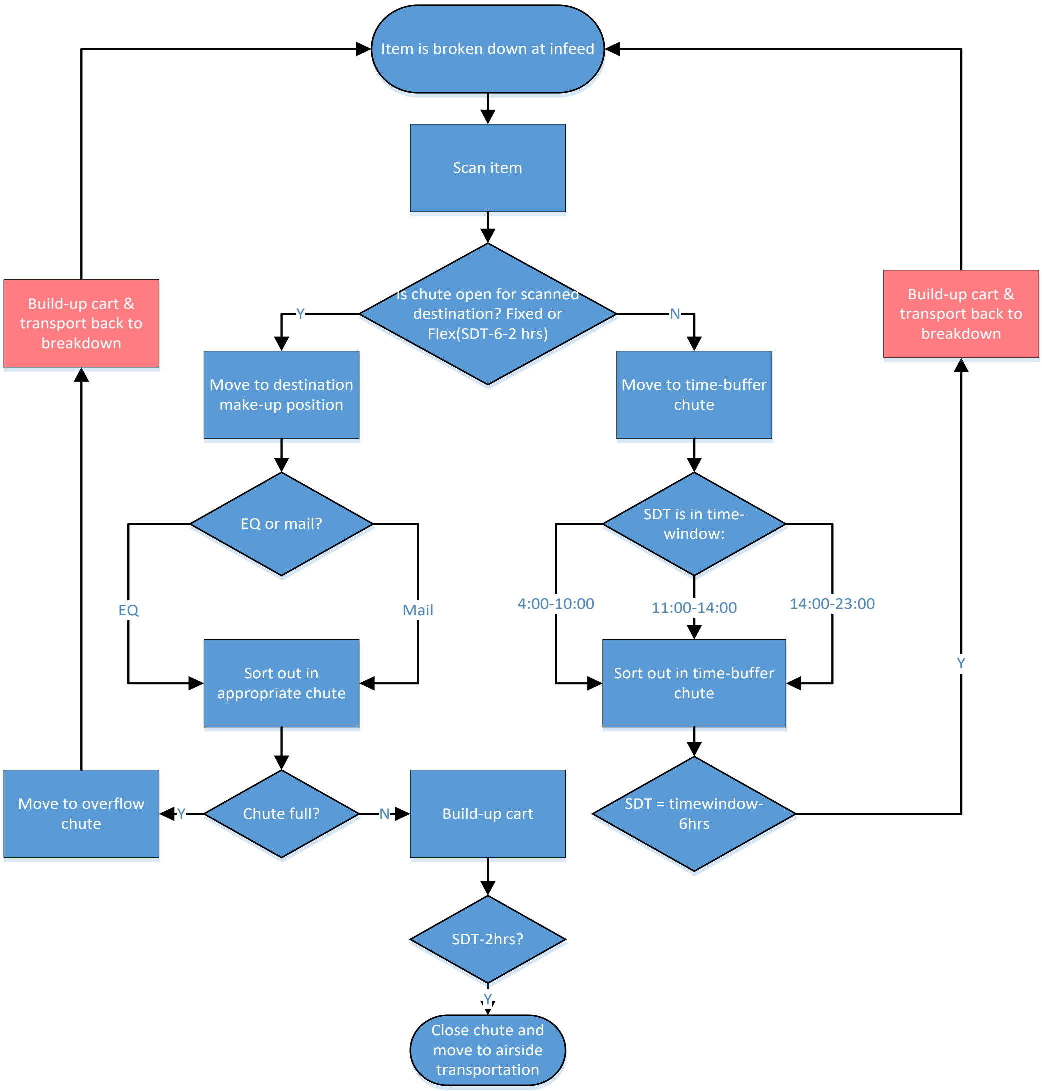


FIGURE 44 CHUTE ALLOCATION DECISION FLOWCHART WITH NON-VALUE ADDING PROCESSES SEEN IN RED.

The items are transported to the chutes by the Posisorter and sorted out based on the decision diagram shown above. The chutes are allocated based on the historical demand data and flight frequencies of this particular day. This allocation determines the amount of overflow items and the number of time-buffered items. These processes are non-value adding and need to be minimized during operation. As can be seen in the flowchart, no distinction is made in the type of mail being sorted out. The initial idea was to sort out prio-mail with equation or in a separate chute but this has been abandoned for the initial start-up phase of the system due to IT-related issues and simplicity reasons for the operators. It might be implemented if the customers become more demanding and if the system has (chute) capacity left, which will become clear by experience.

Implementing in Excel
The implementation in excel was done in conjunction with Ton Hendriks, Equation engineer at KLM Cargo EPS. He provided the excel input data for the model and an example calculation of the number of chutes based on the flight-destination demand on the busiest day and an indicative chute utilization based on volumes per destination/flight. The model was then used to experiment with other chute opening times with regard to the available chutes per time-window and to estimate the chute-filling rate in the other scenarios.

General use of the model specification in similar systems
The quantitative specification of the models in SIMIO or Excel is KLM Cargo-specific.

However, the general features discussed per model are required for specification in discrete-event models in general. The use systems engineering methods such as IDEF0 and flowcharts in the conceptualization, makes specification of the model more comprehensible.

With regards to the specification in Excel, the specification of the most critical day was the most favourable option looking at the variable demand/volume patterns. In case a system with more periodic and more steady demand patterns in terms of destinations and corresponding volumes is analysed, an average day could be specified as well. This could provide a more generalized optimization of the chute utilization.

6.2 Model verification & validation

As mentioned earlier, verification is performed in a modelling cycle in conjunction with the specification and validation of the model. This can also be seen in the modelling cycle in Figure 45. In this chapter the operational validity and model verification is performed.

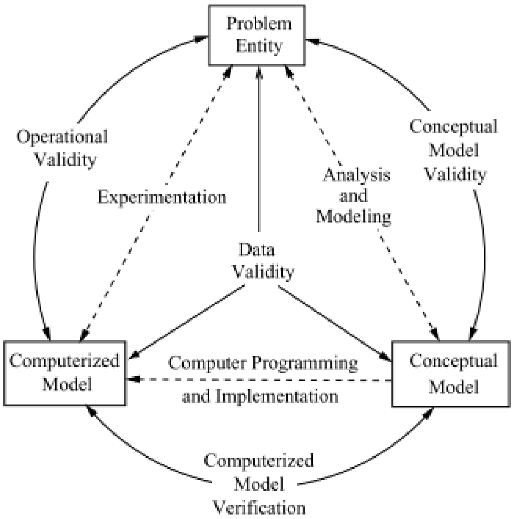


FIGURE 45 MODELLING CYCLE (R. G. Sargent, 2009)

This will be done primarily by tracing entities through the model to check whether the conceptualized models represent the specified models. This is needed in order to determine the model is working properly and can be used to simulate various scenarios. Unfortunately, the most reliable way to test the validity of the model: comparing real data; is not possible as the system is not yet operational and tested. Some scenarios should therefore be simulated during the test period in order to achieve a better validation of the model. For now, the following verification and validation tests are performed:

- *Face validation*
  In the case of the transport model, a face validation has been performed with the chief engineer at Lödige in order to validate the decision and routing logic of the model as designed by Lödige.

- *Tracing of entities*
  Verification and validation, as mentioned by Sargent (2009) can be done by tracing entities through the model, a check is performed whether the created entities as provided by the data rates follows the specified routing and exit the model at a certain time. If there is a discrepancy between these values, the model has created a deadlock in this scenario during the runs. And the results and performance parameters on this model (entity) cannot be utilized for comparison as they are unreliable due to the limited number observed.

- *Sensitivity analysis*
  Another method to validate a simulation model mentioned by Sargent (2009) is to perform a so-called sensitivity analysis on the input parameters. Does the performance of the model change in the direction or quantity, which is expected with a certain higher or lower input?

- *Data validation*
  In the case of the OoG model, no accurate data was available from earlier analysis as in the RFQ document (DENC, 2015) and (Vanderlande & Lödige, 2016) in order to provide a statistically significant sample for the process. Data validation is therefore performed using two-tailed student t-tests in order to find a statistically significant sample to be used as an input for the model.

6.2.1 Transport model verification and validation

Various decision points are checked in order to do so. Also, the processing times are checked with the specified times to verify a correct working of the model. Especially in the case of the transport model, verification is difficult due to the variable routing logic. As mentioned earlier, the model routing has been based on the base-routing of the minimal viable solution and may still require reconfiguration during the test period. The base model logic has been verified with Lödige during the FAT visit at Lödige in January by means of a quick face-validation by the designer of the system.

Model trace

As part of the operational validation/verification of the model, a model trace has been performed on the specified model. As the base-model appeared not to be able to be verified in a number of scenarios estimated, using model trace and sensitivity analysis. The models are actually valid in real as Lödige has predicted in their data analysis that the system was not able to handle the offered demand during peak days and growth over 40%. Other configurations and policies are implemented in order to achieve operational validation of the model in these scenarios. These configurations are included in the model study from now on.

Therefore, in addition to the base-configuration, a peak configuration and a night shift was added for comparison. In Appendix F, the verification and validation model trace data is shown based on 1 of the entities.

TABLE 9 OPERATIONAL VALIDATION OF VARIOUS CONFIGURATIONS BASED ON ENTITY FLOW (TRACE)

Scenario	Base-configuration	Peak-configuration	Base-config. with nightshift	Peak-config. with nightshift
Current average	[green]	[green]	[green]	[green]
Current peak day	[red]	[yellow]	[yellow]	[green]
Extra transfer wave*	[yellow]	[green]	[yellow]	[green]
Extra transfer wave peak*	[red]	[red]	[yellow]	[yellow]
0.5% growth/y overall	[green]	[green]	[green]	[green]
2 % growth/y overall (Capgemini base growth used for comparison)	[yellow]	[green]	[yellow]	[green]
5 % growth overall	[red]	[yellow]	[red]	[yellow]
10% growth	[red]	[red]	[red]	[red]
High competition EQ *	[red]	[green]	[yellow]	[green]
Low competition EQ*	[yellow]	[green]	[yellow]	[green]
Fleet replacement*	[yellow]	[green]	[yellow]	[green]
UPU postal regulations less restriction*	[yellow]	[green]	[yellow]	[green]
UPU postal regulations more restriction*	[yellow]	[green]	[yellow]	[green]

* based on 2% overall growth

Validation= ok, All entities traced (green)	**Model trace= partially ok, not all entities traced in some runs** (yellow)	**Model trace failed= little to none entities are traced** (red)

Sensitivity analysis
This can already be determined with the specified scenarios, which determine the input of the model based on input rates. It is expected that a higher input rate causes higher in-outfeed times due to queuing in the system. In case there is a lower in-outfeed time with a high input rate, the model performs not in line with the expectation and can therefore not be validated. This method can have the same outcome as with the model trace validation due to the fact that only a small number of entities are measured in a non-congested moment of the model run, giving a false indication of the true in- and outfeed times of the entity.

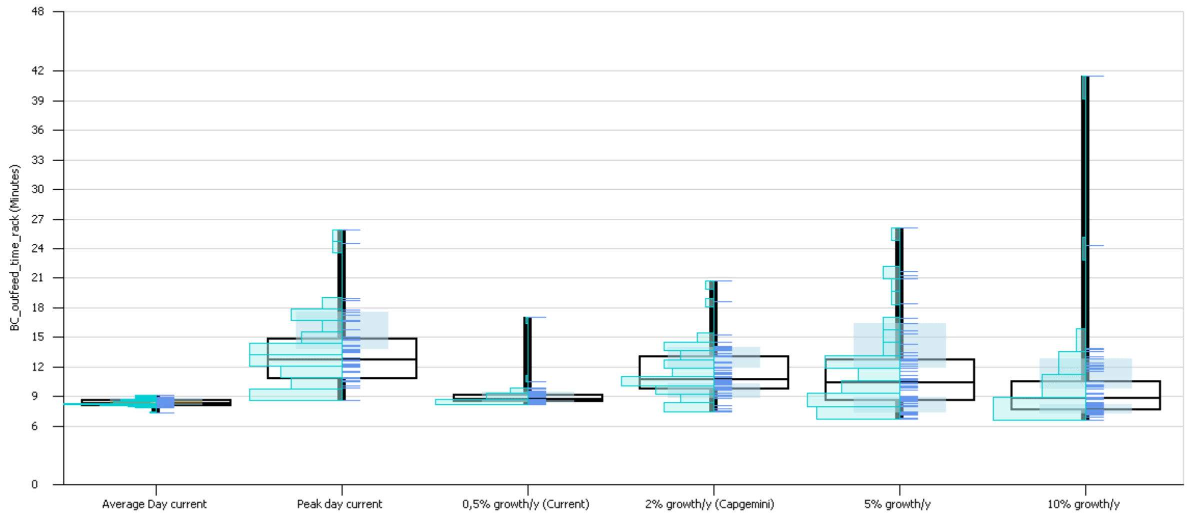


Figure 46 The average outfeed time distribution of a belly cart in the normal, or base-configuration after running the model for a number of replications, the time is expected to increase with a higher input.

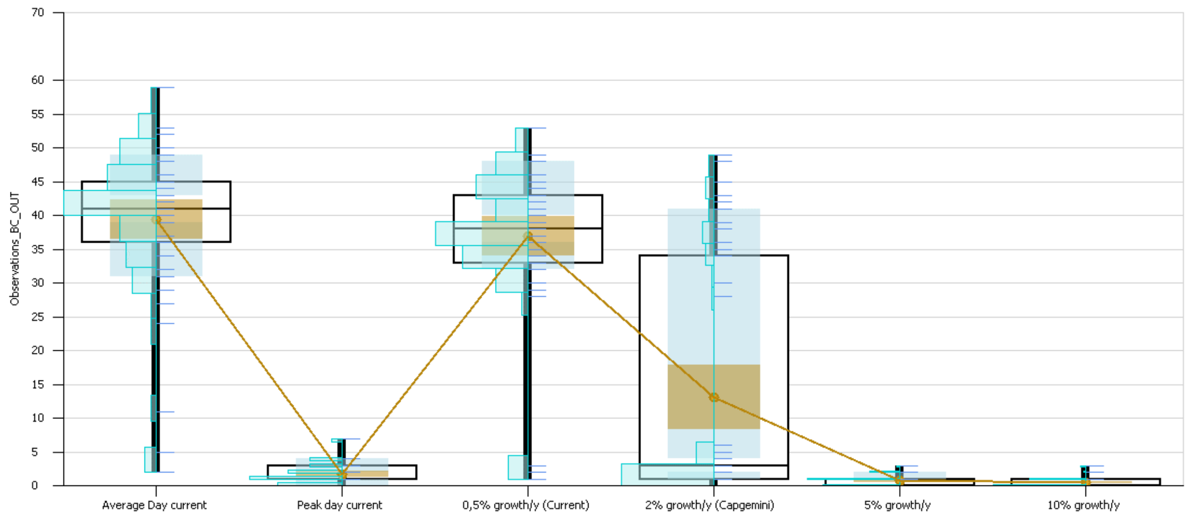


Figure 47 Average number of observations of Belly carts during multiple model runs indicate that in the high growth and peak scenarios the number of observations (model trace) is too small for a valid indication of the outfeed times

The sensitivity analysis for the other configurations of the transport model can be found in Appendix F.

6.2.2 OoG model

The OoG model can more easily be verified and validated as the model is less complex than the transport model. In order to do so, the Entities are traced and a sensitivity analysis is performed on the input in order to test if the behaviour of the model is valid.

Tracing entities

In this case the verification and validation is rather simple in comparison to the transport model, as no interfering or conflicting situations are present to deadlock the model due to capacity constraints. All routing, processes and expected dwell times are within the specified values. The model can therefore be verified, although a limitation in the model is that the rack process is still processing during night hours, this assumes a night shift and nightly outfeed of the system, which is not the case in the current situation. This limitation is already largely captured by the dwell time distribution but still needs to be kept in mind as the validity of the model becomes less.

Sensitivity analysis

The OoG model can be validated by means of a sensitivity analysis as well. Here, the pattern of the content of the racking is used in order to test whether the model is valid based on an input-sensitivity test. This validation can be found in Appendix F.

Data validation

In appendix F, the input data is determined for the model, this input data has been based on a statistically significant sample (0.96 t-test) of the number of colli and a statistically significant weight distribution within this sample (0.7 t-test) of two weeks was found and used as an input for the OoG model. The analysis can be found in Appendix F.

6.2.3 Chute utilization model

The chute utilization model is hard to validate for most of the scenarios as only 1 critical busy day is analysed. The model can also only be validated properly if this “busy” day is simulated in the real-life situation during the test period. Therefore, only qualitative and indicative predictions can be made on the KPI’s regarding the majority of the scenarios analysed in this model.

For the chute allocation model verification is performed together with the validation in conjunction with KLM Cargo.

6.3 Simulation experiments

Next, in order to test assess the performance of the system in terms of KPIs with regard to the future scenarios. The models have to be simulated. In order to do this, first, an experimental design needs to be set up. In order to do this, the warm-up period and the number of replications need to be determined first.

6.3.1 Transport model experimental setup

First, the transport model is set up for experimentation.

Warm-up period

As the model only simulates 1 day, the data is restricted to the actual 24 hours modelled. There is no simulation warm-up time required for the transport model, as the model run starts without transport units in the transport system. Not taking into account the stationary transport units in the racking as these will be created according to the rate table.

Number of replications required

In order to obtain reliable and accurate results from the simulation model, a number of replications need to be runned. These will make sure the specified randomness and distributions in the arrival patterns and other processes will not affect the simulation results significantly. An accuracy or half width *h'* of 2 minutes is chosen as a maximum value, the number of required replications *n'* can now be calculated according to the following formula (Verbraeck & Valentin, 2006):

$$n' = \left[n \left(\frac{h}{h'} \right)^2 \right]$$

with

$$\begin{aligned} n' &= required\ replications \\ n &= initial\ number\ of\ replications \\ h &= initial\ half\ width\ value \\ h' &= desired\ half\ width \end{aligned}$$

As during the verification, the in-and outfeed of Belly carts mail is used as a reference entity to provide the number of minimal replications required, the reference scenario will be the 2% growth scenario in the base-configuration of the system, this will yield enough replications for all verified scenarios and configurations as this model configuration is the least stable in the reference scenario.

In the first 10 replications, the model provides a half width value of 4,6 minutes for the outfeed of Belly carts. In order to increase the accuracy to a 2 minutes half width, this will require:

$$n' = \left[10 \left(\frac{4.6}{2} \right)^2 \right] = 52.9 = 53\ replications$$

In the table below the setup for experiments is provided, the verification has yielded a number of scenario-configurations unusable for experiments due to deadlocking and under capacity. These results will therefore not be shown in the results and the conclusion may be drawn already that the system will not function in this configuration without active intervening control under these scenario-circumstances.

Experimental setup

The experimental setup will provide the basis for the experiments and the outputs to be assessed. The outputs will be given per model configuration and based on the KPI's relevant for the transport model. The values which cannot be validated will not be taken into account for the final analysis. The data-output per model will be given in Appendix F and the results will be summarized in graphs in paragraph 6.3.2 for comparison.

TABLE 10 EXPERIMENTAL SETUP FOR THE TRANSPORT MODEL

KPI's / Scenarios	Max infeed time EQ [min]	Max outfeed time EQ [min]	Max infeed time ACT [min]	Max outfeed time ACT [min]	Average infeed time BC [min]	Average outfeed time BC [min]	Average infeed time ULD [min]	Average outfeed time ULD [min]	Requirements of the outside buffer capacity [#]	ETV utilization [%]	Processing / throughput capacity [#/hour]
0,5% growth/y	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
10% growth/y	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
2% growth/y (Capgemini)	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
5% growth/y	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
Average Day current	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
Competition EQ high avg day (2%/year growth)	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
Competition EQ low avg day (assumed overall 2%/year growth)	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
Fleet replacement_no more combi's	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
Peak day current	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
UPU postal regulations less restriction (dimension)	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
UPU postal regulations more restriction(weight)	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
Wave_added_avg 2%	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]
Transfer wave added in peakday	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[min]	[#]	[%]	[#/hour]

6.3.2 OoG model experimental setup

Next, the OoG model is set up with in the same manner.

Warm-up period

The OoG model has a specified run length based on the sample of OoG taken from a year of data concerning Equation. This sample size is found to be statistically significant regarding the share of OoG as is shown in Appendix F. The experimental setup of this model is such that due to the fact that is an ending simulation and it requires entities to fill the rack a warm-up period is required in order to obtain valid outputs. Verbraeck & Valentin (2006) state that the required warm-up period to be excluded from the output statistics can be acquired graphically by looking at the point where the graph becomes periodically stable for the rest of the run. The average content of the rack over 2 weeks plus a small margin has been chosen as the periodic average.

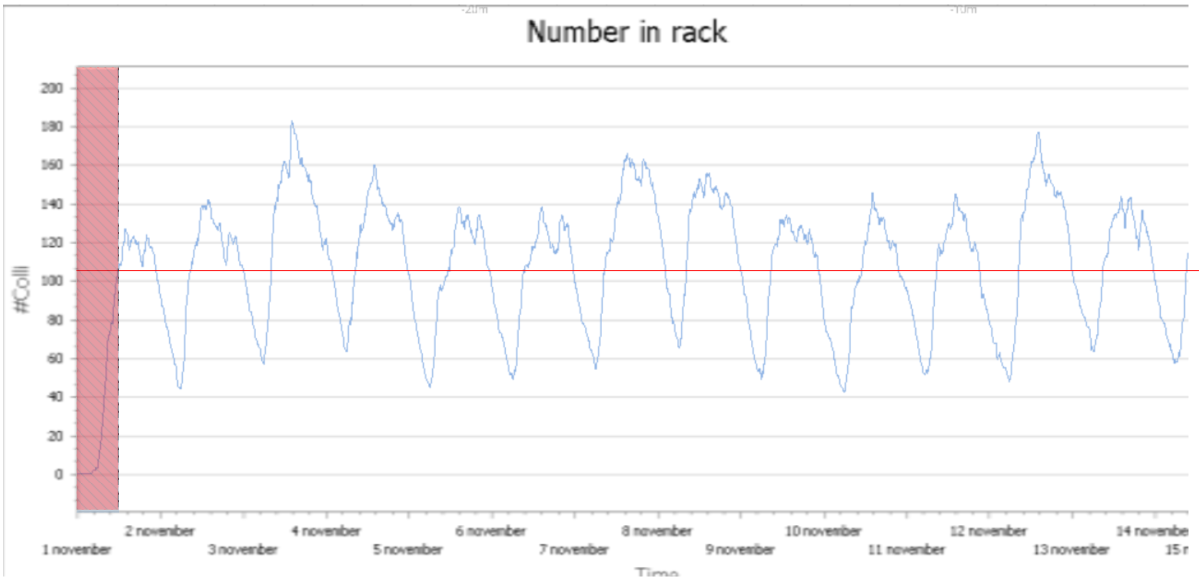


FIGURE 48 WARM-UP PERIOD ESTIMATION OF THE OOG SIMULATION MODEL

This provides a warm-up period of approximately a half day, or 12 hours.

Number of replications required

The number of replications is less relevant in this model due to the high volatility of the main response, the rack content, to be measured and it is very sensitive to the input variables. Also the required accuracy of the response is not high as the surface area required is not a critical aspect of the system as only the maximum number of items is required to determine the rack size. However, in order to increase the accuracy and increase significance the model is runned for 5 replications.

Experimental setup

The experimental setup is such that the required outputs can be measured. There are, however less scenarios to be runned as with the transport model. Fleet changes, for instance, do not affect the rack content. This is due to the scope of the model, which does not include transport units. The same holds for the influence of the transfer wave pattern and the addition of extra destinations which are not directly relevant for the outcome of the model as it does not have an impact on the content of the rack.

TABLE 11 EXPERIMENTAL SETUP OOG MODEL

KPI's / Scenarios	Forklift utilization [%]	Number of forklifts required [#]	Maximum rack processing content [#]	Rack surface area required [m2] Assuming stacking 4 high and combining consignments
Current	[%]	[#]	[#]	[m2]
Current Peak day	[%]	[#]	[#]	[m2]
0.5% growth/y	[%]	[#]	[#]	[m2]
2% growth/y	[%]	[#]	[#]	[m2]
5% growth/y	[%]	[#]	[#]	[m2]
10% growth/y	[%]	[#]	[#]	[m2]
High EQ competition	[%]	[#]	[#]	[m2]
Low EQ competition	[%]	[#]	[#]	[m2]
UPU strict regulations	[%]	[#]	[#]	[m2]
UPU less regulations	[%]	[#]	[#]	[m2]

6.1.3 Chute utilization model experimental setup

As the chute utilization model is static, it does not require a warm-up period or a number of replications. The model is limited to 1 busy day in terms of destinations. As the number of destinations vary a lot in terms of Equation handled it is hard to determine the chute utilization on an average day based on the model. It is therefore not valid to estimate quantitative results for most scenarios based on this model only. A qualitative estimation can be made in terms of expected chute utilization and the required number of chutes but hard data needs to substantiate the qualitative findings. According to Harry de Groot, this had to be done during testing and here a good chute allocation algorithm needs to be determined based on the demands and experiences. This was also acknowledged by Loïc L'Higuinen.

TABLE 12 CHUTE UTILIZATION EXPERIMENTAL DESIGN

KPI's / Scenarios	Time-buffers required/batch chutes required	Average Chute volume utilization EQ	Average Chute volume utilization mail	Total chutes required at busiest moment of the day	Estimated extra personnel
Current (base configuration by Lödige)	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]
Current Peak day (busy day in terms of destinations)	3	22	48	54	0
0.5% growth/y	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]
2% growth/y	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]
5% growth/y	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]
10% growth/y	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]
+10 extra destinations	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]
+4 extra destinations	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]
UPU strict regulations	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]
UPU less regulations	Estimation [#]	Estimation [%]	Estimation [%]	Estimation [#]	Estimation [#]

6.1.4 Cost estimation setup

The costs are, besides the other performance indicators in the integrated situation, still an important factor in the performance estimation of the system. The main costs to be estimated are the required fte for the processes. A portion of the costs is already reduced by the integration of the processes, requiring no internal transport and less build-up-breakdown employees. However, due to the introduction of an exceptional OoG process and the double handling of time-buffered items, the number of employees required increases. It is therefore necessary to make an estimation on which moment extra handlers and operators are required to keep the system operational. In order to do this, a number of assumptions need to be made concerning the threshold at which moment extra personnel is required to operate the stations. The initial requirements for the number of personnel in are stated in the RFQ document (DENC, 2015)

If the utilization of a typical station or transport process in the system is higher than 80%, queuing starts to appear which may affect the performance of the system in terms of throughput times and throughput capacity. If the scheduled utilization of a station is higher than this, an extra employee is allocated to this position in order to increase the processing capacity if possible. For the PLC system or dolly docking, it is not possible to increase the processing capacity with extra employees, the same holds for the (E)TVs.

If a night shift configuration is implemented, the number of employees will increase by 1/3, increasing the OPEX significantly.

If the estimated average capacity utilization of a bathing or overflow chute is higher than 80%, an extra employee is required as to handle these chutes. Regarding the batch and overflow buffer chutes, a rough estimation will be made with regards to the costs for most scenarios as the data and the model are limited to 1 scenario.

The cost per item can eventually be calculated by multiplying the processed transport units by the assumed number of items on the unit. Hereby assuming that all units will be broken down eventually, which is not taken into account for the mail-infeed process.

TABLE 13 PRODUCTIVITY CALCULATION (PERFORMED FOR EACH CONFIGURATION AND SCENARIO)

	Mail	Equation	Combined
Number of units processed (throughput/hour)	[#]	[#]	
Items per transport unit (Vanderlande & Lödige, 2016)	35	5,8	30 on average
Total Items (colli) processed per day combined			[#]
OPEX (fte)			[#]
Productivity per fte per hour (colli/fte/hour)			[Colli/Fte/hour]

This cost estimation is performed for all scenarios and is shown in Appendix F. The results will be summarized in the next paragraph in order to assess the productivity of the system in various configurations.

6.2 Results of the experiments

The raw outputs of the simulation experiments on the KPI's are given in Appendix F. In this paragraph the results are summarized per model with regard to the KPI's. The outcomes will be discussed per model with regard to the corresponding KPI's.

6.2.1 Transport model results

The transport model results are shown in the tables in Appendix F. Now, the results per KPI are given for each configuration or shift policy and discussed. As mentioned earlier, some of the outputs of the model are not valid in some scenarios due to a capacity issue in the system. These outputs are given a maximum value of 100 minutes which is per definition not allowed for the Equation product as the cut-off time is 90 minutes. In addition, the model results of the various configurations and policies are given per KPI in appendix F. In this paragraph the general effects of combining the processes are discussed per KPI.

General model results of the throughput times

In general, the model results show certain patterns with regard the various scenarios and corresponding throughput times. As expected, with a higher overall demand, the throughput times increase in general, this is common in all configurations. In the base-configuration, the throughput times start to increase significantly in growth scenarios beyond 2%/year and in peak-day scenarios. The qualitative results for each configuration are shown below, the actual times can be found in Appendix F. The best option is given a "**+**", the least favourable is " **–** " and finally the option which is not feasible, when a deadlock appears "**NF**".

Below the qualitative summaries of the model results regarding in-and outfeed times of the following commodities are given respectively:

- Equation
- ACT
- Mail

TABLE 14 MAX INFEED TIMES EQUATION: SUMMARY OF THE RESULTS (0-30= +, 30-50 = 0, >50= -)

Infeed times Equation	Low growth 0,5%/y)	Medium growth (2%/y)	High growth(5%/y)	Peak day
Normal config	**-**	**-**	**NF**	**NF**
Nightshift	**-**	**-**	**NF**	**-**
Peak config	**+**	**0**	**0**	**-**
Peak config + nightshift	**+**	**0**	**0**	**-**

TABLE 15 MAX OUTFEED TIMES EQUATION: SUMMARY OF THE RESULTS (0-10= +, 10-30 = 0, >30= -)

Outfeed times Equation	Low growth 0,5%/y)	Medium growth (2%/y)	High growth(5%/y)	Peak day
Normal config	**+**	**0**	**NF**	**NF**
Nightshift	**+**	**0**	**NF**	**0**
Peak config	**0**	**-**	**-**	**NF**
Peak config + nightshift	**+**	**0**	**-**	**-**

TABLE 16 MAX INFEED TIMES ACT: SUMMARY OF THE RESULTS (0-10= +, 10-30 = 0, >30= -)

Infeed times ACT	Low growth 0,5%/y)	Medium growth (2%/y)	High growth(5%/y)	Peak day
Normal config	+	0	NF	NF
Nightshift	+	0	NF	0
Peak config	+	0	0	0
Peak config + nightshift	+	0	0	0

TABLE 17 MAX OUTFEED TIMES ACT: SUMMARY OF THE RESULTS (0-10= +, 10-30 = 0, >30= -)

Outfeed times ACT	Low growth (0,5%/y)	Medium growth (2%/y)	High growth (5%/y)	Peak day
Normal config	+	0	NF	NF
Nightshift	+	0	NF	0
Peak config	0	0	0	0
Peak config + nightshift	0	0	0	0

TABLE 18 AVERAGE INFEED TIMES MAIL & EQ: SUMMARY OF THE RESULTS (0-20= +, 20-40 = 0, >40= -)

Infeed times Mail	Low growth (0,5%/y)	Medium growth (2%/y)	High growth (5%/y)	Peak day
Normal config	+	0	NF	NF
Nightshift	+	0	NF	0
Peak config	+	+	0	0
Peak config + nightshift	+	+	0	0

TABLE 19 OUTFEED TIMES MAIL & EQ: SUMMARY OF THE RESULTS (0-10= +, 10-30 = 0, >30= -)

Outfeed times Mail	Low growth (0,5%/y)	Medium growth (2%/y)	High growth (5%/y)	Peak day
Normal config	+	0	NF	NF
Nightshift	+	+	NF	+
Peak config	+	0	-	-
Peak config + nightshift	+	+	0	0

Buffer area required
In this case, the non-validated statistics are used for comparison in order see the increasing requirement of buffer area in the peak configurations. As the system is not feasible in higher than 2% growth in normal configuration.

TABLE 20 BUFFER AREA REQUIRED OUTSIDE: SUMMARY OF THE RESULTS (0-10 = +, 10-80 = 0, >80 = -)

Buffer area required	Low growth (0,5%/y)	Medium growth (2%/y)	High growth (5%/y)	Peak day
Normal config	+	+	+	+
Nightshift	+	+	+	+
Peak config	+	+	-	0
Peak config + nightshift	+	+	0	+

The buffer area required increases significantly with the peak configuration applied during high-demand growth scenarios and corresponding peak days. It is necessary to notice that this only holds for ULDs and the belly carts do not require significant buffering, allowing equation products to enter the system without significant delays.

ETV utilization rate
For the utilization rate, the non-validated outputs are also in the graph. This points out that in the critical scenarios, the utilization rate reaches 80%, resulting in queuing which causes a spillback over the roller decks up to the infeed points. For the exact results, I refer to Appendix F.

TABLE 21 ETV UTILIZATION RATE: SUMMARY OF THE RESULTS. (0-70%: +, 70%-80%: 0,>80%: -)

ETV utilization rate	Low growth (0,5%/y)	Medium growth (2%/y)	High growth (5%/y)	Peak day
Normal config	+	0	-	-
Nightshift	+	+	0	+
Peak config	+	+	0	0
Peak config + nightshift	+	+	-	+

The ETV utilization rate is an important indicator of the ability to keep the entities flowing in the model and thus not cause a deadlock. At a utilization rate of around 80%, the ETV struggles to prevent queuing as there are multiple tasks to fulfil by the ETV:

1) moving from the roller deck to storage
2) moving from storage to build-up
3) moving from build up to outfeed/bridge

The Peak configuration utilizes the bridge roller deck capacity better during the high morning influx, preventing a deadlock of the system, although the overall infeed time will increase as the ETV will still need to handle the same amount of transport units at the same time.

When a transfer wave is added, the average scheduled utilization goes up, as the demand pattern over the day is more flattened--out instead of high in-and outbound peaks utilizing the ETV more efficiently.

Throughput capacity
The throughput capacity is also a good indication of the performance of the whole system. It provides to total number of handled transport units in the system.

TABLE 22 SYSTEM THROUGHPUT RATE: SUMMARY OF THE RESULTS (0-10 = - , 10-30: 0, >30 = +)

Throughput rate	Low growth 0,5%/y)	Medium growth (2%/y)	High growth(5%/y)	Peak day
Normal config	+	0	-	-
Nightshift	+	+	+	+
Peak config	+	+	0	+
Peak config + nightshift	+	+	0	+

As can be seen above, in the normal configuration, the throughput capacity goes down during high-growth demand levels as well as in peak days. The implementation of a night shift or peak configuration is able to process a higher number of transport units per hour during growth scenarios from 0,5% and higher. The throughput capacity will later be used to assess the productivity.

Summary of the transport model results
Generally speaking, the KPI's are mostly effected by either high overall demand or a sharp peak-demand pattern, from 2%. The other scenarios analysed do have an effect on the overall performance of the system but will generally not cause the system to fail in terms of throughput capacity. In other words, there is either a favourable effect to be noticed or a non-favourable but it will not cause the systems' performance to improve or decline drastically. A few noticeable results, though, can be found:

- A thing which was noticeable was that the introduction of a new transfer wave, has an increasing effect on the utilization of the ETV but the overall throughput was reduced. This may be caused by the increase in mixed in-outfeed flows, which interfere at the roller decks, causing longer travel times in the system.
- Another interesting result is the appearance of a deadlock in the normal configuration when there is a high competition, or lower demand, for equation. This may be caused by the fact that now more mail can be broken down in the first attempt. This will in turn increase the chance that the other remaining equation will start to loop in the system causing a deadlock around the breakdown stations.

It must be kept in mind that it is assumed no human intervention takes place from the control room, this can prevent the deadlocks from happening if they anticipate properly. This, will have a negative effect on the throughput times but will result in a sustained throughput.

6.2.2 OoG model results
The OoG model provides an output based on a representative sample taken from a year of Equation data. The model is runned for multiple iterations in order to achieve a utilization rate of under 80% for the most scenarios. In case of the 5% and 10% the required forklifts in order to achieve this was more than 10, which is not feasible with the number of breakdown stations and manoeuvring area. In addition, the rack surface area was determined. In this case the 2%, 5% and 10% scenarios are also not feasible due to surface area restrictions of about 180m2. As with the internal transport model, the summaries are given below and the raw results are shown in appendix F.

TABLE 23 SUMMARY OF THE RESULTS, APPROXIMATION BASED ON ITERATIONS, NOT ALLOWING QUEUING TO APPEAR IN THE SYSTEM

Number of forklifts required in 2035	#
Low growth (0,5%/y)	2
Medium growth (2%/y)	7
High growth (5%/y)	>10
Peak day	2-3

Also, the rack surface area required is based on these iterations and on the assumption that the racking is 4 high, and 1 x 1 x 2 (L x W x H):

Surface area required in 2035	Approximate m 2 (max = 180)
Low growth (0,5%/y)	170
Medium growth (2%/y)	400
High growth (5%/y)	750
Peak day	100

6.2.3 Chute allocation/utilization model results

The chute allocation calculation has revealed that the optimal chute opening time is 6 hours before standard departure time on this particular day. This is based on the maximum number of chutes available, which is a fixed 54 and the required number of chutes over the day.

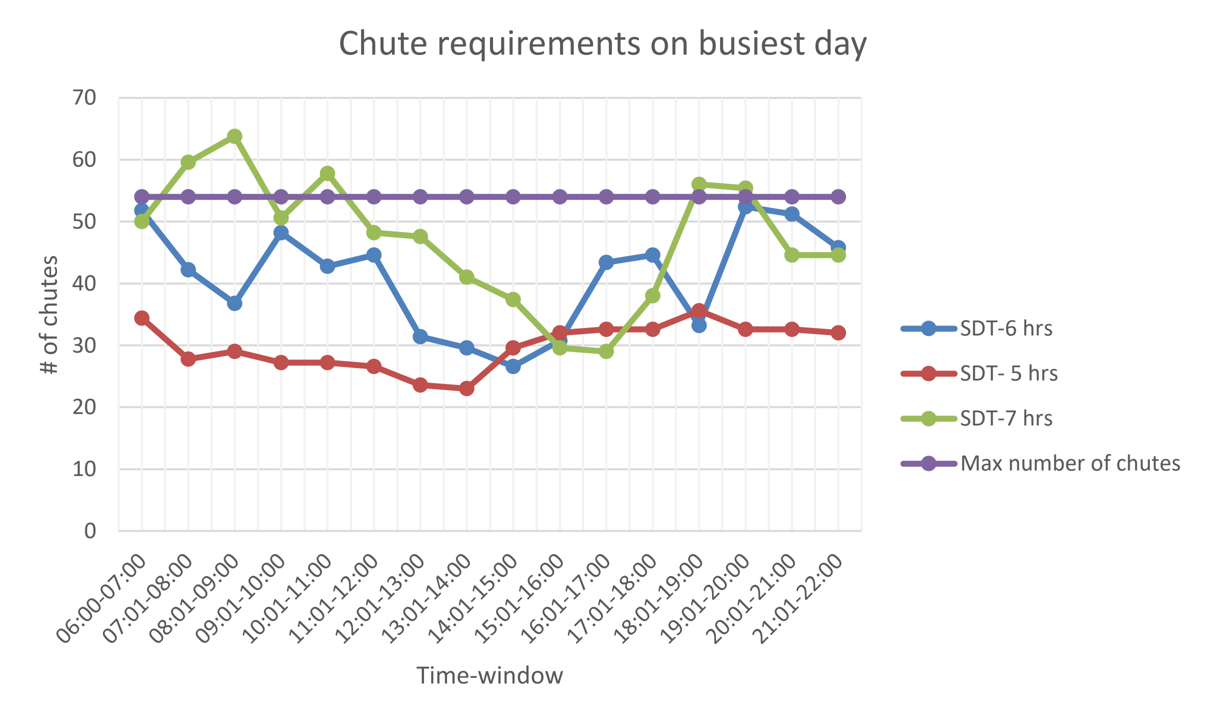


FIGURE 49 REQUIRED CHUTES WITH DIFFERENT ALLOCATION STRATEGIES

As can be seen in Figure 49 the SDT-5 requires the least amount of chutes to be opened. However, this is not considered to be optimal due to more batching and time-buffering. The SDT-7 hours has the highest utilization rate but it exceeds the number of available chutes in the morning and is therefore not feasible. SDT-6 remains under the 54-chute limitation and is therefore considered to be most optimal. In less busy days in terms of destinations, a chute allocation of SDT-7 or more can be used in order to directly sort out all items on the destination.

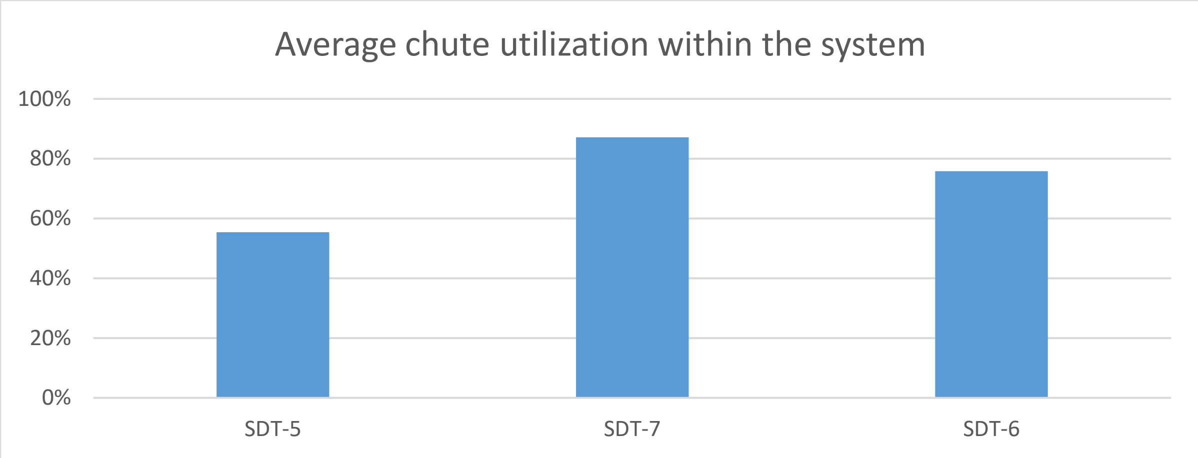


FIGURE 50 CHUTE UTILIZATION BASED ON 3 ALLOCATION ALGORITHMS

Regarding the utilization of the chute capacity, an estimation is performed on the number of items expected to fill the chutes on this particular day. If the chute expected volume exceeds 100% the chute will require emptying before the closure time of SDT-2. This will require extra handlings. In addition, the amount of batching also increases the number of handlings and re-infeeds and therefore the performance of the system. An estimation is therefore performed on the number of extra personnel required to perform these actions. However, it can be assumed that with the correct algorithm the amount of batching required is limited and this can be done by the personnel already available in the warehouse for build-up. It is more interesting when double handling might start to occur if the chutes are full before the closing time of the chutes. A rough estimation is made on this.

The chute utilization is expected to increase gradiently in line with the overall demand. If the volume utilization exceeds 100%, the chute needs to be emptied, which requires extra handling. In Appendix F, the results of the relevant scenarios are given. Below, the results are summarized.

TABLE 24 AVERAGE CHUTE VOLUME UTILIZATION EQUATION & MAIL

Average chute volume utilization	% Equation	% Mail
Low growth (0,5%/y)	25	75
Medium growth (2%/y)	30	95
High growth (5%/y)	45	140
Peak day	25	50

TABLE 25 PERSONNEL ESTIMATION BASED ON CHUTE EMPTYING REQUIREMENTS IN 2035

Scenarios	Estimated extra personnel for double handling
Current (base configuration by Lödige)	0
Current Peak day (busy day in terms of destinations)	0
0.5% growth/y	1
2% growth/y	2
5% growth/y	3
10% growth/y	5
+10 extra destinations/day	2
+4 extra destinations/day	2
UPU strict regulations	2
UPU less regulations	2

6.2.4 Cost and productivity estimation based the models

Combining the results of all models, the costs in required fte and in addition the productivity based on the fte and throughput can be estimated. In appendix F, the calculation can be found. The productivity is compensated for the night shifts. It is therefore expected that the productivity per hour with a night shift is lower relative to the 2-shift policies.

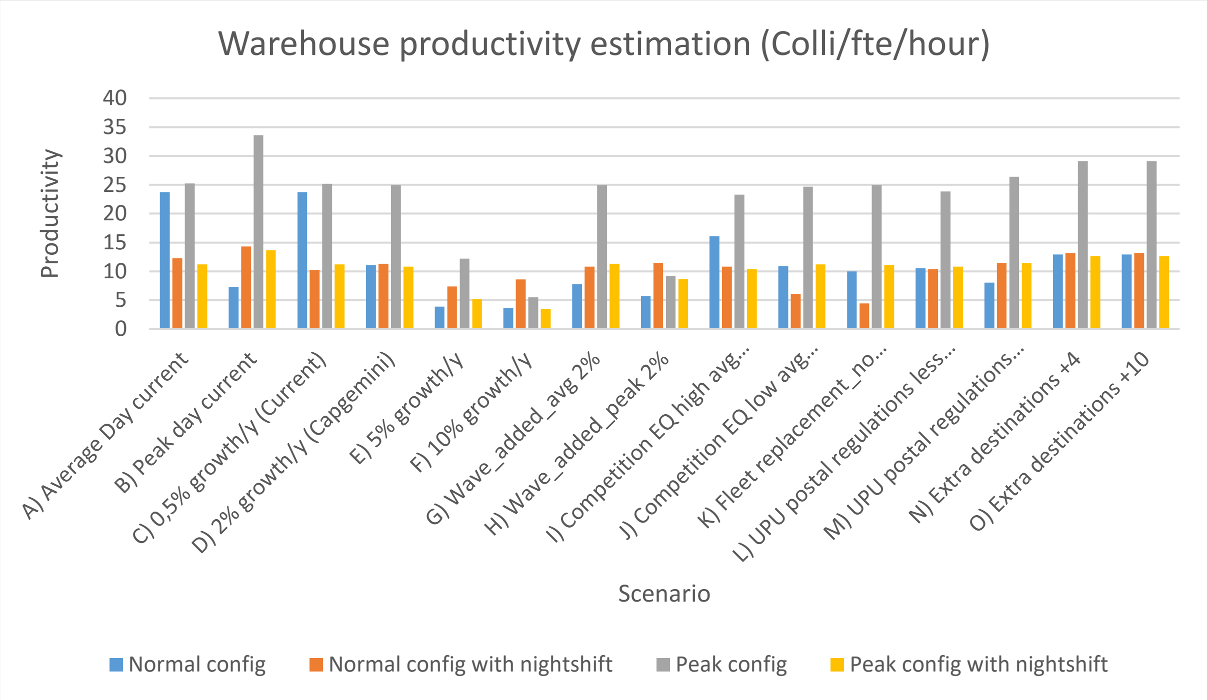


FIGURE 51 WAREHOUSE PRODUCTIVITY ESTIMATION PER SCENARIO FOR EACH CONFIGURATION

The warehouse productivity is a good overall indicator of the processing efficiency and workload. When a night shift is implemented, the workload is more evenly spread and the average productivity per work hour goes down. When the peak configuration is applied, the throughput increases and therefore the workload. During the lower demand scenarios (up to 0,5% growth per year) the throughput for both configurations is similar and a normal configuration will be sufficient to process the demand efficiently. During peak days and high demand scenarios (from 2%/year) the peak configuration is able to offer a better efficiency as the throughput is higher than in the normal configuration. This will have the downside that the overall throughput times will increase per unit and the requirement for buffering will increase. As shown in the Transport model results.

6.3 Bottlenecks and constraints found during the model study

During the model study a number of bottlenecks and constraints of the system are found. These will now be discussed per model. In the end, the effect of the bottlenecks and the interference between the various models will be discussed.

6.3.1 Bottlenecks in the internal transportation system

Especially in the transport model, these bottlenecks became visible. It appeared that the base configuration is not able to handle the loads of a current peak day. This caused a deadlock due to a spill-back from the ETV all the way to the infeed point. This appeared to be the only bottleneck in the system, the other critical processes found using the TOC, such as the PLC, other TVs and breakdown stations, did not result in queuing with the tested model configuration and scenarios.

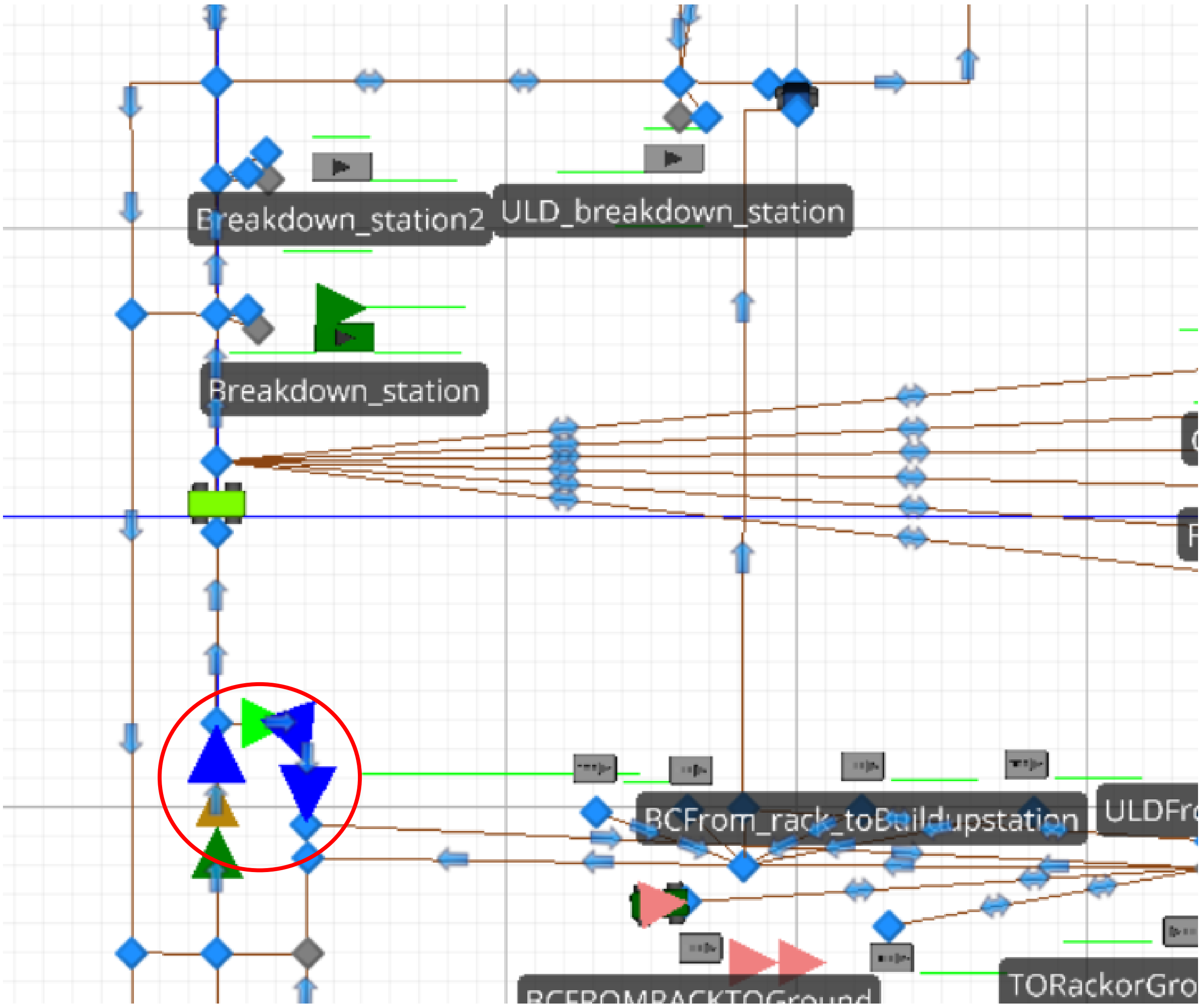


FIGURE 52 6:30 AM, THE ETV IS NOT ABLE TO PROCESS THE DEMAND, QUEUING START TO APPEAR (ENCIRCLED)

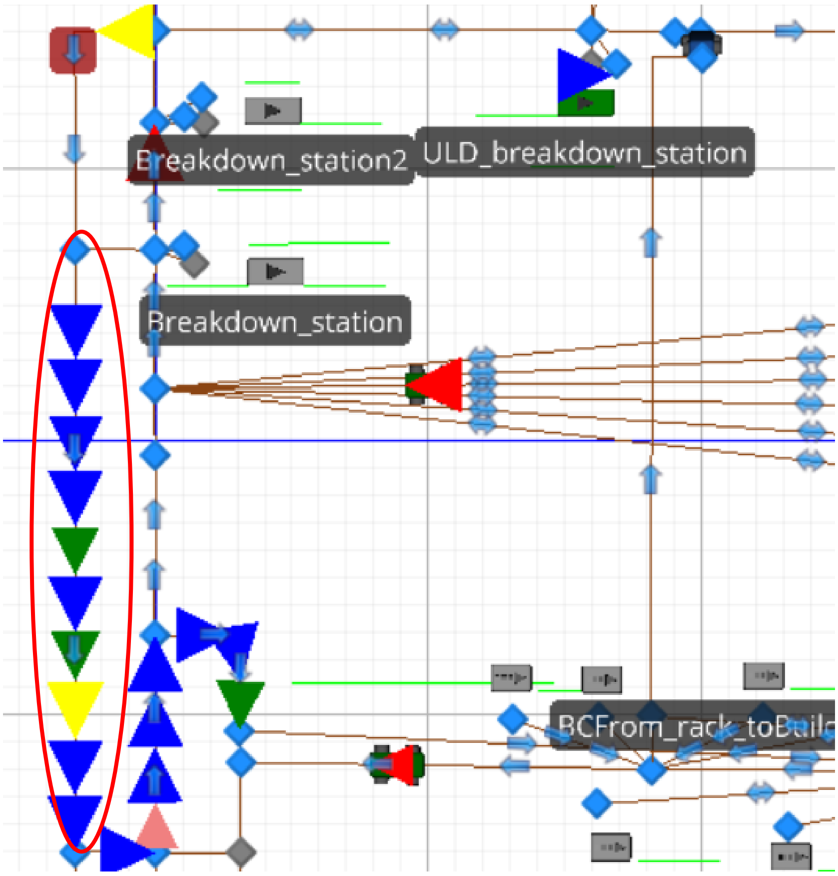


FIGURE 53 7:15 AM, THE QUEUE STARTS TO SPILL BACK (ENCIRCLED) OVER THE ROLLER DECK TO THE AIRSIDE

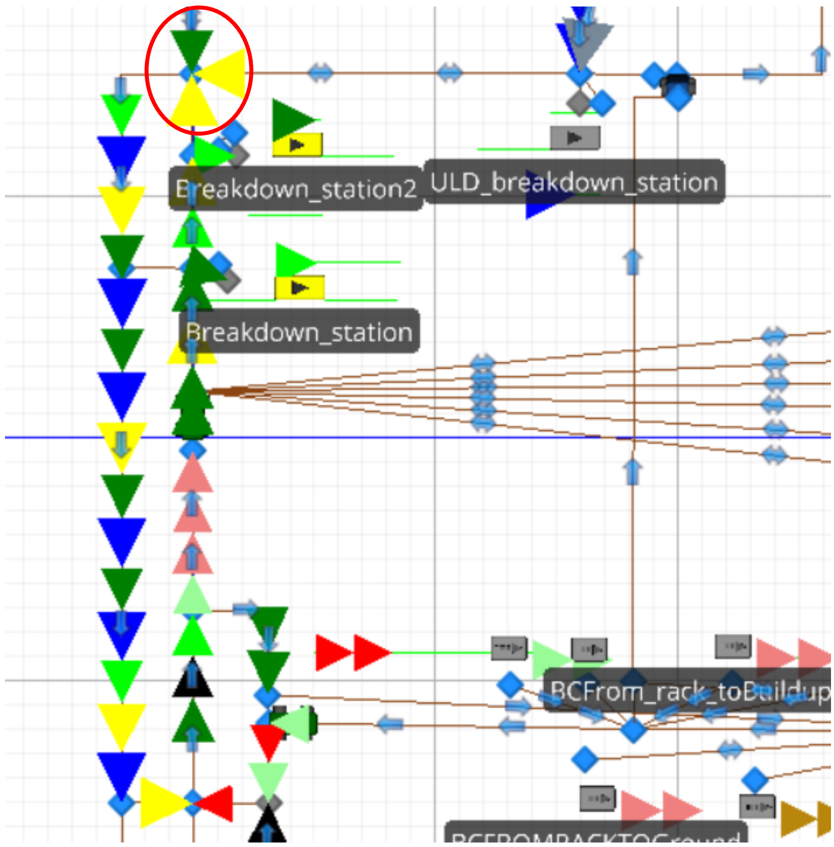


FIGURE 54 8:15 AM, THE SYSTEM HAS A DEADLOCK AS THE OUTFEED IS NOT ABLE TO FLOW OUT OF THE SYSTEM DUE TO THE SPILLBACK OF THE INFEED (ENCIRCLED), CAUSING A SPILLBACK TO THE ETV AGAIN

As a result of this, a number of models could not be validated due to the poor model trace results. As it appeared during validation, the model was not able to process the demands during peak days and higher demand scenarios (from 2% growth per year). In order to try to make the system usable again in these scenarios, new configurations and policies are introduced and tested on the various experiments.

In addition, the breakdown stations where not able to process all incoming transport units at the first attempt, in the case of the mail, this will require a breakdown at a later stage during the day. This specific process has not been modelled and should therefore be considered as an extra load on the internal transport system.

The solution was found to use the bridge as an infeed during these high-demand and peak moments, this relieves the roller deck on the left side and increases the input capacity constraining the system to higher (infeed) loads.

6.3.2 Constraints in the OoG handling process

The constraints found here are mainly due to the available surface area for the racking and manoeuvring, as can be seen in the figure below:

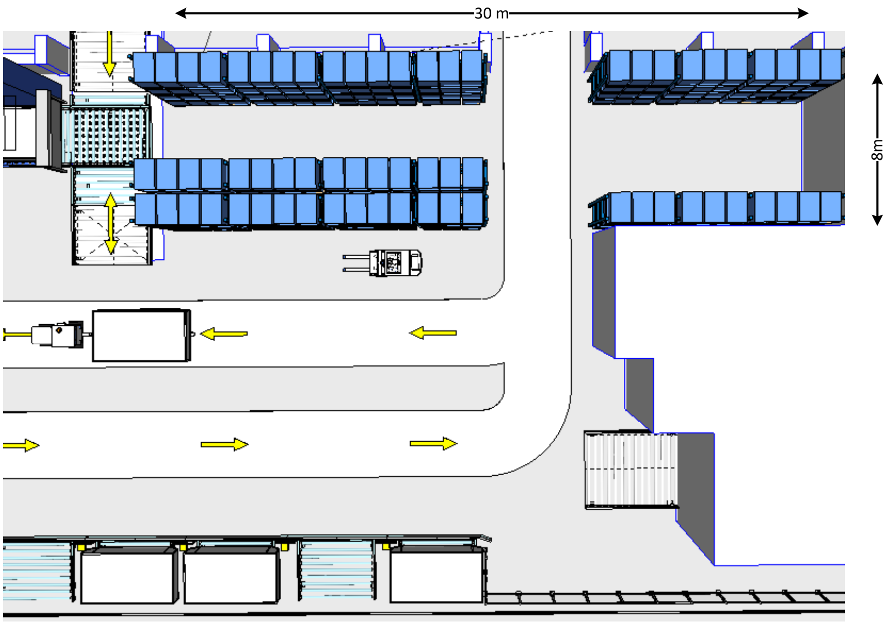


FIGURE 55 OOG RACKING CONSTRAINTS DUE TO SURFACE AREA AVAILABILITY

This results in an available surface area for the racking, with subtraction of the required manoeuvring area of about 180 m2. This will constrict the use of the racking to scenarios up to the 0,5% growth/year. Creating smaller stacking positions for individual items an increase the capacity up to 2% if necessary. Also, it is largely dependent on the share of OoG mail being processed, as this largely determines the content of the racking.

6.3.3 Constraints in the chute utilization/allocation process

In the chute utilization, the constraints are merely based on the available chutes and the physical capacity of the chutes. As this becomes critical, the chutes need to be emptied more often during opening time, this increases the workload, if this is a non-drop chute. However, an increase of the number of destinations can have a worsening effect on the performance of the system due to more batching and double handling. These exact constraints are not fully known yet due to the limitation of the model to only analyse one particular day. It requires, experience with the system and the future demand patterns to understand the constraints and to recalibrate the chute allocation according to the then offered demand. This was also confirmed during the reference visit at Hub Express/SoDeXi at Charles de Gaulle airport.

6.3.4 Interacting effects of the constraints of the individual models on each other

The individual constraints of the models during operation in the various scenarios can have interfering effects on the inputs of the other models. As part of the consideration to specify 3 different models during the model study, these interaction effects need to be taken into account as well. Since the outputs of the individual processes are (in)directly interconnected to each other and will therefore affect the performance of the other models in the case 1 model is constrained in a certain scenario, while the other is not. These interactions are therefore discussed per model.

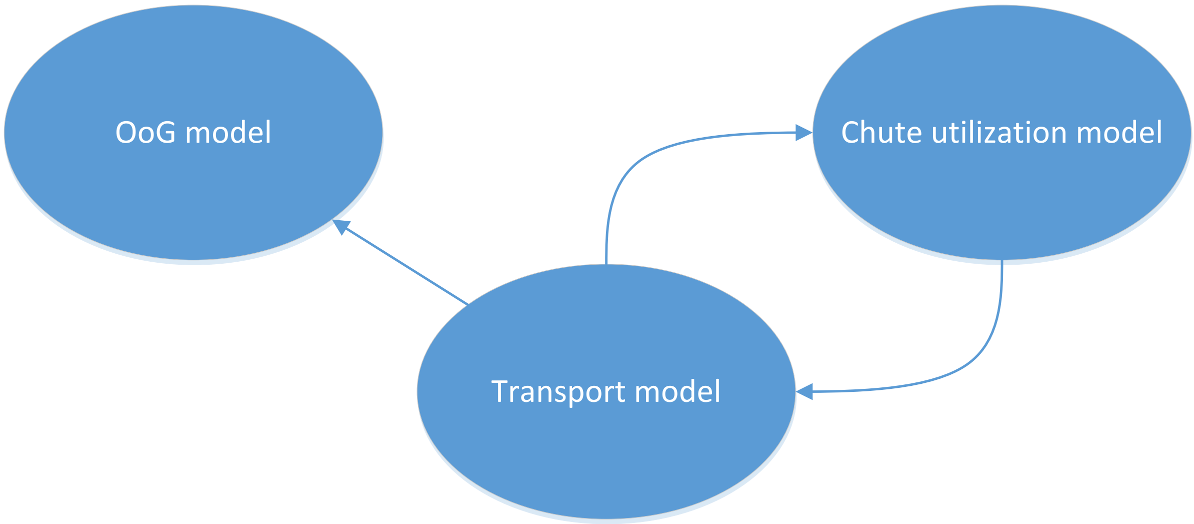


FIGURE 56 MODEL OUTPUT INTERACTIONS

Transport model –> OoG model

The transport model constraints can have a large effect on the OoG model input. As the transport system is congested, the ULDs and Belly carts containing OoG products cannot reach the Airside TV in order to breakdown the transport units, this will decrease the incoming OoG products and therefore reduce or delay the required rack capacity. The same holds for the output, if the transport system is congested, the outbound transport unit is not able to clear the build-up area, possibly resulting in missing the assigned flight. Especially during peak days, high volume demand scenarios (>2% growth/year) and depending on the configuration, this must be taken into account.

Chute utilization model –> Transport model

In this case, the output or allocation of the chutes has an impact on the performance of the internal transport system. As the number of required extra emptying, batching or double handling increases, due to higher volumes or extra destinations in certain scenarios the (E)TVs and the roller decks will have to move these extra number of transport units, either to temporary storage of to the outside buffer. This creates an extra load on the existing bottleneck in the internal transport system. It is therefore necessary to minimize the need of extra emptying, batching or double handling in order to reduce the risk of congesting the transport system.

Transport model -> chute utilization model

The throughput times and especially the outfeed times of transport units in the transport model can have an important effect on the allocation and utilization of the chutes. As this largely determines the required closing time of the chute. If the chute remains open for a longer period, more items can be sorted out directly, reducing the required number extra handlings. Currently, the closing time is set on SDT-2, due to the uncertainty of the outfeed times. If the transport model has queuing on the roller-decks or a congestion, the closing time should be increased to accommodate for the longer outfeed times.

7 Synthesis of analysis and model study

In order to answer the main question and a number of the sub-questions, the results of the analysis and the model study are assessed together and reflected on the methods used. This will be done by comparing the model results with the stated functional requirements of the new system. Comparing the current system performance with the new system performance and by addressing the other effects of combining and automating the processes in VG1.The main question and sub-questions will eventually be answered in the next chapter.

7.1 Comparison with the current system performance

In order to get an idea of the improvement of the new system in terms of KPI's, a comparison is made based on some of the KPI's which could be compared. These are the productivity and the in-outfeed times.

Productivity

The productivity in the current situation was calculated in the data analysis. A standard was set by the highest productivity in colli/fte/hour. From several weeks, this was found to be 19,6 colli/fte/hour approximately. In the combined situation, the productivity is expected to increase in a normal situation, otherwise the system would not prove to be cost-efficient in terms of OPEX.

Productivity standard in current situation	**19,6 colli/fte/hour**

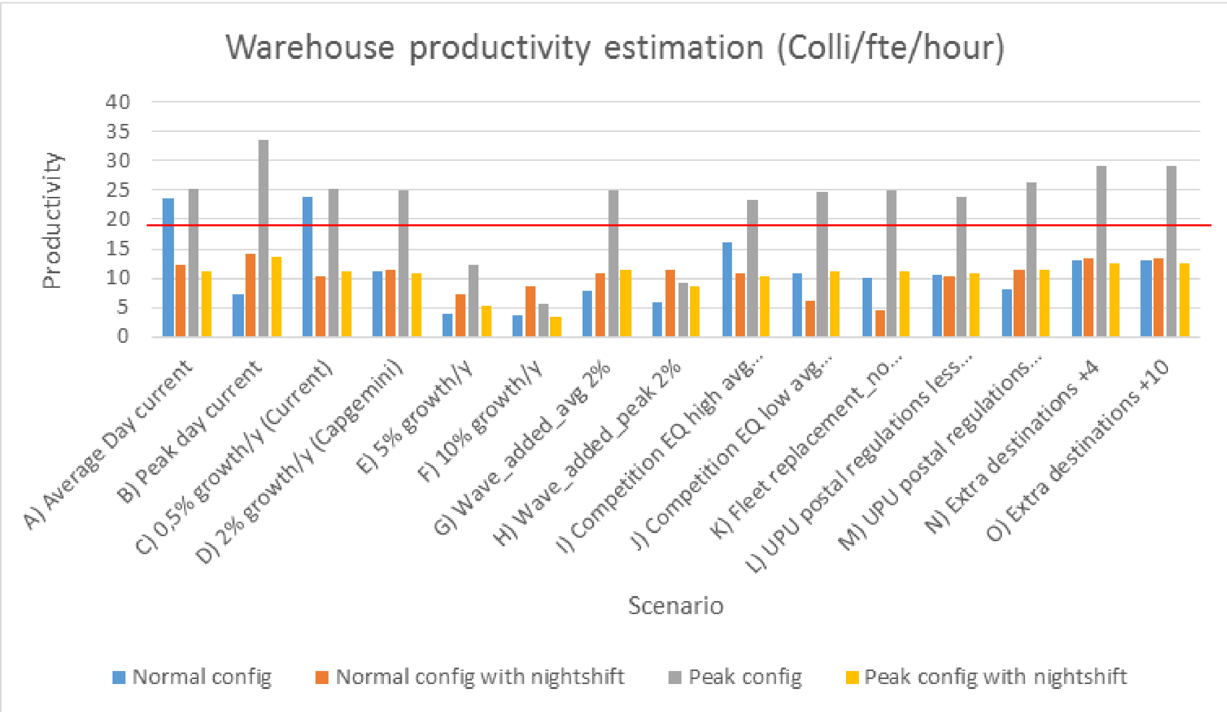


FIGURE 57 PRODUCTIVITY COMPARISON WITH THE CURRENT SITUATION (RED LINE)

As can be seen in the figure above, the normal configuration does offer a higher productivity in low-growth scenarios, whilst the peak configuration offers a higher productivity in high-demand scenarios. This is mainly due to the reduction in throughput in the transport system in the normal configuration. Especially during peak-days, this throughput is especially low due to under-capacity of the transport system. The night shift, does offer a higher throughput during peak hours but the fte required is higher and therefore the productivity decreases. However, only a comparison with the current situation is fair, as an increased amount of fte will be required to process the demand in future situations if the current situation was still in place.

In-and outfeed times

The comparison or the in-and-outfeed times is not straightforward as the current in-outfeed times depends largely on how many carts/dolly's need to be coupled to the tractor. Looking at the block-diagrams of the current situation it becomes clear that the coupling and decoupling takes the longest time. This depends on the amount of transport units being towed. If only 1 unit is fed-in or out it only takes a few minutes. If 4 units need to be coupled, it will take around 12 minutes in total. This is quite similar to the new system. Although, there is no flexibility in the new system as the transport unit cannot be retrieved from the roller decks. Having flexibility is a great advantage in the (express) air cargo business, as it allows for last minute build-ups of belly carts and acceptances, increasing the quality of the product. In the next comparison, the in-or outfeed of a single transport unit is assumed, the given percentages therefore represent the largest difference. Assuming 4 minutes for the infeed and 5 for the outfeed due to weighing.

TABLE 26 AVERAGE INFEED TIMES COMPARED TO CURRENT INFEED TIMES

Average infeed times compared to current situation [%]	Current demand	Low growth (0,5%/y)	Medium growth (2%/y)	High growth((5%/y) (system cannot process demand)	Current Peak day (system cannot process demand)
Equation	+392%	+414%	+608%	n/a	n/a
ACT	+82%	+87%	+123%	n/a	n/a
Mail	+300%	+340%	+520%	n/a	n/a

TABLE 27 AVERAGE OUTFEED TIMES COMPARED TO CURRENT OUTFEED TIMES

Outfeed times compared to current situation [%]	Current demand	Low growth (0,5%/y)	Medium growth (2%/y)	High growth((5%/y) (system cannot process demand)	Current Peak day (system cannot process demand)
Equation	+68%	+79%	+132%	n/a	n/a
ACT	+62%	+65%	+90%	n/a	n/a
Mail	+40%	+50%	+70%	n/a	n/a

7.2 Comparison with the functional requirements

As the system was designed based on a large number of functional requirements stated in the RFQ document (DENC, 2015), it is necessary to compare these requirements with the found results on the various scenarios and indicate where the functional requirements are similar and where are the discrepancies. This will allow KLM Cargo to better understand the operational limitations and allow for a better anticipation in certain future scenarios. The important and most relevant functional requirements and specifications where already mentioned in Paragraph 5.2.1. These functional requirements will now be discussed and compared if possible.

Sorter system capacity

The sorter system capacity is not modelled explicitly but the main influence here is the breakdown speed and the chute utilization. As the breakdown is modelled as a process with a distribution of [minimal 1, mode 4, and max 6] minutes per transport unit assumed containing 35 items, this comes down to more than 525 (assumed 4 minutes) units per hour per infeed point if scanning is required. The RFQ document states that this is 575 units per hour per infeed point. It is further assumed that the conveying system and the Posisorter have the designed sorting capacity, as these are already proven concept-products. The sorter system capacity is therefore assumed to match the modelled situation in all scenarios, since this process has a limited scope.

(Buffer) capacity

The capacity as mentioned in the RFQ document states that system needs to accommodate an amount of 212 carts/ULDs in the whole system. The content of the whole system is not specifically modelled but the required racking capacity can be calculated in the same way as the required OoG racking. This is done by assuming 0 units in the rack and then measuring the in-and outflux of belly carts and ULDs. In the end of the day the number discrepancy from the start value was less than 10 transport units, so over the days the required buffering capacity in the rack does not create issues. However, during the day with high influxes of inbound units, this can cause problems especially during peak days, as discrepancy between in- and outfeed can grow up to 76 units at a certain time-window during the day. If there is a negative requirement, the outfeed is higher than the infeed, this will require sufficient empty units to be stored in the rack at that moment. This amounts to about -82 units at a certain moment of the day. As the buffer areas are able to hold these number of transport units, either outside or in the rack no direct issues are expected here in "normal" peak days but in future peak days, the buffering can become problematic over the day.

ETV moving capacity
The ETV moving capacity has to be 35 cycles per hour according to the RFQ document. The ETV is specified to be able to handle at least 30 units per hour (maximum travel time is 100 seconds including loading/offloading)
In reality, the ETV is able to handle more cycles per hour as the distances are shorter. In most of the scenarios, the 35 minimum is reached as an average of 42 per hour is measured over the day and in some scenarios over 60 cycles per hour are measured. In high demand scenarios from 2% growth per year and onward, the moving capacity goes down due to the throughput constraint to about 20 units per hour.

Chute capacity
The chute capacity seems to be sufficient in the coming years although the expected filling rate in the current situation seems to be overestimated with 75% versus a current 40% on average. This average filling rate will only be reached with scenarios providing 2% growth/year and onwards. However, since the chute utilization model is based on 1 particular day, this cannot be validated and can only be seen as an indication of the filling rate.

In-outfeed capacity, or throughput of the system
As mentioned earlier, this has been set on 35 units per hour, based on the ETV moving capacity. However, the throughput of the system varies a lot depending on the chosen configuration and scenarios. For this comparison, the standard configuration is chosen without a night shift. It can be seen that the system is only able to process the minimum amount of 35 units per hour in the low-growth expectation scenarios. During peak hours, the throughput capacity drops. This was already briefly indicated by Lödige in their data analysis, so this also validates the model.

Travel times in the system
The in- and outfeed times from different locations inside the system are described in the RFQ document. These can now be compared to the outfeed times of various entities (transport units) in the transport model. Below the travel times from the RFQ document are compared with the model for the normal configuration in the current demand scenario.

TABLE 28 TRAVEL TIME COMPARISON RFQ VS MODEL

Travel time in minutes	RFQ-document	Model – transport time (1m)	Difference
From rack to airside (belly cart)	7	7	-
From airside buildup to airside (belly cart)	4	Not estimated specifically: part of overall outfeed times of belly carts but assumed to be 4 as well	-
Buildup under rack to PLC station	7	7	-
Outfeed time of ACT unit via ground (over 3000kg)	8	Max outfeed is 10	+ 25% maximum
Outfeed time of ACT unit via bridge (under 3000kg)	8.5	ACT route over bridge not specified but assumed to be 11 maximum	+25-30% maximum

OoG handling requirement
In the RFQ document, the handling requirement of OoG is estimated to be 1 forklift on normal days and 3 on peak days. This is last number seem to be overestimated as from the model, only 2 forklifts are required to process the OoG products. Although in growth scenarios larger than 0,5%/year the OoG requirements go up and the surface area required for manoeuvring and storage are not sufficient.

Summary

To summarize, the RFQ stated functional requirements, based on an average day assuming no congestion, meet the demands of the coming years and are sometimes over-estimated, however from a growth percentage of 2%/year as Capgemini has estimated, several stated specifications and functional requirements do not meet the demand. Also in peak-days the current base-configuration does not meet the stated functional requirements.

TABLE 29 COMPARISON WITH STATED SPECIFICATIONS: BLUE= BETTER THAN STATED REQUIREMENTS, GREEN = MEETS STATED REQUIREMENTS, YELLOW = PARTIALLY MEETS STATED REQUIREMENTS, RED = DOES NOT MEET STATED REQUIREMENTS

	Posisorter system capacity	Buffer capacity Assumed to be critical in a number of peak scenarios and high-growth(>2%/y)	ETV moving capacity Utilization (Not specifically mentioned in RFQ)	Chute capacity	Throughput capacity transport units per hour Blue=>40 Green=30-40 Yellow=20-30 Red= 0-20	Travel times overall in the system Blue >SR Green= SR Yellow= Some commodities meet SR, some not. Red = deadlock	OoG handling requirement Blue< SR Green= SR Red = OoG handling requirement exceeds physical constraints of surface area
A) Average Day current	Green	Green	Blue	Blue	Blue	Green	Green
B) Peak day current	Green	Yellow	Red	Blue	Red	Red	Blue
C) 0,5% growth/y (Current)	Green	Green	Green	Blue	Blue	Green	Green
D) 2% growth/y (Capgemini)	Green	Green	Yellow	Green	Green	Yellow	Red
E) 5% growth/y	Green	Yellow	Red	Yellow	Red	Red	Red
F) 10% growth/y	Green	Yellow	Red	Yellow	Red	Red	Red
G) Wave_added_avg 2%	Green	Green	Green	Green	Yellow	Yellow	Red
H) Wave_added_peak 2%	Green	Yellow	Red	Green	Red	Red	Red
I) Competition EQ high avg day (2%/year growth)	Green	Green	Red	Green	Blue	Red	Red
J) Competition EQ low avg day (assumed overall 2%/year growth)	Green	Green	Yellow	Green	Green	Yellow	Red
K) Fleet replacement_no more combi's	Green	Green	Yellow	Green	Yellow	Yellow	Red
L) UPU postal regulations less restriction (dimension)	Green	Green	Yellow	Green	Yellow	Yellow	Red
M) UPU postal regulations more restriction(weight)	Green	Green	Yellow	Green	Yellow	Yellow	Red
N) Extra destinations +4	Green	Green	Yellow	Green	Green	Yellow	Red
O) Extra destinations +10	Green	Green	Yellow	Green	Green	Yellow	Red

7.3 Other effects and requirements of combining and automating the processes

In addition to the measured KPI's there are also other effects becoming apparent during the analysis and model study.

Increased cut-off time

For example, the cut-off time previously maintained for Equation is now expected to increase to 120 minutes instead of the current 90 minutes due to the added internal transport time. As Capgemini (Capgemini, 2014) predicts in their market study, the customers expect a lower cut-off time in the future of about 50 minutes. Making sure the outfeed of Equation is not hindered is therefore crucial to maintain the quality of the product. In general, the quality of the equation product goes down in favour of a reduced surface area and operational cost.

Rebooking of Equation becomes necessary

If Equation is booked on a flight in a number of days after arrival, the planning department must now pull the booking forward if possible in order to prevent the consignment to be send through the process of time-buffering multiple times, this will create unnecessary double handling and will use capacity on the sorting system. In the current situation, there is enough surface area to store these products on a single belly cart. In the new situation, this is not possible anymore and the equation should be rebooked on an earlier flight. This will not affect the Flown As Planned criterion, as the FAP is only affected if the consignment is later than the booked flight.

Increased ergonomics & safety for handlers

The new system will utilize ergonomic breakdown equipment and build-up stations in order to increase ergonomics. This is expected to have a positive effect on the sick-rate, compared to the physical heavy mail handling process in the current situation. Also, the minimization of manual transport movements through the warehouse increases safety and damages due to driver error.

Recognizing OoG becomes important

The breakdown personnel, must now be trained to recognize OoG in order not to put fragile items on the sorter which might be crushed or might sustain damage from falling down the drop-chute. Most chutes are suitable for handling fragiles though. As was mentioned during the visit at Hub Express, the mail bags with long tie-ropes can also be hazardous for the sorting system as they may get stuck. In addition, light products, which may fall off the Posisorter due to drag need to be picked out before the combined scanning and weighing device will pick these out and stop the conveyor, causing the infeed to stop, which is not desirable.

ACT products more constrained

Due to the automated internal transport system, the ACT containers are now bounded to the roller deck, as the ACT containers carry pharmaceutical products within a very limited temperature range, they must be fed-in and out of the system as soon as possible. In case the system is congested, the ACT container cannot be retrieved from the roller deck if necessary. The condition and expected traffic on the internal system must therefore be assessed before feeding in or out an ACT container. Otherwise, the service-dock should be used to by-pass the internal transport system.

Prioritization of postal products

Prioritization of large mail customers, such as China post, needs to be specified into the IT-system in order not to lose important customer satisfaction. The prioritization of specific mail products such as Prio-mail and EMS parcels, can also be done with a number of IT-adjustments. However, this can only be done if sufficient chutes are available. Otherwise, the build-up should handler should be instructed that these items should be loaded onto the transport unit first, as is the case with co-loading Equation. This will enhance the quality of the mail product, but it is not yet desired by all clients and should therefore not have a high priority for implementation.

7.4 Discussion on found results and literature

The results found during the analysis and modelling study might can either be in line with the found literature or have different outcomes as pre-assumed from the literature review. These aspects will be discussed in this paragraph as part of the synthesis. Looking at the used methods and theories from literature applied in this study, the main methods are the Delft systems approach (Veeke et al., 2008) and the Theory of constraints (Dettmer, 1997) and Discrete event simulation. The methods where applied on the current situation and the new situation respectively.

DSA

As the DSA includes a large number of methods, not all where relevant to be used in this analysis. And the main goal of the DSA was to assess the performance of the current system, only the relevant methods are utilized from the DSA in order to visualize and scope the current system, as well as to determine the operational performance within this scoping. During this analysis, a number of assumptions had to be made with regard to the scoping and this specific system. One of the assumptions was not to include the Flown as Planned criterion translated into the effectiveness of the operation, as this is not a good indication of the internal process since the root cause can be found outside VG1 in most of the occasions. The DSA was useful to provide a benchmark of the ideal performance in the current situation to be compared to the new system with the same inputs and conditions. The DSA is also limited in the type of KPI's to be measured regarding similar

TOC

The Theory of Constraints, or TOC, developed by Goldratt provides a guideline into both identifying and solving constraints in a system. The theory is applicable for a large number of production line systems and similar systems which have the throughput and costs as important performance criteria. Applying the theory, however, provided multiple possible bottlenecks in the system although the TOC states that only 1 bottleneck can be found in the system. The cause of this is the presence of multiple (contra) flows through the system which can have different processes as a bottleneck depending on the dynamic demand over time. Due to this, a simulation study was required in order to pinpoint the constraining point and what the effects of this point are on the functioning of the system. The TOC is therefore not directly applicable to complex dynamic system with multiple (contra) flows during operation. Another shortcoming aspect of the TOC, which came apparent during the simulation study, is the ability to indicate the effect of a bottleneck on the upstream processes as this had large consequences on the performance of an internal transport system such as in VG1, this may not only apply to more complex systems similar as in VG1 but also other relative simple systems, with certain parallel processes. Including a queuing theory in the TOC, such as Markov models can provide a better understanding of how a certain constraining process in the system will affect the rest of the system by looking at the developed queue. This depends of course on the discrepancy between the throughput capacity of the constraint, the demand and the available buffer capacity between the processes. In case the queuing remains within the buffer area and does not spill back to other performance-critical processes, no intervention is required to keep the system operational. The TOC itself does not make a clear distinction between these effects of a certain constraint. The TOC did provide a good guidance to find solution strategies to mitigate the effects of the constraints as to utilize the bottlenecks capacity as much as possible. These solution strategies were found to be successful for a number of analysed scenarios in keeping the system operational and therefore mitigating the effects of the constraint.

Simulation study

The (discrete-event) simulation study, provided a good distinction between a stable system and a non-stable system where the system provided a deadlock in a certain configuration & demand scenario. Also, the simulation study provided a good insight of the development of the queue over time as a result of the fluctuating demand. In addition, the simulation study allowed for a distinction of commodities within a combined stream of commodities, this provided the ability to specifically measure the effects of various configurations and policies implied on the combined automated sorting system on certain commodities such as Equation and ACT. The application of discrete event modelling and simulation, was therefore of an important value in order to find the actual constraints and solution strategies and therefore builds forth on the modelling studies into single-commodity air cargo hubs by Nsakanda et al. (2004) and Ou et al. (2007) regarding the possibilities and opportunities.

8 Conclusions & Recommendations

In this last chapter, the main question and the sub questions are answered. Next, a recommendation is given to KLM Cargo on what, the best strategy is to follow in the coming years utilizing the system. Finally, a recommendation for further research is given. Some of the findings in this study may also be generalized for similar combined automated systems but the recommended strategies will apply for this particular system case-study and corresponding demand patterns only.

8.1 Research questions

The research questions can now be answered based on the combined analysis and model study. A brief explanation will be provided for each answer.

Main research question:

How can the expected operational performance of a combined automated air cargo sorting facility be assessed and what are the effects of integrating the current operations from a logistical perspective?

The expected operational performance of a combined automated air cargo sorting facility can be assessed by means of a number of steps:

1. Analyse the current demand patterns & processes
2. Estimate future scenarios using literature, expert interviews and determine how these will affect the current demand patterns
3. Determine operational KPI’s of the specific system, if not yet present. *Operational costs, system utilization, travel times, throughput and surface area required* (if applicable) and others.
4. Identify the systems’ constraints with regard to the KPI’s using the Theory of Constraints, if there are multiple constraints, go top step 5. Otherwise solve the constraint by continuing the TOC.
5. Conceptualize the system around the constraining processes within the scope.
6. Perform a (discrete -event) modelling study on these constraining processes in order to determine the responses on the KPI’s based on various scenarios and corresponding inputs
7. Implement and test strategies into the model to, if necessary, improve the systems’ performance.

Now, the expected performance can be assessed based on the estimated future scenarios.

The effects from a logistical perspective of integrating the current operations have been determined by comparing the new situation with the current processes. It was found that there are a number of changes from a logistical and planning perspective given an estimated growth.

- Less overall flexibility in handling
- Inter-Product quality becomes more equal, less priority distinction is made between Equation and mail
- Within the products, more handling distinction can and must be made in terms or priority: Prio-mail (can), OoG (must).
- Reduction in handling costs and surface area
- More planning and rebooking is required in order to prevent the automated system become inefficient due to double handlings and prevent congestion on peak-hours
- The cut-off time and interconnection time is increased for the Equation product due to longer & less flexible outfeed time, possibly reducing the available connections if no alternative by-pass process is implemented.

Sub questions:

How is the automated sorting and storage facility expected to perform in terms of KPI' in comparison to the functional requirements and the current operation?

The automated sorting and storage facility is expected to perform as described in the functional requirements in the current demand-pattern scenarios. However, in higher demand scenarios and peak days the overall system does not perform as stated in the functional requirements. Especially throughput requirements, ETV handling requirements and travel times through the system are not met during peak and high demand periods. Also the OoG area reserved for storing and handling OoG is found not to be sufficient in medium and high demand scenarios.

In comparison with the current operation, the system does perform well, looking at the productivity KPI in *colli/fte/hour.* Especially in the average current demand scenario, the system out-performs the current situation, however during peak hours, the throughput goes down due to congestion on the internal transport system, reducing overall performance. In future high demand scenarios, the current situation, due to the absence of a throughput limitation is expected to perform better. However, it is not taken into account that an increase in fte. will be required for these situations, which can eventually result in a similar productivity.

What are the operational benefits and drawbacks of combining the mail, express and refrigerated commodities from a logistical perspective?

A number of these have been answered in the main question but, a clear distinction will be made between benefits and drawbacks per commodity:

TABLE 30 EFFECTS OF COMBINING THE PROCESSES PER COMMODITY

	Benefits	Drawbacks
Mail	- Increase in operational safety & ergonomics - Less surface area required for storage and sorting - Lower operational costs (OPEX) & increased overall productivity - Prioritize within product	- Prioritization on postal client becomes more difficult - Extra handling process for OoG mail is required
Equation	- Less surface area required for storage and sorting - Increase in operational safety & ergonomics - Lower operational costs (OPEX) & increased overall productivity	- Less flexibility for in-and outfeed, this is crucial for Equation - Rebooking for equation is required if a multiple day dwell time is present in order to prevent looping in the system, this requires an extra workload for the planner to check which earlier flights have volume available - Quality of the Equation product goes down, a higher cut-off time means that clients need to off their products longer before the due flight time than in the current situation (90 minutes) Interconnection time (180 min currently including transportation) becomes critical in a number of future scenarios, connections for Equation products may not be achieved due to the longer in-and outfeed times. Requiring extra by-pass processes to keep the FAP criterion, which are less efficient. - Extra exceptional handling process required for DG and OoG Equation
ACT	- Automated internal transport reduces required OPEX	- Less flexibility for in-and outfeed, this is crucial ACT products

What are the operational constraints of the automated sorting and storage facility regarding the future arrival and departure patterns?

A number of future scenarios have been analysed and applied as input variable in the model. It becomes clear that the system is able to perform well up to around 2% growth/year on average. Totalling a growth of 40% in 2035. During peak days, the systems' operational performance is critical already in the current demand pattern. Regarding the other scenarios, which have been applied regarding the 2% growth/year. The changes in demand pattern will have a minor effect on the operational KPI's. In terms of in-and outfeed times this will only deviate up to 5 minutes from the 2% growth/year base-scenario, depending on the specific scenario. In the peak days, the system is not able to handle the high influx during the morning peak, this will cause a deadlock in the internal transportation system. This will affect the other crucial processes, resulting in a reduced overall performance of the sorting and storing system.

How can the system be configured or what measures can be taken in order to perform optimally in terms of KPI's during peak demand patterns?

The system can be reconfigured in order to accommodate higher demands; however, some considerations need to be made. This will allow the system to process all commodities and ensure a higher throughput capacity. A distinction is made in handling ULD's and belly carts. By infeeding the belly carts over the overhead bridge, extra buffering capacity is created for the ETV. Also, the outside buffer will now be used to buffer ULDs. This will enable the more crucial belly carts, which may contain Equation, to be feeded into the system with less traffic on the roller-decks during peak-days. However, the best measure to handle peak-days is the implementation of a night shift, which separates the inbound-outbound overlapping peaks in the morning for mail. This will keep the operational performance in terms of in- and outfeed times and throughput capacity acceptable although the cost will increase.

8.2 Recommendations for KLM Cargo

Assessing the results of the data analysis and model study, there are a number of recommendations to be given for KLM Cargo with regard to the possible future scenarios.

First of all, if there are no technical or IT related issues, the system will fulfil the operational requirements stated in the RFQ document for the average demand patterns up to 30-40% growth in 2035. So, no further actions are recommended here apart from recalibrating the chute allocation regularly.

Internal transport system

However, in peak days and higher demand scenarios, the system is not able to process the offered demand and adequate measures should be taken here. A reconfiguration of the system, utilizing the bridge as an infeed for ULDs will result in a higher utilization of the buffering capacity of the system and the throughput of the offered demand is realised. However, implementing the peak-configuration will have a worsening effect on the other operational KPI's such as the throughput times during peak-days as there is an overlapping inbound and outbound peak during the morning. Requesting a very high utilization of the ETV. It is therefore recommended to implement a night shift during peak-days to separate the inbound and outbound flows and to utilize the ETV moving capacity better by spreading the demand. If the overall growth exceeds 2% per year, it is recommended to implement the peak-configuration during average days, due to the lower costs. An overview of the recommended strategies with regard to the KPI's is provided below. It is necessary that the throughput of this system is maintained and that the transport units keep moving over the roller decks as it affects all other processes in the sorting and storing system. The controller should therefore prevent deadlocks at all costs.

TABLE 31 RECOMMENDED STRATEGIES FOR KLM CARGO

Scenario	Average day	Peak day
<2% growth/year (<40% in 2035)	No actions required	Implement a night shift in VG1
>2% up to 5% growth/year (>40% in 2035)	Implement peak-configuration	Implement a night shift and peak-configuration
>5% growth/year (100% in 2035)	Do not accept the cargo in VG1	Do not accept the cargo in VG1

The implied strategy or configuration has different effects on the performance of the operation during peak days. Implementing the peak-configuration compromises in-and outfeed times for lower costs. The night shift implementation does not compromise on in-and outfeed times but does increase the costs. KLM Cargo should therefore determine whether the priority lies in the quality of the product or efficient internal operations. Also, organisational changes must be made in comparison with the current 2-shift operation. As the 3-shift operation is already in place at VG2 &3, the same organisational structure of rotation could be implemented temporarily at VG1, although this must be arranged in the conditions of the working-contract of the employees at VG1.

In order to further reduce the load on the transport system, it is also recommended to increase the possibility of co-loading mail and equation on 1 transport unit. Currently, this can only be performed at a dozen outer stations, as the majority is not yet capable of handling the two processes. This could be done by instructing the other outer stations on how to separate the products and handle them accordingly. This can be done via lobbying at the UPU or other overarching organisations regarding postal and parcel products. This can also be the incentive for certain outer stations to implement a similar combined system, reducing overall operational costs over the whole chain.

OoG-process
In addition, is necessary to analyse the OoG process more closely during testing and obtain a representative sample of the mail. There are still a lot unknowns regarding the share of OoG within mail. As this share of OoG determines the required storage capacity and handling requirements, it is recommended to build the rack based on the amount of Equation OoG with a little margin for mail with the opportunity to expand it if necessary during the years. Reducing the number of OoG products within mail can also be done by applying for more regulations at the UPU, or which may induce stricter sanctions on postal companies who violate the regulations. Also in order to reduce the dwell-time and the required rack capacity, it is recommended to rebook the OoG equation to an earlier flight as well.

Chute allocation
The chute allocation should be performed based on the then available demand. It is preferred to utilize all chutes in the system and therefore the system needs to be optimized further by recalibration over time.

Rebooking of equation
It is recommended to start rebooking Equation products on earlier flights if possible in order to reduce the load on the storage system and increasing the load-factor on the aircraft. Another reason for doing this is that it prevents Equation to keep looping through the system and being handled multiple times.

8.3 Recommendations for further research

Apart from the recommendations specific for KLM Cargo, more general research recommendations were found as well.

Market-effects
A further research into the effects of the possible increased cut-off time on customer satisfaction is recommend as well as the ability to prioritize in mail. How does this affect the business performance the air cargo hub? What is the elasticity on demand and cut-off time in the new situation, especially regarding the opposite customer expectations of reduced cut-off times found by Capgemini?

Predictive control & resource utilization of the system
When more data becomes available and forecasts become more accurate, it is possible to control the system more dynamically and based on the expected demand patterns on an hourly level. A fast reconfiguration of the system or a dynamic human resource planning not based on the current shifts are interesting topics for further research as it may increase the efficiency and utilization of the system even more.

The chute utilization optimization strategy
As was found during the research it is hard to find an optimal chute allocation for an average day. In order to still use the available chutes optimally, a number of strategies looking at different common demand patterns for various days and destinations could be implemented for a better utilization of the chutes, minimizing requirement of extra handlings.

9 Reflection

In this chapter, the academic and personal reflection on the research are discussed.

9.1 Academic reflection

As mentioned in the introduction, and problem description, the specific outcomes and recommendations of this research are only applicable to the KLM Cargo case. However, the general direction of the results and conclusions are also applicable to similar automated combined sorting systems. The overall levelling-out of the quality of the products is a characteristic which can be assumed to be a common effect in other automated combined facilities.

The used methodology had to be determined based on a number of existing methods and findings during the study, the original plan for the used methodologies have been slightly altered, especially during the transition from data-analysis to the modelling study. The methods used where eventually very useful for the conceptualization of the critical processes.

Sections of the Delft systems approach (Veeke et al., 2008), or DSA, were very useful to estimate the current performance as a benchmark for the new system, although little adjustments had to be made to make the DSA applicable for the specific sorting and storing system at KLM. The scoping must be done concisely here, especially with regards to the KPI's. Only use the KPI's which are relevant for the operational performance within the warehouse.

The existing Theory of Constraints by Goldratt (Dettmer, 1997) was considered to be the most suitable method to identify and mitigate bottlenecks for an input-output system present at VG1 regarding the found KPI's. The TOC did have some limitations in terms of handling more complex dynamic systems with multiple flows. Applying the TOC provided multiple possible bottlenecks, although this is not possible according to Goldratt, Moreover, the TOC did not provide a clear indication of how the bottlenecks could possibly affect other processes in the system due to spillbacks. In order to pinpoint the most constraining bottleneck, causing the system to deadlock and providing a low throughput, the system had to be modelled and simulated over time. The TOC did provide a number of solution directions which were applied and tested successfully.

In addition, the TOC does not directly provide an indication of the utilization of the system, the chute allocation is an example of this. As the chute allocation is largely system specific and demand/flight schedule dependent, no general guideline or heuristic method can be applied for other sorting systems and should therefore be based on interviews and experience in testing.

The modelling methods used, such as discrete event simulation, where very useful for some of the problems found. Especially for the modelling of the internal transport system, the use discrete event simulation was of added value due to the complex routing and mix of entities going through the system as a necessary complementation to the TOC. The dynamic behaviour and effect of the spillback caused by the bottleneck could not have been found easily by means of other modelling methods. Thus, for this specific roller deck-system it was a good choice to opt for discrete event modelling. However, it may be that for more simple, internal transport systems discrete event simulation will not be required to identify the bottlenecks as the TOC will be able to identify the single bottleneck, requiring less time and provide a guideline for solution strategies.

The use of discrete-event simulation requires very accurate data in order to specify the models accordingly. As the input data of the models in the KLM Cargo case was only available on an hourly-level this may be a limitation of the model study when comparing in- and outfeed times on a minute-level. The results are therefore hard to validate 1-on-1 with the real situation although by running multiple replications we are able to capture a part of the arrival-interval stochasticity.

Another limitation of the model, is the possible effect of manual intervention by the controller. This may, for example, prevent extreme long in- and outfeed times of individual transport units and deadlocking of the system. As it was not feasible to predict when and what kind of manual intervention can take place, this was left out of the scope in this research but should be considered when the system is subjected to high loads.

For the modelling of the OoG process, in hind side, a static modelling method could have been used as it is a relative simple input-output process. However, the time invested in specifying would have been similar, as the input data analysis consumed the majority of the time. Moreover, the use of simulation (animation) was found to be a powerful tool in presenting the results to the project team.

With regard to the chute allocation model, no clear methods where determined beforehand and based on the available data and the characteristics it was found that there was no clear method to determine the optimal allocation strategy in general. Therefore, it was decided to determine an optimal allocation strategy for 1 particular day and make a qualitative indication of the direction of the expected requirements in other scenarios.

All in all, I think the general results of this study are useful in terms of the found methodology to determine the expected performance and constraints of a similar combined automated air cargo sorting system. Although not all methods used can be applied in general to estimate the full- performance of the system, as is the case with the chute allocation.

9.2 Personal reflection

Personally, I consider my internship at KLM Cargo and doing this thesis as a very pleasant and useful experience. From the start of the thesis, I was involved closely into the project team and could utilize my experience and skills obtained during my studies well during meetings. It was very satisfying to see how the theories and methods I have learned during my study could substantiate the assumed issues or revealed that expected problems will not appear in the actual system. It was sometimes challenging to find the right balance between the more generalize theoretical aspects preferred by TU Delft and the more specific and practical KLM Cargo aspects of the research but I think the final report is fairly balanced.

Another challenge was the availability of accurate data at KLM Cargo. It was at some moments quite hard to puzzle together the data in order to obtain the usable input data for the model, although in the end by means of interviews and supported assumptions I was able to complete the data analysis.

Due to a large reorganization within KLM Cargo halfway during the project, it became sometimes more difficult to find the right person to obtain the right information. However, this independence was also useful in some way. It prompted me to take more initiative in obtaining information from various other sources and come up with more creative solutions from my own perspective, my supervisors at TU Delft and available literature. An example of this is the location of the perceived bottleneck in the system, which was pre-assumed to be the PLC-system only by KLM Cargo. Assuming this was correct, I first started with focussing on analysing this system, although it became clear when applying the TOC as means of substantiating this claim, that this was not the only focussing point. This finding became an important switch in scoping, which would not have occurred if I would not have applied the TOC and could have resulted in another outcome of the research. Thus, remaining critical on obtained data and information was a very useful learning point during this research.

Furthermore, the opportunity that KLM Cargo provided to visit a similar hub at Charles de Gaulle airport and to visit the Lödige factory in Germany was very useful in for accomplishing this master thesis, it provided very useful insights in the experience with a combined sorting hub and on how crucial aspects of the system will work as this is difficult to imagine if the system is not yet in operation.

All and all, it was a very good and nice experience to perform this master thesis at KLM Cargo.

Bibliography

AF-KLM Cargo. (2016a). Equation: Your right speed mode! Retrieved October 18, 2016, from https://www.afklcargo.com/FR/common/common/pdf/Brochure_Equation_pour_web_0305.pdf

AF-KLM Cargo. (2016b). *Master EPS wachtrapport*. Amsterdam.

Airbus. (2016). A320: dimensions & key data. Retrieved October 17, 2016, from http://www.airbus.com/aircraftfamilies/passengeraircraft/a320family/a320/specifications/

Bannò, M., & Redondi, R. (2014). Air connectivity and foreign direct investments: economic effects of the introduction of new routes. *European Transport Research Review*, *6*(4), 355–363. http://doi.org/10.1007/s12544-014-0136-2

Boeing. (2014). World Air Cargo Forecast. Retrieved August 8, 2016, from http://www.boeing.com/resources/boeingdotcom/commercial/about-our-market/cargo-market-detail-wacf/download-report/assets/pdfs/wacf.pdf

Boeing Commercial Airplanes. (2013). 737 Airplane Characteristics for Airport Planning. Retrieved October 17, 2016, from http://www.boeing.com/assets/pdf/commercial/airports/acaps/737.pdf

Börjeson, L., Höjer, M., Dreborg, K. H., Ekvall, T., & Finnveden, G. (2006). Scenario types and techniques: Towards a user's guide. *Futures*, *38*(7), 723–739. http://doi.org/10.1016/j.futures.2005.12.002

Capgemini. (2014). *Business case study alternatives VG1*. Amsterdam.

de Leeuw, A. (2000). *Bedrijfskunding management*. Assen: Van Gorcum.

DENC. (2015). *RFQ Logistics Solution*. Bussum.

Dettmer, W. H. (1997). *Goldratt's Theory of Constraints: A Systems Approach to Continuous Improvement - H. William Dettmer - Google Boeken*. (J. Bohn, Ed.). Milwaukee, WI: Quality Press. Retrieved from https://books.google.nl/books?hl=nl&lr=&id=pinJA4-spBAC&oi=fnd&pg=PR21&dq=theory+of+constraints&ots=_uNSgnR5Ns&sig=e-1eQ7SF8DMMSiZfSu7E0WbU0Qs#v=onepage&q=theory of constraints&f=false

Doganis, R. (2010). The economics of air freight. In *Flying Off Course: Airline Economics and Marketing* (4th ed., pp. 305–306). New York: Routledge.

Envirotainer. (2016). Envirotainer RKN e1 container. Retrieved November 25, 2016, from http://www.envirotainer.com/en/active-containers/Our-Container-Products/Envirotainer-RKN-e1/

IATA. (2015). IATA Cargo Strategy. Retrieved August 8, 2016, from https://www.iata.org/whatwedo/cargo/Documents/cargo-strategy.pdf

IATA. (2016). AIR MAIL & CONSUMER e-COMMERCE. Berlin. Retrieved from https://www.iata.org/events/wcs/Documents/WCS2016posteventmaterials/e-commerce-No-Sponsor-DONE.pdf

ICAO. (2014). Forecast of Scheduled Passenger and Freight Traffic. Retrieved August 8, 2016, from http://www.icao.int/sustainability/pages/eap_fp_forecastmed.aspx

Kasarda, J. D., & Green, J. D. (2005). Air cargo as an economic development engine: A note on opportunities and constraints. *Journal of Air Transport Management*, *11*(6), 459–462. http://doi.org/10.1016/j.jairtraman.2005.06.002

Kirmani, S. N. U. a., Viswanadham, N., & Narahari, Y. (1993). Performance Modeling of Automated Manufacturing Systems. *Technometrics*, *35*(4), 456. http://doi.org/10.2307/1270286

Klein Douwel, D. (2015). Dynamische Resource Planning: Roadmap 2016. Schiphol.

KLM Fleet Development & Aircraft Trading. (2016). *KLM Group KLM Fleet Intranet Overview*. Schiphol. Retrieved from https://www.klm.com/corporate/myklm/documents/11015/205929/Fleet+Intranet+Overview+July+2015/426b1902-1fea-491a-b2f3-bea1c60ae563

Liang, Z., Liu, Y., Wang, H., & Li, J. (2010). Slider automatic sorting system modeling and simulation based on

AutoMod. *Logistics Technology*, *1*(29), 139–141.

Lödige GmbH. (2016). Sketchup impression model VG1. Warburg, Germany: Lödige.

Masel, D., & Goldsmith, D. (1997). Using a simulation model to evaluate the configuration of a sortation facility. In S. Andradóttir, K. J. Healy, D. H. Withers, & B. L. Nelson (Eds.), *Winter Simulation Conference* (pp. 1210–1213). http://doi.org/10.17226/13497

Nsakanda, A. L., Turcotte, M., & Diaby, M. (2004). Air Cargo Operations Evaluation and Analysis through Simulation. In *Proceedings of the 2004 Winter Simulation Conference, 2004.* (Vol. 2, pp. 711–719). http://doi.org/10.1109/WSC.2004.1371531

Ou, J., Zhou, H., & Li, Z. (2007). A Simulation Study of Logistics Operations at an Air Cargo Terminal. In *2007 International Conference on Wireless Communications, Networking and Mobile Computing* (pp. 4398–4402). IEEE. http://doi.org/10.1109/WICOM.2007.1086

Porter, M. (1990). The Competitive Advantage of Nations. *Harvard Business Review*, *68*, 73–93.

Royal Dutch Virtual. (2016). Capacities in the KLM Route Network – Part 2. Retrieved November 17, 2016, from https://royaldutchvirtual.com/blog/2014/12/explained-capacities-in-the-klm-route-network-part-2-2/

Sargent, R. (2000). Verification, validation, and accreditation: Verification, validation, and accreditation of simulation models. In and P. A. F. J. A. Joines, R. R. Barton, K. Kang (Ed.), *Proceedings of the 32nd Conference on Winter Simulation* (pp. 50–59). Syracuse.

Sargent, R. G. (2009). Verification and validation of simulation models. In *Proceedings of the 2009 Winter Simulation Conference* (Vol. 37, pp. 162–176). http://doi.org/10.1109/EMR.2009.5235461

Schiphol. (2016). Odd size baggage. Retrieved December 7, 2016, from http://www.schiphol.nl/Travellers/AtSchiphol/Luggage/OddSizeBaggage.htm

Schiphol Group. (2016a). Arrivals. Retrieved November 22, 2016, from http://www.schiphol.nl/Travellers/FlightInformation/Arrivals.htm

Schiphol Group. (2016b). Verbouwing A-pier - Schiphol. Retrieved August 31, 2016, from http://www.schiphol.nl/Reizigers/OpSchiphol/SchipholVernieuwt/NieuweTerminalEnApier.htm

sea rates.com. (2016). ULD Container Types. Retrieved November 9, 2016, from https://www.searates.com/reference/uld/

UPU. (2013a). Letter Post Regulations Final Protocol. Retrieved September 28, 2016, from http://www.upu.int/uploads/tx_sbdownloader/actRegulationsLetterPostFinalProtocolEn.pdf

UPU. (2013b). Parcel Post Regulations Final Protocol. Retrieved September 28, 2016, from http://www.upu.int/uploads/tx_sbdownloader/actRegulationsPostalParcelsFinalProtocolEn.pdf

van Amstel, G. (2009). *Integration of the airmail and equation operations at the KLM Cargo terminal*. Delft University of Technology. Retrieved from uuid:db38e3af-aff6-49b8-8e00-fb5b3b5c3226

Vanderlande, & Lödige. (2016). *Results from known data analysis*. Schiphol.

Veeke, H., Ottjes, J., & Lodewijks, G. (2008). *The Delft systems approach : analysis and design of industrial systems*. London: Springer-Verlag London Limited. http://doi.org/10.1007/978-1-84800-177-0

Verbraeck, A., & Valentin, E. (2006). *Discrete systems reader EPA1332*. Delft: Delft University of Technology, Faculty of Technology, Policy and Management.

Versleijen, J. (2016, February). Schiphol sloopt slechts 33% van vrachtloods KLM. *Nieuwsblad Transport*. Retrieved from http://www.nieuwsbladtransport.nl/Nieuws/Article/ArticleID/48508/ArticleName/Schipholslooptslechts33vanvrachtloodsKLM

WBS. (2016). Worldwide Baggage Services. Retrieved December 19, 2016, from http://baggage.nl/faq/

List of figures

List of tables