

Increasing air cargo throughput per ground surface unit under footprint constraints

A case study at Amsterdam Airport Schiphol



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By

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This thesis is confidential and cannot be made public.

Preface

This thesis has been written as the final assessment towards the degree of Master of Science in Transport, Infrastructures & Logistics. I got the chance to do my graduation thesis at Schiphol, department Cargo, on the subject 'development of new air cargo warehouses under footprint constraints'. It was a great opportunity to apply all knowledge derived during the courses of the bachelor and master program.

It would not have been possible for me to carry out my research without the support of my supervisors. Firstly I would like to thank Hendriena Ritsema, my supervisor from Schiphol. She enabled me to do my project at Schiphol Cargo and supervised me on a daily basis. I enjoyed our conversations, research related and also about our joint hobby. Second, I would like to thank my daily supervisor from the TU Delft Bart Wiegman for all his time and effort by giving me research inputs and by helping me structure my report. Last but not least, I would like to thank the chairman of my graduation committee Alexander Verbraeck and second supervisor Sander van Splunter. Although their time schedules were strict, both supervisors were always able to make time for me to help me solve my (urgent) problems.

I would also like to thank all my friends that helped me out during my research, from checking my texts till cooking nice dinners for me. I apologize for my absences lately but I will make it up to you all soon!

Finally I would like to thank my family. They always supported me through the whole process in all possible manners. I admit that I was not always nice to them. Lucky for them that they live in Russia/Poland, so they did not have to experience my erratic behaviour every day.

I truly hope that this research contributes to the development of new air cargo warehouses at Schiphol. May this report lead to a more attractive air cargo handling industry!

Marlot Schoenmaker

Delft 25 February 2016

List of abbreviations

AAS	Amsterdam Airport Schiphol
ACN	Air Cargo Nederland
AGV	Automatic Guided Vehicle
AWB	Air Way Bill
BIP	Border Inspection Point
BUP	Build Up Pallet
CCC	Customs Control Centre
CPD	Central Pickup and Drop-off Point
CSD	Cargo Satellite Design
DGVS	Documentloos Goederen Volg System/ Documentless Goods Tracking System
ETV	Elevating Transfer vehicle
FLT	Fork Lift Truck
FTF	Fast Track Facility
IATA	International Air Transport Association
JIC	Joint Inspection Centre
PCHS	Pallet Container Handling System
SADC	Schiphol Area Development Company
SAL	Summiere Aangifte voor Tijdelijke Opslag/ Summary Declaration for Temporary Storage
SLA	Service Level Agreement
SRE	Schiphol Real Estate
SSC	Shared Service Centre
ULD	Unit Load Device
VOT	Value of Time

Management summary

Schiphol Group, aspires to grow its cargo volume to 3.0 million ton in the future. To successfully achieve this, handling capacity needs to be expanded by developing high performance cargo facilities that will fit within the restrictive area constraints at Schiphol. The expansion of the passenger piers has enforced the cargo facilities among the Romeo and Bravo platform to be relocated in the near future. A location at Schiphol South-East is earmarked for new build. The size of the new location is comparable to the current one, but needs to accommodate facilities with double the current cargo capacity. In order to be able to handle 3.0 million ton cargo. This research provides concept designs for these first line warehouses to be built.

Problem statement & methodology

Statement for this research is:

How to increase handling capacity using warehouse design variables under footprint constraints?

This report is structured as per the Engineering Design Process (EDP) (Khandani, 2005), which is applied in 3 phases:

1. Analysis current warehouse operations.
2. Literature study - generically applicable throughout the air cargo industry.
3. Case study Amsterdam Airport Schiphol – generic conclusions from the literature study applied to the objectives and constraints of the near term capacity expansion at Schiphol.

1. Analysis current warehouse operations

This research scope is limited to first line facilities (i.e., warehouses with direct access to the platform). A warehouse area can be split into three sections (Figure 1):

- Airside area: the area for storage of cargo that is ready for transportation toward the platform, or the cargo that has been offloaded from the aircraft and has been brought to the warehouse.
- Warehouse building: the physical building where the cargo actually is handled.
- Landside area: the area in front of the warehouse used for truck and car access.

High competition between ground handlers, the operators of the first line warehouses, results in low profits and closed information provision. The consequence of this is the inhibited development in an already conservative sector (Ritsema, 2015), which complicates commitment in innovation projects. It is therefore important to involve ground handlers in the warehouse design process in order to create support from the air cargo industry. After all, the success of the cargo ground handling at Schiphol relies on the ground handlers work and commitment

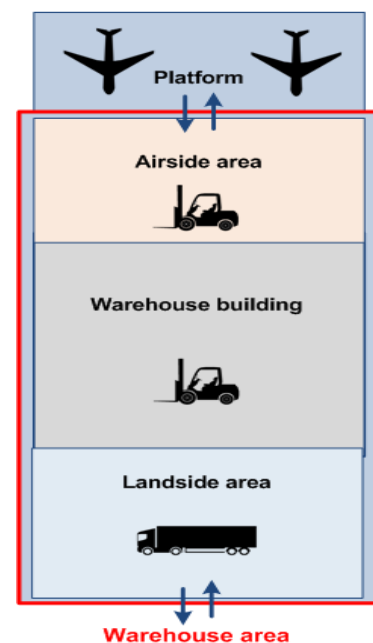


Figure 1 Three sections of the warehouse area (Author, 2016)

2. Literature study

Two factors drive the warehouse layout: costs efficiency and footprint reduction. Two dominant cost efficiency factors are of influence on the warehouse shape:

- Minimization of internal transport (Cusumano, 1994).
- Avoidance of corners in and around warehouses to optimize productivity (Bartholdi & Gue, 2004).

Together these two factors lead to an I-shape as most optimal warehouse shape.

Airside footprint reduction can be achieved by removing the buffer function and store buffered ULDs in the warehouse. Another option is an off-airport empty Unit Load Device (ULD) storage. However, this appears to be an expensive solution with relatively small impact on the footprint reduction.

Increasing the number of warehouse layers goes along with the mechanization level. These variables have major influence on the footprint productivity, as floor surface is enlarged and height is better utilized. The last recommendation to reduce the warehouse footprint is to create a Fast Track Facility (FTF) outside the warehouse area, enabling large volumes to be transhipped over the first line in a more efficient way (Kallen, 2015).

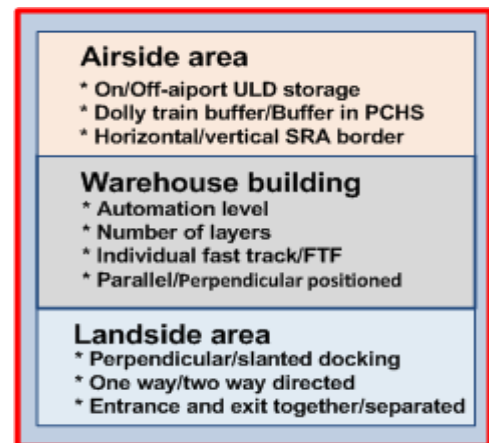


Figure 2 Warehouse design variables of influence on footprint reduction (Author, 2016)

The landside area footprint can be lowered by elimination of bottlenecks. This can be achieved by separating the truck entrance and exit and provide a one way road, to reduce truck crossing lines. Slanted docks have significant influence on footprint reduction. However, slanted docks complicate the unloading process and are therefore only recommended under extreme ground scarcity conditions.

3. Case study Amsterdam Airport Schiphol

For the Amsterdam case study several warehouse alternatives are created which comply with the previous warehouse requirements. The alternatives vary on the mechanization level, as this is determinative for the handling capacity (Districon, 2015); (IATA, 2015). Along with the mechanization rate goes the number of warehouse layers (Districon, 2015), varying from 1 till 3. The alternatives are visualized in Figure 3.

Alternative 1: the basic warehouse design is the least advanced option with a mechanization rate comparable to the current Schiphol situation. All operations are on the same level, also in case of the multi-level building (horizontal separation between the layers) to meet the objective: operational handling flexibility. To increase the handling capacity a manual operated FTF has been implemented, to meet the flexibility objective.

Alternative 2, the semi-advanced warehouse design, is more advanced in a way that all warehouse operations are divided over two levels, with truck supply on the first floor. This design requires more mechanized solutions to capture vertical transportation.

Alternative 3, the advanced warehouse design, is advanced in a way of a fully mechanized 3-layer warehouse for the handling of general cargo (WH1), to meet the productivity objective. However, this alternative still requires a handling solution for specials (WH2). Seen from the platform is the specialties warehouse is located behind the high mechanized general cargo warehouse. To realize even more capacity an automated general FTF is also implemented. The handling operation in this alternative is spread over three locations: general cargo warehouse, specialties warehouse and the FTF.

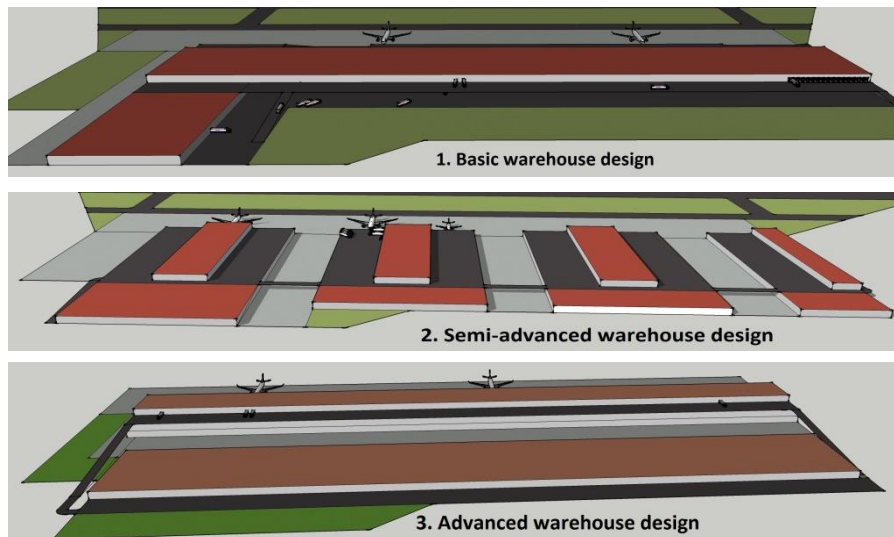


Figure 3 Visualization of the three alternatives. Top left: Basic designs, top right: Semi-advanced designs and under: Advanced design (Author, 2016)

The alternatives are reviewed on the basis of KPIs, divided into four important KPI categories, derived from literature (Cai, Liu, Liu, & Xiao, 2009); (Samson, 2015): productivity, financial, flexibility and Social Corporate Responsibility. The results of this analysis are presented in Table 1. Remarkable is the footprint productivity of the basic design compared with advanced design, as advanced design is designed with the concept of height optimization. The higher footprint of alternative 3 can be explained by the fact that it also includes a large ‘standard’ one layer warehouse. Another remarkable outcome is the score of alternative 3 on the equipment costs. The full automated warehouse of alternative 3 requires a lot of equipment. However, as the process is much faster than a manual operation, there is a relatively lower amount of equipment required for alternative 3. Alternative 3 scores the worst on both flexibility KPIs, as the operation is divided over 3 locations: FTF, General cargo Building and special cargo building. This increases the handling complexity and complicates rent ability of the warehouses.

For justifying the alternatives, different non-empirical validation methods have been performed, on the basis of answering three standard validation research questions (Wieringa, 2010):

1. Are the design alternatives correct? During the Phase validation by experts, the semi advanced design came forwards as not feasible due to the potential of blocking caused by dead ends in the designs.
2. Are the design alternatives sensitive for different contexts? This question has been answered on the basis of a robustness analyses. First the flexibility in building construction has been investigated. The basic design scores better in the way that it consists of more modules than the advanced design. The second robustness analysis that has been performed is about the adaptability on commodity

growth (general and special cargo). The advanced design is most robust on a general cargo as it is specialized in it. However, the basic design is more robust in the case of a growth in special commodities due to the total flexibility of the design (1 layer operations, with a low mechanization rate).

3. Do the design alternatives contribute to stakeholder goals? The semi advanced warehouse design does not contribute to the stakeholders' goals. The opinions about the Basic and Advanced designs are mixed. All stakeholders realize the importance of proven concepts and warehouse flexibility. However, sticking to a standard design could have negative consequences on the future competition position.

Case study evaluation

The case study did not have the desired outcome. Therefore a new alternative has been set up: alternative 3-light. This alternative combines proven concepts with positive feedback of experts: low mechanization rate and total handling operation in one building (Figure 4). The KPI result of the basic, advanced and 3-light warehouse designs are presented in Table 1.

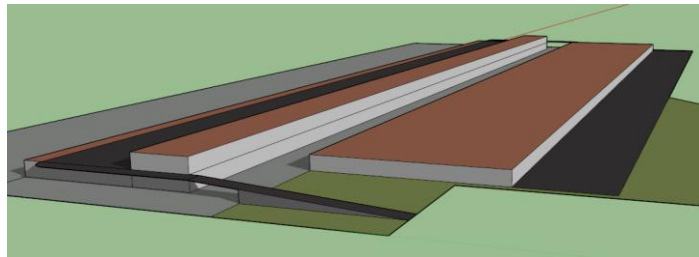


Figure 4 3-Light design (Author, 2016)

Table 1 KPI scores for three mechanization levels alternatives (Author, 2016)

Productivity	1. Basic design	2.Semi-advanced design	3. Advanced design	4. Alternative 3-light
Total capacity per year	1,892,000 ton (+FTF:392,098 ton)	2,286,700 ton	2,152,960 ton (+FTF:392,098 ton)	2,254,000 ton
Total warehouse floor	189,200 m ²	228,670 m ²	234,700 m ²	225,400 m ²
Footprint productivity per year	10 ton/m ²	Multi-level 13 ton/m ²	Multi-level: 26 ton/m ² Single-level: 10 ton/m ²	Multi-level: 13 ton/m ² Single-level: 10 ton/m ²
Total warehouse footprint	119,200 m ² +FTF: 6,460 m ²	180,880 m ²	134,600 m ² +FTF: 2,200 m ²	182,800 m ²
Financial	1.Basic design	2.Semi-advanced design	3. Advanced design	4. Alternative 3-light
Building investment costs (SRE)	€ 205,585,546	€ 230,788,394	€ 225,063,270	€ 232,265,860
Equipment investment costs (Handler)	€ 23,845,000	€ 41,286,000	€ 25,123,800	€ 37,689,000
Rent price (year)	€ 22,704,000 FTF € 775,200	€ 24,573,000	€ 22,134,000 FTF € 775,200	€ 24,762,000
Flexibility	1. Basic design	2.Semi-advanced design	3. Semi-advanced design	4. Alternative 3-light
Handling flexibility	+	0	-	0
Rent flexibility	+	+	-	+
Social Corporate Responsibility	1. Basic design	2.Semi-advanced design	3. Semi-advanced design	4. Alternative 3-light
CO2 emission	0	-	+	0

The overall face validation of the 3-light design has been performed by H. Ritsema (Schiphol Cargo) and R. Bakhuijsen (Schiphol Real Estate). According to them is the 3-light design by itself a feasible design for Schiphol. The one-way directed landsides together with sufficiently wide ramps are

considered as positive design elements. However, Ritsema wonders how well a multi-level design will be adopted by the market (Schiphol's ground handlers) and if the used elements are proven technology in an air cargo environment.

Conclusions from literature

- The most appropriate warehouse layout is an I-shape parallel to the runway. However, when ground scarcity becomes more important it is recommended to rotate the warehouse 90°.
- Footprint reduction can generally be achieved by optimizing the process, outsourcing processes to a second line location and optimization height utilization (sweating the asset).
- Three general factors are important to take into account during by warehouse surface determination: Automation level, warehouse levels and market demand.

Conclusions from the case study

The stakeholder at Schiphol would like to innovate. However, only designed with proven design elements. This makes the 3-light design an interesting alternative.

Conclusion regarding the added value of this research to air cargo warehouse design literature

As there is not much literature available about air cargo warehouse designs, cross dock literature formed the basis. This study forms a contribution to literature by:

- Indicate distinctions between air cargo warehouses and cross docks, with corresponding differences.
- Provides scientific substantiation of existing warehouse designs.

General recommendations

- Investigate local influences which have impact on the existing productivity rates (e.g. existence of a fast track, import-export distribution).
- Study the impact of mechanization on operational costs, dedicated to the air cargo industry.

Recommendations for Schiphol

- Investigate how flexible renting arrangements between SRE and handlers could work at Schiphol.
- The last recommendation is to reconsider the possibility of purchasing ground of Mr. Poot, creating a rectangular lot for area A. It is recommended to investigate what prevails:
 - Take the current lot into account with the risk of a less flexible ground handling operations and more costly buildings *or*
 - Consider a rectangular lot, with an expensive land purchase, enabling a more appropriate warehouse layout for the operation as well for the building costs

In case of option 1 it is recommended to work out the basic and 3-light designs into further detail, using the basic design as a reference case and the 3-light design as an innovative design. If land acquisition is contemplated, the recommendation is to design new, less complex, schematic designs. However, the literature, non-case specific criteria and the design method of this case study still forms a good framework for potential new designs.

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1. Introduction

Schiphol is one of the largest airports in Europe, both in terms of passengers and freight. On the freight side it ranks third, with around 1.6 million ton cargo handled annually (Schiphol Group, 2016). The growth rate of Schiphol was significantly higher than those of its key competitors, the airports of Paris and Frankfurt (Osinga, 2015); (Seaburry, 2015). Key drivers for this success deemed to be: the large number of freighter operators active at Schiphol (currently over 25), the existing air freight connections with growth market China (de Wit, 2014) and the growing export to North America (Schiphol Group, 2016). Volume growth forecasts for Schiphol are therefore bright with expected growth towards 2.6 million ton cargo in 2025 and even to 3 million ton in the years thereafter (Ritsema, 2015). As 100% owner of Schiphol Airport, AAS (Amsterdam Airport Schiphol or Schiphol Group) is the sole provider of cargo warehouse infrastructure at this airport. Air cargo accounts for approx. 15% of the operational result (gross profit) of AAS (Osinga, 2015).

At Schiphol, upgrading passenger facilities (building of three new piers) will require relocation of the existing cargo facilities along the Romeo and Bravo platforms to Schiphol South-East (Figure 5). Furthermore, new cargo facilities should be able to handle twice the volume of today, to cope with the increasing cargo volumes. The only vacant area to accommodate these higher capacity cargo facilities is situated at Schiphol South-East. This lot allows a maximum warehouse length of approximately 2,200 m, which is comparable to the total length of the current warehouses. Hence a solution needs to be found to handle 3 million ton of cargo while keeping the same total warehouse depth and length.

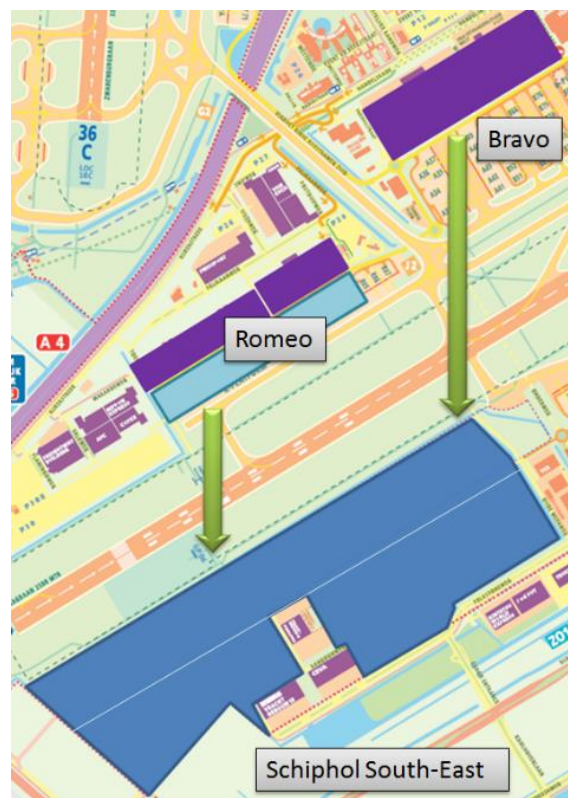


Figure 5 Schiphol map (Ritsema, 2015) edited by the author

1.2 Problem & Research Statement

At Schiphol ground scarcity forms the largest problem for first line warehouses (i.e. having direct access to the platform). Different concepts dedicated to Schiphol have been proposed to mitigate the pressure on first line warehouses. The Central Pick-up and Drop-off point (CPD) was studied by de Wit, Lubbe and van der Donk (2015). This concept assures a fast cargo throughput within the warehouse, by the direct

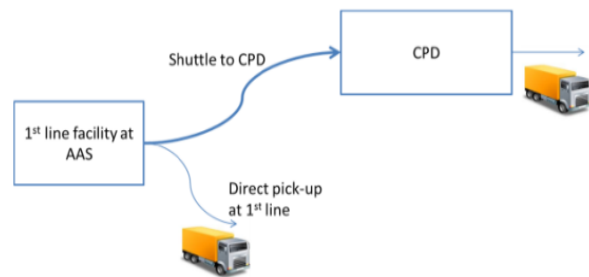


Figure 6 Central Pick-up and drop-off point (de Wit, 2015)

transshipment towards a CPD (Figure 6). A General Fast Track, designed by Kallen (2015), even enables the transshipment of Unit Load Devices (ULD's) from the platform direct to a location further away, without the need of first line warehouse. These studies have been done in order to achieve faster overall cargo throughput while lay-out and processes of first line warehouses have been left untouched. However, worldwide benchmarking data suggests that Schiphol warehouses still have room for improvement on these aspects (Antun, Lozano, Alarcón, González, Pacheco, & Rivero, 2010). One Schiphol-specific study has been performed by Vonk (2003) that focuses on the warehouse lay-out and internal processes. However, this research is partly outdated as the situation has changed in the meantime. In 2003 more surface at Schiphol south-east was available, as the buildings of Rhenus, Panalpina and Ceva were not developed yet. The focus of this thesis is therefore on the first line warehouses. The forced relocation and ground scarcity emphasize the need to investigate whether there are other warehouse designs possible. The following problem statement is therefore formulated:

***How to increase handling capacity using warehouse design variables under footprint constraints?
– A multiple actor scenario study***

To answer this question the following sub questions are relevant:

1. *What is an appropriate air cargo warehouse infrastructure layout?*
2. *Which footprint reducing design variables can be obtained from literature?*
3. *Which factors influence the required warehouse surface determination?*

Sub-questions applying to the Schiphol case study specific criteria:

4. *How do stakeholders drive the development of new air cargo warehouses?*
5. *Which warehouse configurations are feasible after applying local constraints?*

1.3 Contribution of this research

This research will focus on air cargo warehouses. Almost all airports over the world have to deal with scarcity problems regarding air cargo handling. This study will contribute to solving a practical problem on airports. However, this problem is also faced in many other fields. The practical outcomes of this research could therefore not only be applied to airports, but also on many other facilities, from ports to distribution centers.

An intended outcome of the study, on theoretical level, is to identify a preliminary set of warehouse concepts, applicable in the air cargo industry. On practical level, the secondary intended outcome of

this study, is to design a warehouse concept based on the theory fitting the constraints of Schiphol and give an advice on the basis of a conceptual design for the future warehouse design at Schiphol South-East.

1.4 Research outline and methodology

In general two research methods could be applied carrying out scientific research: The scientific and engineering method (University of Canterbury, 2007). The scientific method is about understanding nature, understanding what *is* by observations and experiments, requiring a hypothesis that might offer a solution to the problem. The engineering method is about *creating* what *has never been* – Theodore von Karman (1945), with a design statement that identifies limiting factors and criteria for success (University of Canterbury, 2007).

For this thesis a new warehouse concept will be created and therefore the engineering method is most applicable. The five-step Engineering Design Process (EDP) adjusted from Khandani (2005) corresponds with the engineering method and will be used as framework for this research. The five steps are useful for structuring the problem in a systematic way from an initial problem to a comprehensive conclusion (Figure 7).

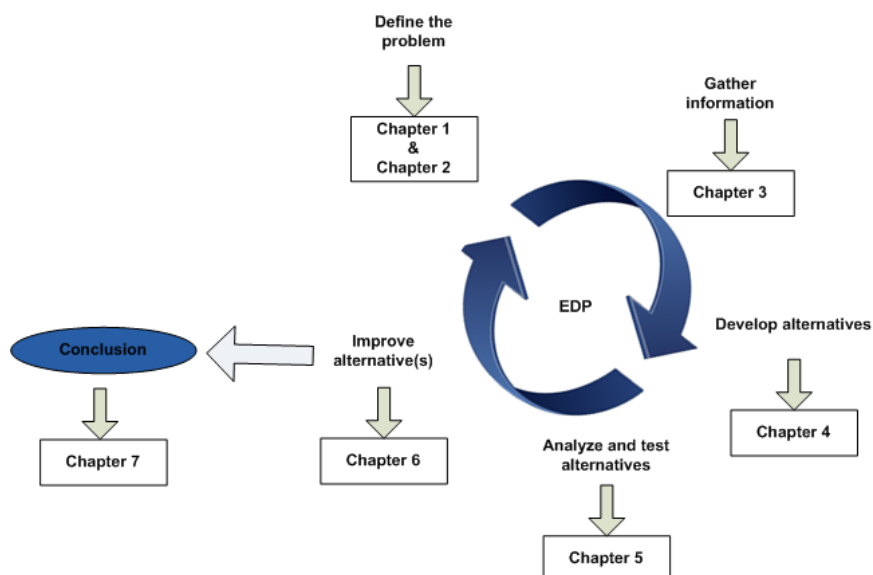


Figure 7 Research build up and with the applied methods based on (Khandani, 2005) edited by the author

As can be deduced from Figure 7 is the EDP a continuous framework, however due to time limitations this research will only perform one iteration. The last step is modified in “improve” instead of “test and implement” as Khandani prescribes. This modification enables design adjustments without going through the whole EDP loop again.

In Chapter 2 the research problem is defined and a general explanation of the position of air cargo warehouses is given. Chapter 3 contains literature research on the problem, matching the ‘gather information’ step of the EDP method. Solutions are developed in chapter 4, followed by an evaluation in chapter 5. Chapter 6 evaluates if design requirements are met in the “improve” step. Conclusions and recommendations in chapter 7.

2. The air cargo warehouse:

Definition, infrastructure, actors and processes

The value of time of cargo is important for the modality decision (Tavazzsy, 2014). The predominant decision variables in air cargo supply chain are speed and reliability, what differentiates the air cargo supply chain from most other supply chains (Unz&Company, 2008). This chapter will elaborate on the definitions, design and processes of cargo warehouses in a speed driven environment to describe the system environment of this research. Every section will start from a general point of view working towards a specific interpretation of the current situation at Schiphol. The current warehouses at Schiphol form the context of this study. In the final section of this chapter the real study object will become clear with an explanation of the base case for this report.

2.1 Definition and function of air cargo warehouses

The function of air cargo warehouses is to facilitate the airside-landside connection for cargo (Damme, Radstaak, & Santbulte, 2014). Warehouses physically located nearest to the apron, on the airside-landside border, are called first-line warehouses. Other warehouses without access to the airside are second line warehouses. In the end all cargo enters airside via a first line facility. The maximum handling capacity of first line warehouses is dependent on the available platform length, which makes the first line area scarce. The focus of this research is therefore, on first-line warehouses.

Cargo is secured within the warehouse under the responsibility of the ground handler. It is therefore required that the warehouse area is not accessible for unauthorized persons. The persons check is performed at the landside gate enabling the warehouse area a secured premises area. Before entering the platform all persons and equipment are checked, making the platform a total secured area, the so-called Security Restricted Area (SRA)-Critical Part (Lowijs, 2016). First-line warehouses are positioned between the airside and landside gates. The area between these two gates could be split into three sections (Figure 8):

- **Airside area of the warehouse** – the area for storage of cargo that is ready for transportation toward the platform, or the cargo that has been offloaded from the aircraft and has been brought to the warehouse. This area will be referred as airside area.
- **Warehouse building**– the physical building where the cargo actually is handled.
- **Landside area of the warehouse** – the area in front of the warehouse used for truck and car access. This area will be referred as landside area.

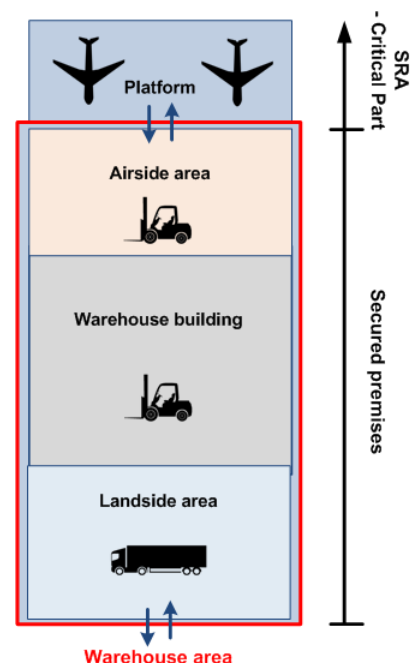


Figure 8 First line warehouse area between the landside- and airside gate, divided in three sections: Landside, warehouse and airside (Author, 2015)

2.2 Actors involved in the warehouse operations and their relationships

Different actors are involved in the warehousing process (Figure 9). Based on physical presence at the warehouse area or coordination function over the warehouse area the following actors are explained: AAS, ground handler, trucking operator and customs (Figure 10). For a broader view of the actors within the whole air cargo supply chain Appendix A2 could be consulted.

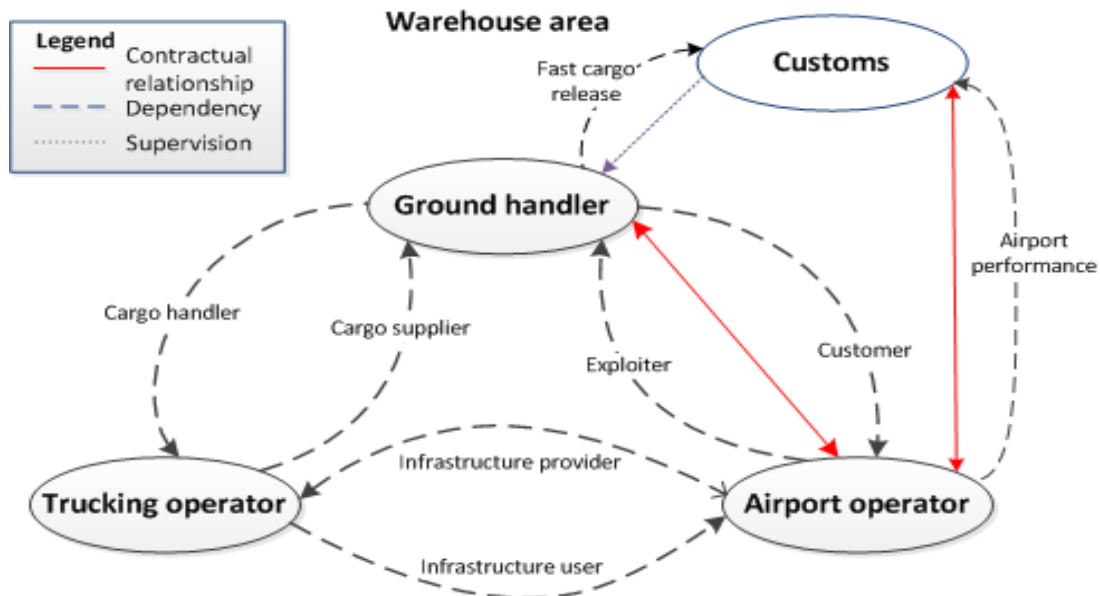


Figure 9 Actors active on and around the warehouse area (Author, 2015)

2.2.1 Active actors around warehouse area

An actor that is not involved in the physical cargo transportation is the airport operator. The airport operator is responsible for exploiting airport infrastructure of the warehouse area and its surroundings (Economic Development Board Metropoolregio Amsterdam, 2011). Airport operators are not keen on selling their ground. Instead, they rent their ground with buildings to third party ground handlers (Laurey, 2015). The success of the airport operator is dependent on the operational success of the ground handlers. Conversely, the ground handlers are dependent on the airport facilities developed and owned by the airport operator.

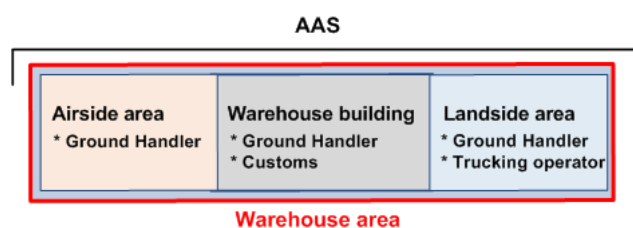


Figure 10 Actors in the warehouse process

Schiphol

For the purpose of this research the entire Schiphol Group is considered as (a group of) internal stakeholders. All other stakeholders are considered external. AAS is divided into three business areas: Aviation, Consumer Products & Services and Real Estate (SRE) (Figure 11) (Schiphol Group, 2015).

Aviation business area is responsible for service provision to airlines, ground handlers and logistics services. It is also responsible for the security coordination on the platforms and airside terrains of the warehouses. Schiphol Cargo, the problem owner in this research, is also part of the Aviation business area. Another department of Aviation which benefits from participation in the development negotiations is the department Security and Policy (S&P), responsible for the persons and equipment

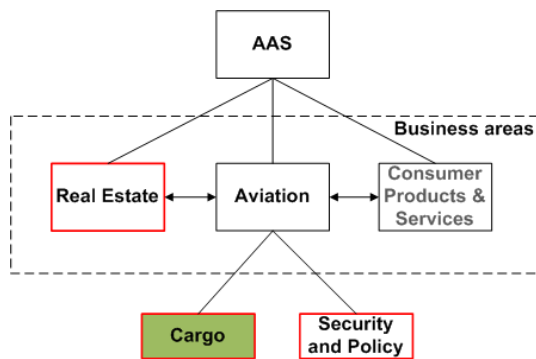


Figure 11 Schiphol Group business areas (Author, 2015)

check at the SRA border. The warehouse design on it owns is not of interest for this department, their main concern is the design of the SRA border. SRE develops and manages real estate at AAS ground, and is thus responsible for current and the still to be developed warehouse buildings. SRE owns 205.684 square meters of warehouses and exploits these to 7 different ground handlers. Only KLM, the home carrier, has her own warehouse, although the ground is still AAS property. Appendix D2 gives a broader explanation of the department within AAS.

2.2.2 Active actors on warehouse area

The role of a (third party) ground handler is to facilitate the transfer between landside and airside. This includes offloading of trucks at the warehouse docks. Trucking operators are in service of the airlines. This arrangement requires ground handler and trucking operator to cooperate without a contractual relationship. Although they have a common objective to make the transfer of cargo as efficient as possible, the absence of a contract forms in some cases a bottleneck in the handling process. Innovation in the cargo handling at landside requires support of both parties, what often results in the lack of a real problem owner and the willingness to invest in these projects.

Within the warehouse the cargo has to be secured. It is possible to already deliver secured cargo at the warehouse by the 'Known Shipper Concept' (Van Damme, Radstaak, & Santbulte, 2014). Other cargo should still be checked by customs at the airport. The arrangement is executed in different ways per airport. Collaboration between the airport operator, ground handlers and customs is necessary to minimize the disruption to the logistics flow. The success of the ground handling operation is among other dependent on the speed of the cargo security checks.

Schiphol

The local oligopolistic market offer great opportunities for (potential) customers, which are focused on the lowest shipment prices (Ritsema, 2015). The airlines are a relatively stable factor at Schiphol. They are able to switch between handlers every time their ground handling contract expires. This causes shifts between handlers. Resulting in high competition between the handlers, with low profits and closed information provision. The consequence of this is the inhibited development in an already conservative sector (Ritsema, 2015).

Air cargo in Western Europe mostly is transported by truck, due to relative small distances between airports. A dichotomy in trucking operators could be made regarding the destinations of the trucks. Truckers with destination one airport and its hinterland are referred as AMS trucking operators at Amsterdam. The other part of the trucking operator operates between airports, the so-called Road Feeder Network service (RFN), with the "trucking under a flight number" concept.

The customs' regime at Schiphol is attractive for (potential) customers. Dutch customs are world leader in cooperation with the industry (Schweig, 2015). With the Joint Inspection Centre (JIC), more cargo checks can be performed in a shorter period. (JIC is explained in section 2.4.2).

2.3 Equipment and infrastructure of air cargo warehouses

To understand the warehouse process, this section will explain the warehouse infrastructure and dedicated equipment. This will be done in a systematic way, according Figure 8.

2.3.1 Equipment and infrastructure at the airside area



Figure 12 from the left to the right: Dolly, mega-trailer truck and a pallet mover (de Wit, 2015)

The airside area of the warehouse is dedicated to airside equipment. In general, dolly trains are used as transportation modality towards the passenger aircrafts as belly freight. For the supply and (un)loading of full freighters pallet movers are used (Koet, 215). In exceptional cases mega trailer trucks are required for transport on airside. The airside area infrastructure should be flexible for the large variability of airside vehicles. The different airside equipment can be seen in Figure 12.

Schiphol

Although airside equipment is standardized, disparities could be observed in airside infrastructure at Schiphol. Most airside areas of the warehouses are restricted areas. After the SRA-check the restricted area-critical part could be accessed (the platforms). The SRA-check on this location offers opportunities for shared gates over more handlers Appendix A3. Menzies has the SRA border between the warehouse building and the airside area of the warehouse, what offers opportunities for a fast transshipment between the platforms and the airside area of the warehouse.

2.3.2 Equipment and infrastructure within the warehouse

Landside truck docks form the transshipment point between modalities. Trucks will be unloaded and the transportation will be taken over by forklift trucks (FLT). Handling speed is a key driver for warehouse capacity, handlers therefore try to keep the distance between the truck and aircraft as small as possible, according the lean principles to minimize the transportation distance within the warehouse (Jones, 2003). All cargo is placed in or on a ULD, visualized in Figure 13 and further explained in Appendix A1. An ULD for passenger aircrafts has a maximum height of 1.60m and an ULD for full freighters may be up to 3.20m high (Damme, Radstaak, & Santbulte, 2014). Special Working stations have to be available to ensure a safe working environment (Figure 13).



Figure 13 Air cargo container (left), pallet (middle) and a working station (right) (de Wit, 2015)

To ensure handling speeds extra process steps are avoided and therefore vertical storage is not common in air cargo warehouse infrastructure. Resulting in generally low warehouse structures compared with other types of warehouses. There are no strict height requirements for air cargo warehouses, but in most cases the roof clearance is between 6 and 9 meters (Schiphol Real Estate, 2003); (Airports Council International, 2013). However, automated systems are able to optimize the height, where manual storage is bound to the height restriction of the FLT. Automated warehouses need therefore more roof clearance than manual operated warehouses.

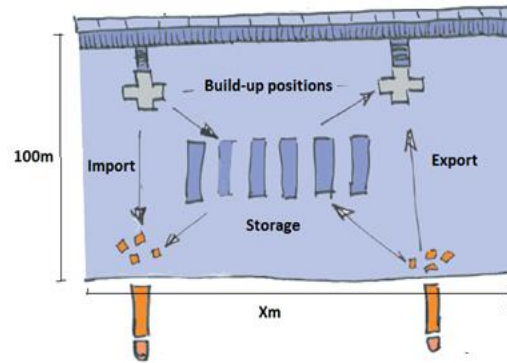


Figure 14 traditional warehouse dimensions; the depth and height are fixed (for the optimal process) Adjusted from (Vonk, 2003)

From lean principles the transport distance for the equipment within the warehouse should be minimized (Cusumano, 1994). Figure 14 zooms in on the process steps within the warehouse building. Taking all process steps into account, in practice this leads to an optimal warehouse depth of 100m (Kervezee, 2015).

Standard warehouses consist of one layer. More layers complicate the process and adds vertical transportation steps to the process. Nonetheless, if ground scarcity plays a major role, more levels could be added. This is done in the case of the warehouses of Cathay Pacific (Hong Kong), with 7 layers and British airways (London), with 4 layers. In principle this is possible on every location if the height restriction is not exceeded.

Schiphol

All warehouses at Schiphol consist of one layer. Some warehouses can be identified as Basic Cargo Warehouse as the operation isn't automated, investments are low and the administration is mostly done on paper (Berkelaar, 2014); (Bisschop & Rotteveel, 2014). As the main equipment within Basic Warehouses are FLT's, the roof clearance in a Basic warehouse is around 7 meters. However, it is not possible to store all cargo vertical manually¹, due to exceptional weight or dimensions. This leads to a dichotomy in the import and export buffer process. Export cargo is bundled making vertical storage not common (heavy and large dimensions). Contrary, import cargo is broken down, what makes it more appropriate for vertical storage. Thereby, the average storage time for import cargo is less than the storage time of export cargo. This results in different ground surface requirements. Kervezee indicates that due to the vertical storage the import side (Figure 14) of the process requires 1/3 of the export required surface.

The warehouses of KLM, Menzies and Aviapartner are equipped with an mechanized ULD storage, as shown in Figure 15, what could classify them as Mechanized Warehouse (Rotteveel & Timmermans, n.d). (Semi) automated warehouse buildings can be recognized by higher buildings, due to storage height requirements. However, there is hardly any height differences observable at Schiphol between the Basic Operational and the Mechanized warehouses, what could implicate that there is a

¹By Fork Lift Trucks (FLT)

lot unused height in the manual warehouses (Antun, Lozano, Alarcón, González, Pacheco, & Rivero, 2010).

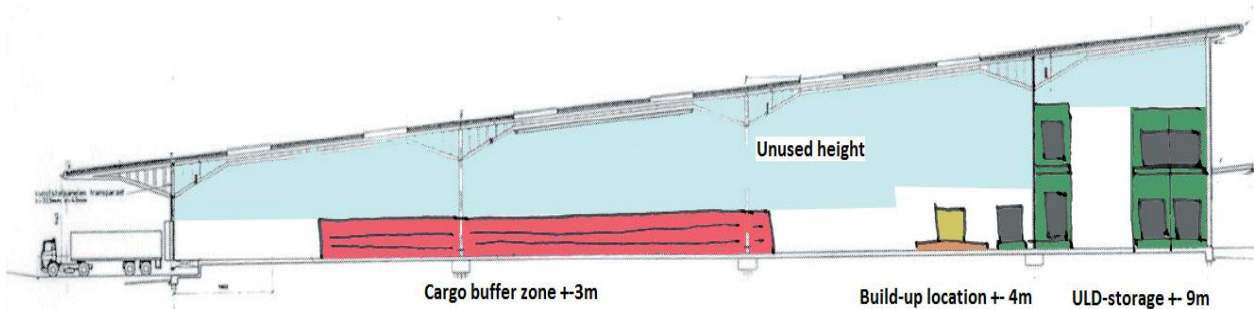


Figure 15 Warehouse of Menzies with automated ULD storage (de Wit, 2015)

2.3.3 Equipment and infrastructure at the landside area

The air cargo supply is done by trucks (Van Damme, Radstaak, & Santbulte, 2014). The landside area is therefore dedicated to road vehicles. The only way to enter the warehouse area is by passing the landside gate. For costs reasons (manpower) the landside gates form the entrance as well as the exit. The landside is two ways directed, with a lot of crossing movements between trucks, as a result of the combined entrance and exit. During peak times it occurs that all docks are occupied, which forces trucking operators to park their trucks on the landside area of the warehouses. For the optimal combination of the equipment states: docking, maneuvering and waiting, the flexibility of the landside terrain is assured by a flat concrete surface, only with marks in front of the docks. As the landside gate is the only entrance to the warehouse building, it is therefore also the entrance for employees and visitors. Separation of the trucks and cars is from safety point of view recommended, but due to ground scarcity problems not always feasible.

Schiphol

All equipment is equal at the landside warehouse areas at Schiphol, because trucks and cars comply with national and international legislation. Variables in the landside's infrastructure are possible; most handlers have a combined entrance and exit as described above, some other handlers even share their gate and thus their landside area, in order to save costs (Menzies, WFS, Freshport).

2.4 Processes at the warehouse area

As the warehouse process is adjusted on flight schedules, it has to deal with large fluctuations. For large international airports the peaks are in general in the morning, the time when the large intercontinental flights arrive. The import and export peaks alternate one other and will therefore never be on the same time.

2.4.1 Processes at the airside area

Export cargo, ready for departure, will be picked up at the airside terrain of the warehouse. In this stage the cargo is secured, however the driver and its equipment are not. The last check, which will be performed before entering airside, is the SRA-CP check. Every time the driver passes this border, he has to be checked, which on average takes 5 till 10 minutes (Eijk, 2015). For import cargo the SRA-check is not necessary. Import cargo is as well buffered at the landside area, before it will be handled in the warehouse.

2.4.2 Processes within the warehouse

After the truck is docked, the ground handler will unload the truck using Fork Lift Trucks (FLT). The unloading time is dependent on the filling rate of the truck and if the cargo is bundled or not. First the cargo will be placed on the extension area of the truck in the warehouse for the first check. Thereafter, the truck will leave the dock and the cargo will be transported to the assigned position in the warehouse. The position depends on the type of cargo, if the cargo is secured and the departure time of the assigned flight. An overview of different cargo types and their handling methods are showed in Appendix A5. Most delivered cargo is already secured due to the 'Known Shipper Concept'. The remaining cargo still has to be checked by the customs before further handling. The execution of the customs check is quite different per airport. In some cases the cargo should be physical present at the customs building, in other cases the customs will execute the checks on location. The departure time of the assigned flight determines if the cargo first should be buffered or that the ULD build-up can start. To optimize the weight and balances it is necessary that at the start of the build-up 70%-80% is present at the warehouse (Kervezee, 2015). When the build-up has been completed, the ULD is transported towards the airside area of the warehouse.

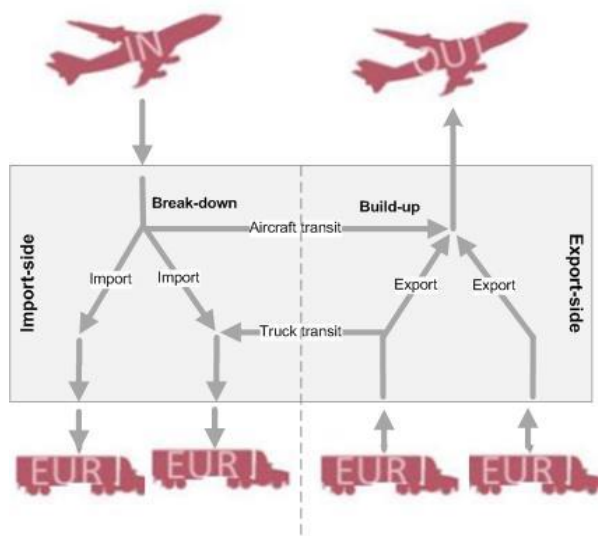


Figure 16 Cargo flows within the warehouse, based on (Bronsing, 2013)

Some ground handlers have a fast track in their warehouse. This is a track from the dock immediately towards the airside area. Precondition for this concept is that the trucking operator delivers or picks up a full built up ULD, a so called Build-Up-Pallet (BUP).

As explained above not all cargo under an airway bill number is actually transported by air. The modality decision is dependent on the network of the airline. Part of the cargo delivered to the warehouse by truck is also picked up by truck to complete the main transport leg. Air cargo may also be transported by two or more successive flights to arrive at the destination airport, with warehouse handling at each airport transit on the way. This is how different types of cargo flows are handled in air cargo warehouses. The flow patterns are visualized in Figure 16. The export process within the warehouse is visualized in Figure 17. Visualization of the import process can be found in Appendix A4.

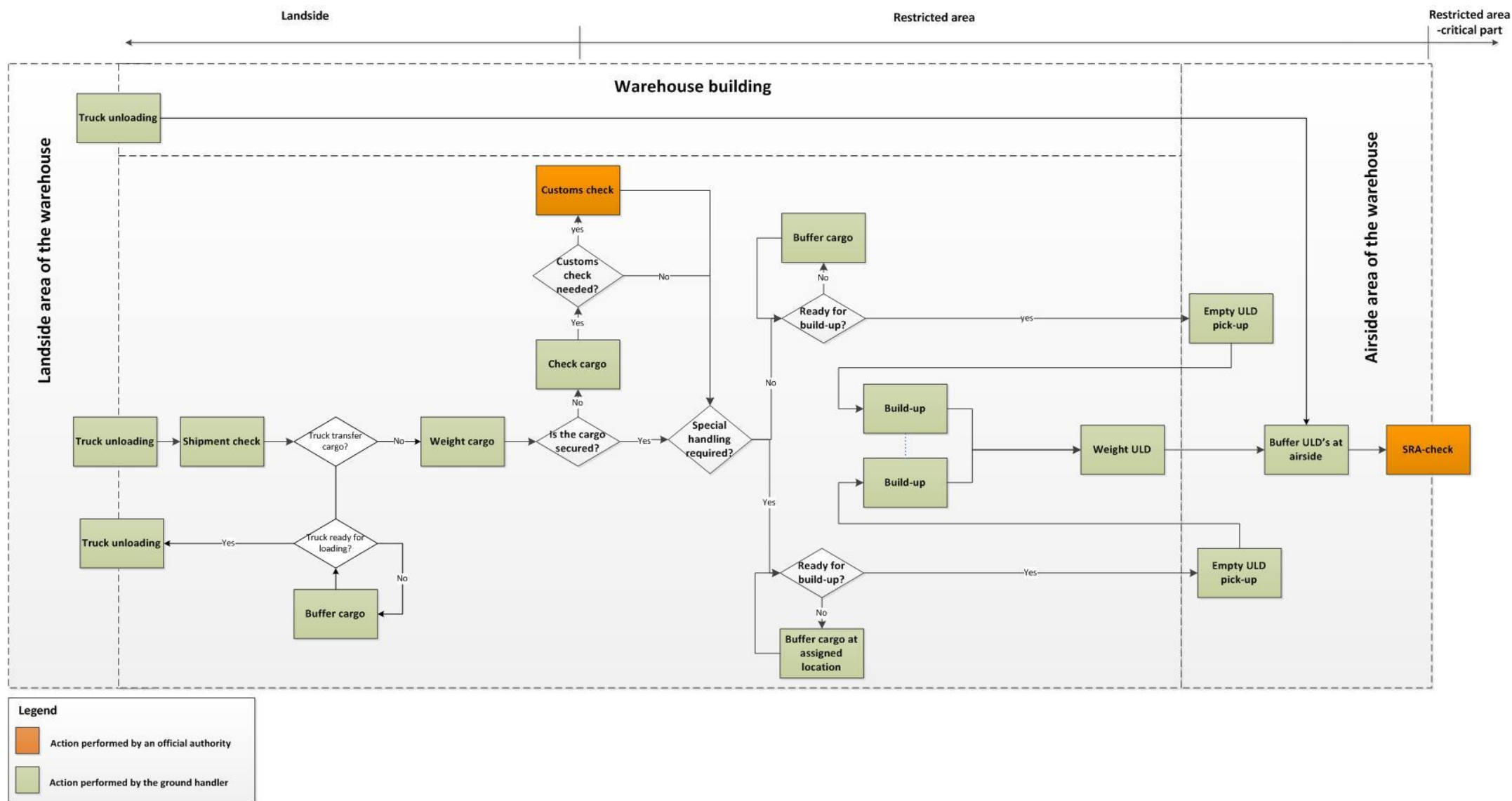


Figure 17 Warehouse export process (Author, 2015)

Schiphol

The customs process at Schiphol is remarkable. Amsterdam Airport customs are market leader in the cooperation with the ground handlers with their Joint Inspection Centre (JIC). Goods are monitored and controlled throughout the chain. Based on the cargo nature supervision can be determined. Checks at Schiphol can be executed with the aid of mobile scanners and a remote scan (ground handlers performs the check and the customs could watch via a camera) (Schweig, 2015). In this way minimal disruption to the logistics flow is created (Schiphol Cargo, 2015).

2.4.3 Processes at the landside area

The warehouse process is triggered when a truck arrives at the gate. After the trucking operator has permission to enter the landside area he has to arrange the documentation physically at the warehouse office. Some handlers assign a dock to a trucking operator at the gate. RFN operators tend to maximize the loading degree of the truck by bundling cargo of different handlers conform strict time schedules. Truck maximization is also the aim of the other trucking operators (AMS), however, they are not restricted to a schedule. These operators wait till there is more cargo to bundle. The RFN trucking operators cause with their business strategy high pressure on the land side terrain due to their multiple visits and the other trucking operators cause pressure on the warehouse due to the later pick up. The landside process is visualized in Figure 18.

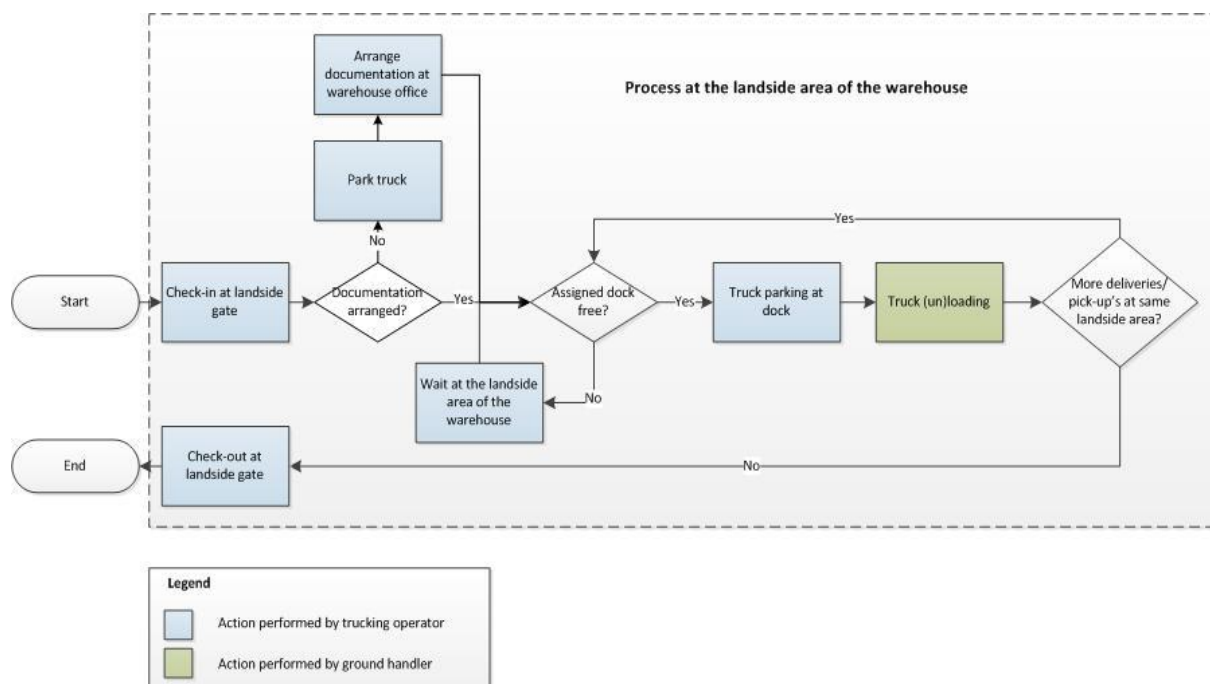


Figure 18 Export and import processes at the landside area of the warehouse (Author, 2015)

Schiphol

The warehouse landside areas at Schiphol are crowded with trucks. Two main explanations could be given for this phenomenon. First, trucks for air cargo transportation have on average low filling rates, due to the type of cargo and the strict schedules (Pieters, 2014). An important factor thereby is the lack of first line surface. Trucks have limited space for parking, loading and manoeuvring. During peak times, waiting trucks are blocking the trucks that have to manoeuvre for the docking stations, what disrupts the whole docking process. This could increase the trucking process time till 45 minutes extra (Kuiken, 2015).

2.5 Base case of this research – Schiphol Airport

In this chapter a general overview has been given concerning the definition, actors and processes of first-line air cargo warehouses. Problems where all airports have to deal with is limited space around the platforms and increasing cargo volumes, what leads to ground scarcity problems.

The focus of this report is on new warehouse designs, in order to respond on the growing scarcity problems at airports. This research is commissioned by AAS, what offers opportunities to take Schiphol airport as base case for this research.



Figure 19 Current length first line area (red line) and potential first line length (green line) (Author, 2015)

At Schiphol around 2570m first-line length is currently available, corresponding to the platform length. Figure 19 visualizes the current first-line length, indicated with the red lines. The green lines indicate potential first line ground, approximately around 1800m. The warehouses of KLM, Aviapartner and (part of) WFS should be relocated to Schiphol South-east (research object of this study). The available surface is given (33Ha) divided over two lots, A and B, separated by existing buildings (Figure 20).

Although the focus lies on the warehouse design, it isn't realistic only taking the warehouse building into account, as the total surface should be divided over the warehouse, landside and airside area. The total warehouse area will be taken into account in this research, but the building has the focus. The warehouse design on high level is important for AAS as exploiter of the facilities. Detailed arrangement within the buildings is in the hands of the ground handlers, and will therefore not be taking into account.

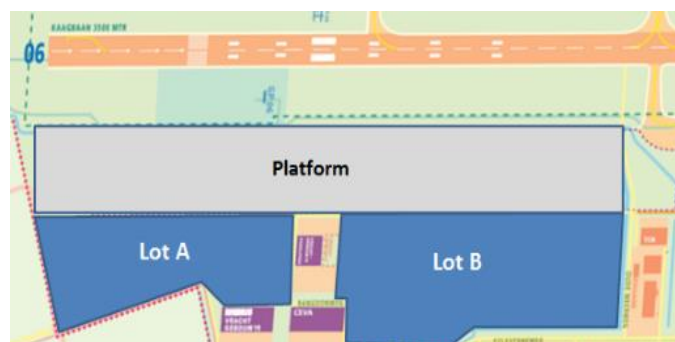


Figure 20 Research object: Empty lot Schiphol Southeast, with in the middle (purple) existing buildings (Author, 2015)

3. Designing an air cargo warehouse site:

A literature review

This study is based on the Engineering Design Process (EDP), as explained in the introduction. Chapter 3 elaborates on the 'gather information' step of the EDP, i.e. gaining information about the design and infrastructure of the warehouse. The design process comprises different process steps, starting from an aggregate level moving towards a more detailed level. As all design steps influence each other, the design process should be seen as an iterative process, with in each step a level of freedom for the design as well the opportunity to adjust the design (Leo, 2015). Figure 21 shows the relationship between the costs associated with design adjustments and the stage of the project at which these adjustments are introduced (Smith & Tardif, 2009). The cost of design changes in an earlier stage is smaller than those in a later design stage. This is explained by the fact that changes in a later stage cause re-work of earlier stages. To reduce the overall design cost (and overall project cost), it is suggested to shift the detailed design towards an earlier stage (front-end loading). Figure 21 shows the comparison between the traditional design process and the Integrated Project Delivery (IPD) process. In the IPD process the first two stages - the pre-design and schematic design - are the most important design phases. As the focus of this research is on the conceptual design, the first two stages of the IPD process will be addressed in this report. The conceptualization will be addressed in section 3.1. The output of conceptualization will form the input for section 3.2, what will elaborate on the second phase of the process design; the schematic design variables. Chapter 3 will end up with a synthesis; a conclusion for all three warehouse components and a method to combine the three areas into one schematic warehouse design.

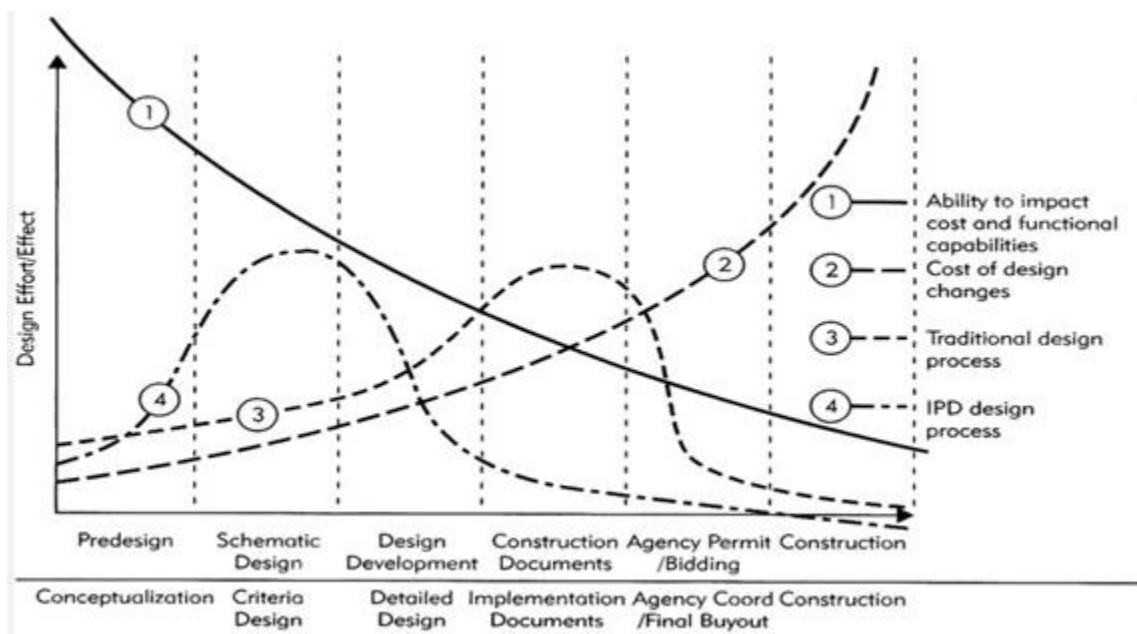


Figure 21 Traditional versus IPD workflows relative to design effort and cost of change over a project timeline (Smith & Tardif, 2009)

3.1 General warehouse performance measurements and evaluation

Goal of this research is to investigate several schematic warehouse design variables and their influence on warehouse capacity. Before considering warehouse design alternatives it is useful to determine in the pre-design important design criteria (Lowney Architecture, 2014). Section 3.1.1 elaborates on design criteria and how designs can be evaluated on the base of the set Key Performance Indicators (KPIs). The performance measurements and evaluation methods will form the input for the schematic design, section 3.2.

3.1.1 Performance and measurements of air cargo warehouses

In dynamic supply chains, continuously improving performance has become a critical issue to gain and sustain competitiveness (Cai, Liu, Liu, & Xiao, 2009). Proper selection of equipment, machinery, buildings and transportation fleets is a key component for the success of dynamic supply chains. However, the efficiency within the supply chain mostly depends on management decisions (Goa & Liu, 2014). Monitoring and improvement of supply chain performances has therefore become an increasingly complex task. Therefore, performance measurement is widely used in all type of sectors to help organizations to define and measure progress toward the organizational goals (Reh, 2015). The most important performance measurements on aggregate level are Key Performance Indicators (KPIs). KPIs give an overall indication of the respective system aspects concerning the company's strategy (Kaplan & Norton, 2000).

Widely used KPI categories in supply chain management are: quality, time, costs and flexibility (Cai, Liu, Liu, & Xiao, 2009). As part of the air cargo supply chain these KPI categories could be converted to air cargo warehouse specific KPIs. However, the KPI categories time and quality are into too much detail for performance measurements retrieved from a schematic design. There is one more important KPI category dedicated to air cargo warehouses: productivity; to quantify and compare warehouse performance with competitors (Ankersmit, 2013).

Traditional reporting on financial and operational performance is expanded by taking social and environmental performance into account. Corporate Social Responsibility (CSR) holds an important place in annual reports and has never been so present in the corporate strategy before (Samson, 2015). The European Commission defines CSR as "a concept whereby companies decide voluntarily to contribute to a better society and a cleaner environment" (Commission of the European communities, 2001). Increasing transparency and use of information technology are driving forces which make both consumers and organisations more aware of the planet's limit, the consequences of climate change and resource depletion (Samson, 2015). Porter stated: "The purpose of the corporation must be redefined as creating shared value, not just profit per se" (Porter & Kramer, The Big Idea: Creating Shared Value, 2011). The idea behind this theory is that the companies, who are able to create a win-win situation for both business and society, will have a unique competitive position and much more impact (Porter & Kramer, Strategy & Society. The Link Between Competitive Advantage and Corporate Social Responsibility, 2007). Airports are also benchmarked by the Airport Carbon Accreditation. Air cargo operations are included in this benchmark, what emphasizes the importance of taking CSR into account in the performance measurements of an air cargo warehouse.

3.1.2 Performance measurement evaluation

Once the Company specific KPIs are established from the given KPI categories, the performance of a company can be evaluated. This is often done by the aid of Multi-Criteria Analysis (MCA) models. Multi Criteria Decision Making is a study of methods by which conflicting criteria can be formally incorporated in the decision-making process. It structures and rationalizes the decision by mapping criteria and alternatives against each other and provides the decision maker with an integral overview of the current trade-offs (Ragsdale, 2011). However, these measurement models have their limitations for supply chain and thus also for warehouse performance evaluations. Firstly, there are too many individual measurements being used in the context of the supply chain. Individually these measurements form valuable information for decision making, selection and making trade-offs. However, obtaining effective and crucial strategy information from different measurements is a difficult task for different supply chain participants (Cai, Liu, Liu, & Xiao, 2009). Secondly, these models do not provide definite cause-effect relationships among numerous (and hierarchical) individual KPIs. Although existing models do illustrate the cause-effect relationship between different goal-related KPIs, they are inadequate for quantitative analysis of intricate intertwined relationships. Traditional Balanced Score Card (BSC) and scoring models generally assume that KPIs are uncoupled (Martinsons, Davison, & Tse, 1999). The Analytical Hierarchy Process (AHP) is a tool that solves problems of performance metric trade-offs by weighting the importance of different KPI. This approach provides a quantitative decision making tool for linking the scorecard's KPIs to the overall mission, objectives and strategies (Liberatore & Miller, 1998). However, by using the AHP approach, only the weight or relative importance of individual KPIs is determined, but the relationships amongst KPIs and their role to accomplishment efforts are not established. The latter, are very important factors for continuous supply chain performance improvement in a dynamic environment (Cai, Liu, Liu, & Xiao, 2009). The theoretical foundation of the AHP model is criticized because it could reverse in decision-makers' preference because the pairwise comparison matrix fails to perfectly satisfy the consistency required by the AHP approach. AHP model uses the weight only for the relative importance identification, but it does not specify the relationship among KPIs and their role in accomplishment.

It cannot be categorically stated that the air cargo warehouse KPIs are uncoupled. E.g. operational flexibility could be achieved by doing the whole operation manually, however this could influence throughput time and operational costs. In practice, most of the KPIs in a supply chain are correlated and have tangled cause-effect interplays (Kleijnen & Smits, 2003). There could be argued about the context of the cause effects between KPIs, but the presence of the cause effects could not be excluded. Another criterion for a well-defined KPI is that it should be measurable. In this way the criteria could be clearly interpreted and better compared with other criteria in a MCA or BSC (Panusuwan, 2008). However, not all stated KPIs are as good measurable. The KPI flexibility is not as quantifiable as the KPI cost. This leaves room for the researcher to manipulate the overall alternative rate (Roy, 1995). These facts complicate an overall alternative measurement and it is therefore recommended to compare KPIs between alternatives on an individual level. In that way individual KPIs could be compared to standard ratios, for example the IATA productivity ratio, or with performance indicators of other warehouses (benchmark). The KPIs which are not measurable (flexibility) could be compared qualitatively (Wieringa, 2010).

3.2 Air cargo warehouse area design variables

The Engineering Design Process model is used as framework for the overall design process, however, for the schematic design specific for a warehouse, a more detailed framework is required. Most of the frameworks dedicated to the schematic design have the focus on software usage, as BIM and AutoCAD. But the use of software is not required for the schematic design. For this research the framework of Gu et al. is used, which focuses on the different elements in a design that are relevant for the schematic design phase. This framework works from an aggregate level towards a more detailed level in the following steps: overall warehouse structure, warehouse size and dimensions, department layout, equipment selection and operational strategy (Gu, Goetschalckx, & McGinnis, 2007). The latter two components of this framework are out of scope of the airport operator. However, equipment selection could have a major impact on the warehouse design and attractiveness for ground handlers to hire the warehouse building. Therefore options for equipment selection and operational strategy must be included in the warehouse design framework.

In this 3.2, the schematic design phase is discussed, starting from the airside area, through the warehouse itself and ending up at the landside area. Each of these three areas are examined in accordance with the framework of Gu et al., focusing on the following three aspects: structure, dimensions and dedicated equipment and layout.

3.2.1 Schematic design variables of the airside area

Airside area structure

Main function of the airside area of the warehouse is buffering ULDs, which are ready for pick up or which are delivered, and the storage of empty ULDs. Not much literature is available on this subject. Nevertheless, the airside area function can be compared with the function of a storage yard in ports, used for in and out going (full) container storage (Adisasmita, Mislihah, Samang, & Sitepu, 2012). Containers at the storage yard will be stored longer on this location, where the actual storage of air cargo will be done in the warehouse. However differences between air cargo warehouses and container terminals are fading on a macro level as the functions of either tend increasingly towards transitory sorting facilities in which low inventory is held and throughput speed is high (Bronsing, 2013) and both operations have to deal with the storage of empty ULDs and containers respectively.

Required airside dimensions and dedicated equipment

Generally the length of the warehouse is equal to the length of the airside area, and traditionally they are I-shaped, positioned parallel to the runway. However, this shape is not obligatory. The cargo buffer should be sufficiently wide to park a dolly train of six dollies, the maximum length of a dolly train. To reduce footprint, slanted dolly parking is recommended (Figure 22). Total surface required for the airside is dependent on the average buffer time of the cargo on airside. The required total surface can be determined by the number of dolly trains arriving per (peak) hour multiplied by the average buffer time. The longer the buffer time, the more airside surface required.

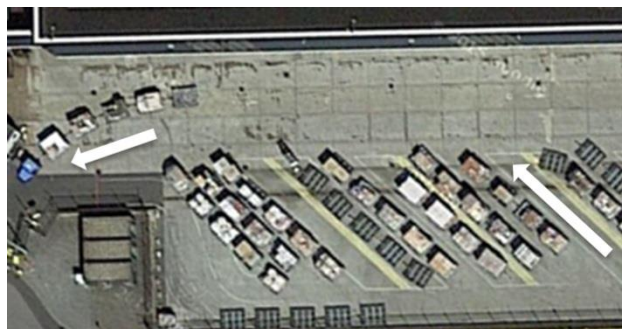


Figure 22 Slanted dolly parking on the airside area of the warehouse. (Google Maps, 2015)

Moreover, in this process the import and export flows alternate each. In general the airside area depth equates to 30-50m (Districon, 2015). Export wise the airside depth could be reduced by buffering the ULDs in the warehouse longer. This can be enabled by buffering the ULDs in the PCHC in such way that a dolly train can drive by and enable immediately dolly train loading. This method requires a PCHS output on the same level as the dolly train. This method is also applicable for import flows by immediately unloading the dolly train and store the ULDs direct in the HTCL, but it requires that all ULDs should be buffered/go through the HTCL system, demanding more ULD locations in the HTCL system. This ULD buffer method is already applied in the HACTL terminal in Hong Kong (Ho, 2010).

The design for empty ULD storage has various degrees of freedom. As these ULDs do not carry specific cargo, the LIFO (Last In First Out) may be used. This opens the option for vertical storage. The only discriminating attributes to be considered are the dimensions and the owner (airline operator). Containers have a height around 3 m and can be stacked. A FLT can stack two containers, a mechanized system is able to stack up to any height restriction of the warehouse. The latter option obviously reduces the required footprint of the airside area of the warehouse. As ULDs are standardized and empty, an automatic storage system is relatively easy to implement.



Figure 23 Triple deck empty container storage (Laxmi Engineering, n.d.)

Although, it can be questioned whether empty ULDs should be stored on first line ground. A known concept in ports is the off-dock container yards (Tarkenton, n.d.) or even storage of empty containers at inland terminals (Mol, 2007). For the empty ULD supply could be looked at the off-airport CPD concept of de Wit (2015). For the CPD supply shuttle service were suggested, but this way of supply could form problems for the landside terrain concerning congestion. A more innovative direction could be an underground empty ULD supply, which is not dissimilar from an Underground Logistic Systems (ULS). This concept combines the advantages of taking traffic movements underground with economic advantages as unimpeded automated transport over dedicated infrastructure. But on the other hand completely new underground infrastructure must be provided, which requires high investments.

For Schiphol a project was investigated for the underground supply of general cargo over longer distances (as far as 100-200km). This project never materialized. The main barriers for this concept at Schiphol came from the potential users, who generally doubted the reliability and speed of this ULS solution. Although ULS variable costs are considered relatively low compared to existing modes, the investment proved prohibitively high (Konings, Pielage, Visser, & Wiegman, 2010). The ULS required support of many actors. However, it lacked a real, single problem owner. For this reason

underground ULD supply over a few hundred meters would be an order of magnitude easier to realize, but would also have accordingly smaller business impact.

Airside Layout

An important decision variable for the airside layout: The type and location of the SRA-border. All person and equipment which are crossing the SRA border have to be checked, an obligation from EU-legislation (Section 2.1). Although it might seem so, it is not obligatory to locate this border exactly between the platform and the warehouse airside area, which makes the SRA-border an important layout variable. To reduce congestion during checking, some checks designed as so called transfer points, where persons themselves do not cross the border but instead hand over the equipment (e.g. driving equipment) to already cleared person at the other side of the border. Relocating the border could even further simplify the check. Locating the SRA border between warehouse and the air side of the warehouse makes that all persons and equipment at the airside area are already checked which enables free access to the platforms. This is a strategy already used by some handlers at Schiphol (Eijk, 2015). This concept offers opportunities for ground handlers. However, this strategy requires that the airport operator provides SRA border check point at each individual warehouse, what increases the security costs for the airport operator.

The location of the warehouse relative to the SRA border is decisive for the determination if a warehouse is first or second line. The length of the SRA border defines the length of the first line ground which makes it a critical parameter concerning the determination of the first line length. An artificial shift of the SRA border more towards the second line would increase the circumference of the SRA border and thus the surface for first line ground. However, this enlargement could never be without restrictions due to ground scarcity and security issues concerning the SRA-border. Vonk (2003) elaborated on this concept with the Cargo Satellite Design (CSD), including single and double layer warehouses, shown Figure 24. Most innovative concept in this design is the horizontal SRA-border within the double layered warehouses, with floors dedicated to landside or airside. In the CSD the ground levels are dedicated to airside and upper levels to landside. As the ground surface is still airside, it is possible to shift the airside border further backwards. The single layer warehouse designs in the back could be compared with the traditional warehouses, and could be used for the handling of odd size cargo or by handlers which have too small an operation for a double layer warehouse. The CSD is visualized in Appendix A3 gives a broader explanation of the CSD.

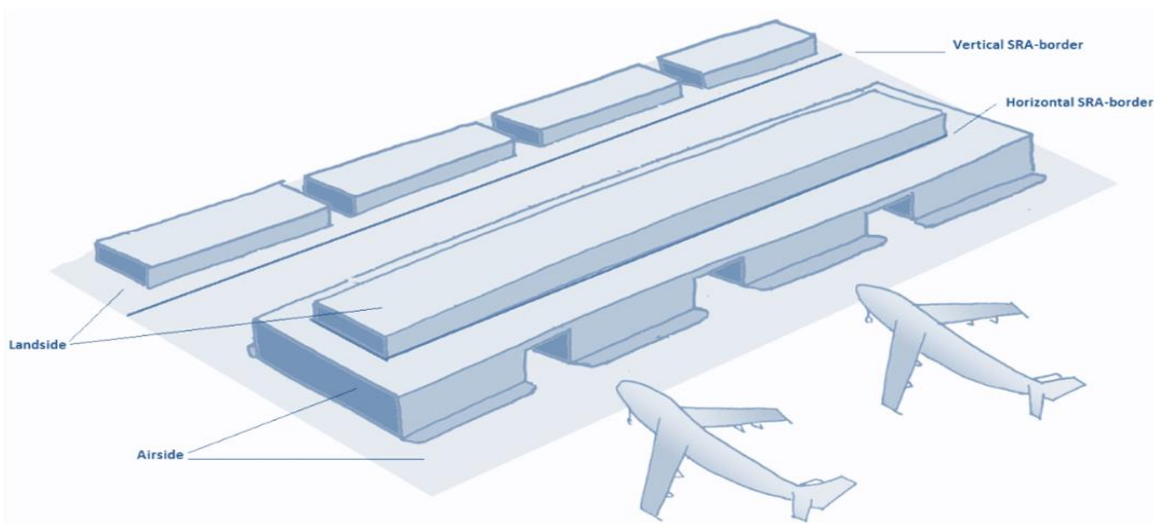


Figure 24 Cargo Satellite Design, adjusted from (Vonk, 2003)

3.2.2 Schematic design variables of the Warehouse

Warehouse structure

The type of warehouse is determined by the processing strategy. In general, the term warehouse covers a building that facilitates four major functions: receiving, storage, picking and shipping cargo (van den Berg & Zijn, 1999). Depending on the function, three basic warehouse types can be distinguished:

- Distribution warehouses
- Production warehouses
- Contract warehouses

The influence of lean management has led to the cross-dock concept, with as basic concept to transfer incoming road shipments directly to outgoing vehicles without storing them in between (van Belle, Valckenaers, & Cattrysse, 2012). Dealing with truck transport, large efficiency gains can be realized by stabilizing the vehicle arrival rates. An advantage of this concept is cost reduction due to the elimination of the most costly functions: storage and order picking. This concept requires less storage space and enables shorter delivery times (Bartholdi & Gue, 2004). The emphasis of an air cargo warehouse lies on the distribution; cargo from different suppliers to different customer (van den Berg & Zijn, 1999), which makes an air cargo warehouse comparable to a cross dock. The cross dock concept makes the term warehousing for an air cargo facility disputable. Although, they have the same objective: Fast cargo throughput. The shorter the dwell times in the cargo building, the higher the capacity will be, and so the higher the earnings can be (Bisschop & Rotteveel, 2014), cross docks and air cargo warehouses cannot be seen as identical. A temporary storage (buffer) should always be available in an air cargo warehouse to match imperfect synchronization between trucks and aircrafts. In addition, the preferred arrival rate of a cross-dock is stable (Bartholdi & Gue, 2004). At the first line warehouse the arrival rate is fluctuating due to the flight schedules (Pieters, 2014). These points are pitfalls that block a pure cross-dock implementation. The term warehousing will still be used for the designation of air cargo facilities.

Required warehouse dimensions and dedicated equipment

Height optimization; Storage requires the most height of all processes in the warehouse in general. The required warehouse height is therefore dependent on the storage process (Districon, 2015). Vertical storage offers opportunities to reduce the footprint to mitigate ground scarcity problems (Berry, 2007). Vertical storage by FLT's is limited due to safety considerations (Kervezee, 2015). The height utility can be improved by increasing mechanization rate of the storage process. An example of a full mechanized storage system is the Pallet Container Handling System (PCHS), shown in Figure 25. Next to the height optimization of a certain process is it also possible to increase the height utilization of the whole warehouse process by adding warehouse layers. This is against the lean theory, which emphasizes the importance of reducing internal transport distances (Cusumano, 1994). However, in air cargo warehouse design footprint reduction often takes priority over this parameter, despite the fact that it leads to higher buildings with increased (vertical) travel distances. This however can be mitigated by use of even

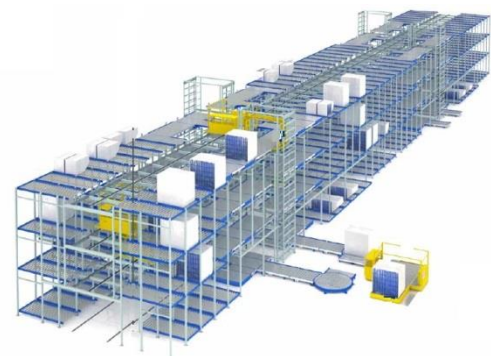


Figure 25 PCHS system for automatic ULD storage (Districon, 2015)

more capable and efficient mechanized transportation solutions. It can be stated that mechanization of the handling process enables height utilization and contributes to a higher productivity warehouse rate.

Surface optimization; Next to the height optimization, also the efficiency of warehouse floor space utilization can be increased. Material flow patterns have major impact on required warehouse surface and layout. For cross docks, which are strictly limited to handling inbound and outbound flows, the flow pattern may be one of the following: (appendix C1).

- straight through flow
- U-pattern flow
- Modular flow

(Nashville State Community College, 2011)

Generally in an air cargo warehouse all three of these patterns may be located within one warehouse building. The import and export flows each usually are of the straight through flow pattern. Truck and aircraft transfers are two U-flow patterns. Dedicated fast tracks within the handler's warehouse typically are of the modular patterns. For basic cargo and basic warehouse operations it is important to make the warehouse process so called "Poka Yoke" (fool proof), to avoid circulation problems (Factory Magazine, 1988). Many ground handlers have implemented Poka Yoke by separating the (straight through) import cargo and export cargo flows. This concept can be expanded to separating the U-flows for aircraft and truck transfers from these straight through flows. However, most warehouses still handle the transfer cargo in the same location as the 'normal' straight through cargo, increasing transportation distance and probability of errors. Separation of the flows contributes to the objective 'reliable warehouse operation' but does not necessarily contribute to the objective 'maximization of the ground utilization' as all flows need their own dedicated part of the warehouse. However, a flow separation that does contribute to the ground utilization objective is enabled by a Fast Track Facility (FTF). A FTF creates a total separated flow by bundling straight through import flows of different handlers in one facility (Kallen, 2015). As the FTF enables large volume handling on a relative low footprint, it is recommended to implement a FTF. However, there is point of concern as ground handlers are not keen on sharing facilities. The FTF is further explained in Appendix B2.

The Poka Yoke concept is not applicable on automated systems, as automated systems² remove mental labour. This creates options for handling import and export cargo making use of common infrastructure alternating. Thereby offers automation in the warehouse process even more benefits. Automatic systems are rapidly deplorable, reduce costs over manual operations and significantly increase the cargo flow rate within the warehouse (Loose & Walters, 2000). Theoretically it is possible to automate the whole warehousing process (for general cargo). However, the more degrees of freedom the harder it is to automate the process. Automation offers more flexibility in design, as flows do not need to be separated and distances are easier to cover. But in the handling

² Mechanization refers to the replacement of human power with mechanical power of some form. Mechanization saves the use of human muscles whereas automation saves the use of human judgement. Mechanization displaces physical labour, whereas Automation displaces mental labour as well. (SOMETECH, 2013)

operation itself automation reduces flexibility, e.g. handling of animals or odd-size cargo. A total automated air cargo warehouse therefore can hardly be classified as an all-purpose warehouse.

Mechanization and automation increase the handling capacity and thus the productivity rate. It should be mentioned that automation is only possible as the process already is mechanized (Figure 26). The International Air Cargo Association (IATA) based their productivity ratio on the level of automation and thus also with a certain level of mechanization. The following categories are distinguished:

- Low automation level $5 \text{ ton/m}^2 \cdot \text{yr}$
- Medium automation level $10 \text{ ton/m}^2 \cdot \text{yr}$
- High automation level. $17 \text{ ton/m}^2 \cdot \text{yr}$

(IATA Airport Development Reference Manual)

This ratio, merely based on tonnage and the level of automation, seems to be accurate. However, research under the eight largest cargo airports in Asia (2010) tried to disprove the accuracy of this ratio. The outcome was that there was only one cargo warehouse with a capacity rate as high as $13,2 \text{ ton/m}^2$ warehouse surface even the most high level automated warehouse HACTL had a lower productivity rate than 10 ton/m^2 warehouse surface (Antun, Lozano, Alarcón, González, Pacheco, & Rivero, 2010).

In a more recent study, Districon did not make a distinction between different levels of automation, but instead recognized the number of warehouse layers. This number can be used as an indicator for the mechanization level because mechanization in warehouses is usually implemented to cover vertical transport (Districon, 2015). Both ratios are based on a certain level of warehouse mechanization (Figure 26). For medium automated one-layer warehouses the ratios are aligned, but with increasing automation levels and warehouse layers the ratios begin to diverge, shown in Table 2. Rotteveel stated that by e.g. doubling the number of layers it cannot be assumed that the capacity will double too, as the IATA ratio implies (Rotteveel & Timmermans, n.d).

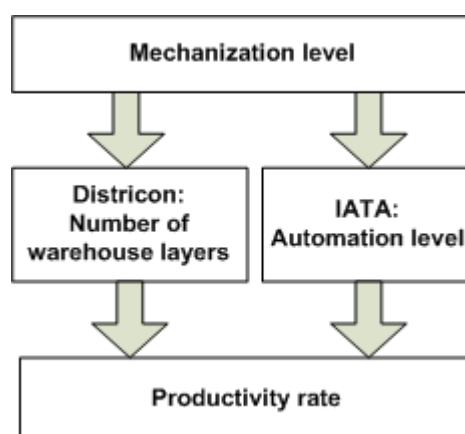


Figure 26 The productivity rate variable of Districon and IATA with both mechanization level as basis (Author, 2012)

Table 2 IATA ratio compared with the Districon ratio and actual productivities (Districon, 2015); and adjusted from (IATA, 2015)

IATA		Districon		Field data
Automation level	Footprint capacity* [$\text{ton}/\text{m}^2 * \text{yr}$]	Number of warehouse levels [$\text{ton}/\text{m}^2 * \text{yr}$]	Footprint capacity $\text{ton}/\text{m}^2 * \text{yr}$	Actual capacity [$\text{ton}/\text{m}^2 * \text{yr}$]
Low automation level	5	-	-	
Medium automation level	10	One layer	12	9
High automation level.	34	Two layers	28	17
	+ 17 ton/m ² per level	>two layers	39	No represented set

*The IATA ratio is modified in this table. High automated warehouses generally consists of more layers, therefore is the high level automation straightened with the two or more layers of the Districon ratio. IATA takes for high level automation 17 ton/m²/year into account, what comes down to 34 ton/m²/year in a double layer warehouse and +17 ton/m² per level. e.g. 3-level warehouse has a footprint productivity of 17*3= 51ton/m² per year

It is remarkable that the field data does not stroke with the given ratios. That can be explained by missing factors in these ratios. Examining the air cargo demand side may offer an explanation for these lower actual productivity ratios. E.g. the IAG Ascentis building is highly mechanized and partly automated, designed for general cargo. The growth in demand however turned out to be in special cargo (Districon, 2015). Another example supporting this explanation is the better performing HACTL terminal in Hong Kong. This building was designed especially for general cargo and is indeed used for this purpose only which led to a much higher productivity ratio (and due to sufficient demand) (Districon, 2015). Market demand is an uncertain factor that impacts warehouse productivity estimation. Examining actual data of other air cargo warehouses worldwide may be useful to benchmark. A few international air cargo warehousing benchmarks are given in Appendix D6. Hence it can be concluded that it is important to take the following variables into account when estimating warehouse productivity:

- Mechanization and automation level
- Warehouse levels
- Market demand

Though, Rotteveel and Bisschops (n.d) observe that the resulting level of detail of the ton/m²-ratio cannot be used for justification of a business case, supported by the ACI which uses the IATA ratio only as macro benchmark (ACI, 2013). Factors like volume and handling procedures are not considered. E.g. an integrator handles large volumes and little weight compared to standard handlers, which, according to IATA ratio, leads to a low productivity of the integrator. However, the scope of this current research is optimizing schematic warehouse design, and to this end only all-purpose handlers are considered and the ton/m²/yr ratio is used as the key measure to evaluate solutions. Factors like weight/volume ratio and handling procedures could form additional information for a more detailed design.

Warehouse layout

An important principle in Cross dock layout designs is that corners reduce the efficiency due to lower usable space for (un)loading (Figure 27). Several studies underpin the I-shape layout as most useful layout due to the smallest across-travel distance and the least number of corners. But, the problem with I-shape warehouses is the fast increasing diameter when dock numbers are increased (Appendix C2). The more docks, the lower the efficiency expressed in terms of centrality (Bartholdi et.al, 2004). Other shapes (T, X), with more corners, become interesting if the total number of docks exceeds 150. However, in the air cargo industry to have such large dock numbers in one building is uncommon. E.g. Schiphol, the third largest cargo airport in Europe, counts 250 truck docks in total, operated by 7 handlers (Lubbe, 2015). A driver for several handlers to share one very large warehouse would be to increase centrality, to share resources more easily in order to increase the efficiency of each participant. In practice this seems unfeasible (Bartholdi & Gue, 2004); (Lubbe, 2015). Even the largest air cargo handling handler in Hong Kong has less than 150 docks in total (Ho, 2010). However, with growing air cargo volumes it is possible that the number of docks might exceed 150 in the future. But, the differences between cross docks and air cargo warehouses should be kept in mind. Cross docks have in general one flow, from inbound to outbound, and can therefore be seen as one large operation. On the other hand, air cargo warehouse operations handle more flows (e.g. import, export and transfers), which can be seen as two operations in one building. In a manual operated warehouse operation the import and export flows are separated, what divides the warehouse into two 'separated' processes, what decreases the number of docks per process. Therefore, it can be concluded that the I-shape layout will remain the best warehouse layout, even when the number of docks exceed 150.

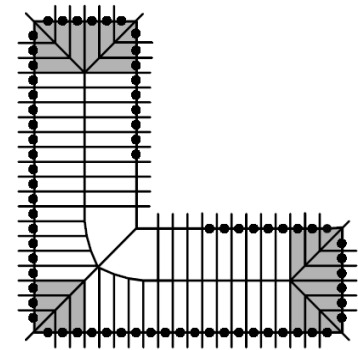


Figure 27 Cross dock efficiency reduction due corners in the warehouse (Bartholdi & Gue, 2004)

The considerations above are largely based on cross dock literature, assuming truck transport on either side of the warehouse. Hence the bias towards I-shaped warehouse layouts. Reality is that air cargo warehouses have aircrafts on one side. Therefore we should not be blind for alternatives, one of which is offered in Figure 28: a U-shaped design. The warehouse will be built around the platform. This layout better utilizes the excess width of the land strip available for buildings and aircraft stands (platform). Truck docks of which many are required, are located on the outside of the U. Aircraft stands, of which there are fewer, are placed on the inside of the U. The truck dock area is enlarged and the distance to the aircrafts is still minimal. This layout has a negative influence on the flexibility within the warehouse (according the centrality principle). Moreover a likely challenge is the distribution of the aircraft stands over the handlers, as there are relative few stands. The trend that ever more cargo is transported by passenger aircrafts would reduce this problem (Appendix D3). However, the aspiration of Schiphol to grow to 3 million t cargo annually, would likely still result in a net increase in number of full freighters to be handled (Ritsema, 2015).

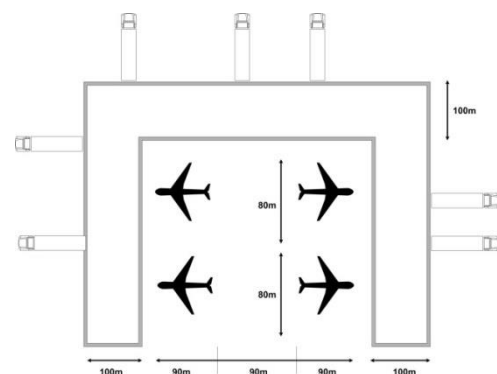


Figure 28 U-shape cargo terminal (Author, 2015)

Next to the warehouse layout options it is also useful to investigate the warehouse orientation relative to the runway. Traditional warehouses are built parallel to the SRA-border line to minimize truck-aircraft distances. This however results in a large ground surface occupation on the scarce first line ground. An important question is which parameter should carry a higher weighting, truck-aircraft distance or first line footprint?

3.2.3 Schematic design variables of the Landside area

Landside structure

The main function of the landside area is to enable the warehouse supply by trucks. There is not much literature available explicitly addressing the landside area of air cargo warehouses. However, the landside area of an air cargo warehouse has the same function and processes as landside areas of ports and cross docks as they all have to deal with supply by trucks. Few benchmarks of airport landside areas are available.

Required landside dimensions and dedicated equipment

The main design objective for a landside area under surface constraints is footprint reduction. The size and dimensions of the landside area are dependent on the productivity within the warehouse. The required number of docks can be estimated in a simple way by using Little's Law, i.e. multiplying the required throughput of trailers by the average (un)loading time (Bartholdi & Gue, 2004). This method is not accurate enough when taking data over longer period, due to high peaks. To avoid recurring capacity shortfalls, the number of docks should be based on the peak time data. The ratio between dock numbers and warehouse size as per the Air Cargo Guide of the ACI is 0.3 truck docks per 1,000 sq.ft. (approx. 100 m²) of warehouse floor area. However, due to the enhanced truck utilization in America, the planning factor of 0.6 docking stations per 1,000 sq.ft. The ACI states that this ratio is not a substitute for obtaining more systematic data (Airports Council International, 2013). The ratio is not accurate enough, because the surface of the warehouse is not the only factor that determines the productivity (shown in section 3.2.2). In general the whole landside façade could be docking area for truck. One important thing must be taken into account in landside layout: corners reduce efficiency. In the (inner) corner it is not possible to dock trucks at the same time as they would cross each other (Figure 29).

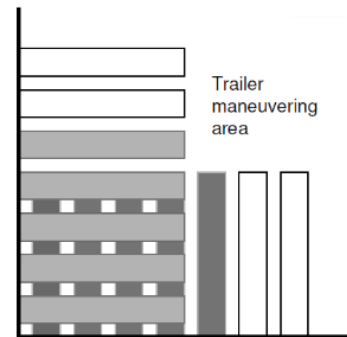


Figure 29 (Bartholdi & Gue, 2004)

Another way to avoid truck blocking on the landside area is to separate processes. To stimulate the truck flow and decrease crossing lines it is recommended to create one way truck flows on the landside area using separate entrance and exit gates. This will incur relatively little cost as it is not necessary to man the exit gate (Lowijs, 2016). Moreover, in this way landside areas can be shared by different ground handlers, to reduce security costs.

Generally 35 m till 40 m depth is required for docking and driving on the landside area (Districon, 2015). Extra surface is required for truck parking places, if needed. A concept used in ports to reduce the landside area footprint is the drop-and-hook concept: the trucking operator drops his trailer on the land side area, or an assigned location elsewhere, not occupying scarce land. Meanwhile, the truck picks up another trailer, if available (Tompkins & Harmelink, 2004). Parking trailers on the

landside does occupy scarce land, but at the same time provide free storage taking pressure of the actual warehouse storage space and facilitating planning of the trucking operation (“storage on wheels”). Parking trailers off site provide this free storage. However, this time without occupying scarce land. The drop-and-hook concept requires an additional process step for the ground handler: Pick up of the trailers. From the warehouse operations view, a more effective concept would be to handle trucks on request, a known concept in London Heathrow (Sanders, 2015). The advantage of the storage on wheels remains, but the ground handler does not need to add an extra process step to the ground handling operation. This concept requires more information sharing between the ground handlers and trucking companies, which is in the most countries not shared yet (Kuiken, 2015). But in the end it contributes to both processes; the ground handling process and trucking process.

Landside layout

The easiest way to accomplish a low footprint is to locate the docks as close as possible next to each other. Perpendicular docking is the standard as the linear structure of the façade requires minimum adjustments for docks, which makes it the cheapest and most easy editable dock structure. However, a large turning radius is required to dock trucks under a 90° angle. Less surface is required by docking under a smaller angle (45°), a common concept applied in the situation of ground scarcity problems (Sanders, 2015). Docking under a 45° angle only takes approx. 2/3 of the surface needed for Perpendicular docking, shown in Appendix C5. Precondition for non-perpendicular docking, in order to reduce the footprint, is the ability to leave the dock in the same direction as the truck has been arrived. Although this concept contributes to a smaller footprint, it has a negative influence on the (un)loading process within the warehouse. (Un)loading resources have to deal with a curvature in the process. Extra process steps add risks on damage (Koet, 215), what is against the lean principle to make processes fool-proof (Cusumano, 1994). Thereby, adjustments to the façade are required for the slanted docks, which increase the building costs. Slanted parking is therefore only recommended if straight docking is not possible.



Figure 30 Slanted docking, sight lines (Nova Technology, 2013)

A smooth landside operation could be created by a one way directed truck flow. But, there is another important design variable what should be combined with the one-way direction: separation of the entrance and exit. The importance of the combination of both concepts could be illustrated by an example of a warehouse at Heathrow. This landside design is designed as a horseshoe, with a one way direction, however with a combined entrance and exit. During peak times there are significant congestion problems in the horseshoe (Districon, 2015). By designing a one-way landside it is important to determine the best docking way. As the truck drivers are positioned on the left side, they have the best sight on the façade at the left part of the truck, shown in Figure 30. This should be taken into account by determination of the driving direction on side and thus the locations of the entrance and exit.

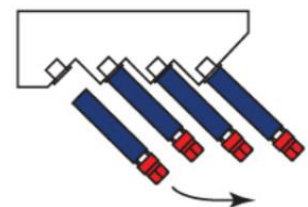


Figure 31 Slanted docking (Nova Technology, 2013)

3.3 Synthesis

In section 3.1, general KPI categories have been shown. Subsequently in section 2 schematic design variables for the three components of an air cargo warehouse are shown with an examination of their influences on the given KPI categories. These components should be combined to form a complete air cargo warehouse design. The following sections summarize recommended warehouse design variables (section 3.3.1) and a method is suggested to combine variables into a total warehouse design (section 3.3.2).

3.3.1 Applicable design variables

In section 3.2, various design variables have been discussed. This section shows recommended design variables which contribute to increasing air cargo throughput per ground surface per unit ground surface under footprint constraints. The recommendations given are based on ideal situations, as no local influences are taken into account (e.g. height restrictions, lot dimensions). The gross design variables are shown in Figure 32, following a description of these recommendations.

Airside area design variables

The function of the airside area is to buffer full ULDs and store empty ULDs. The following dedicated footprint reductive design variables emerged in section 3.2.1:

- Off airport storage is only recommended under extreme ground scarcity problems
- ULD buffer in PCHS is recommended with the prerequisite that the PCHS has enough capacity and is set to immediate (un)loading of dolly trains

Another design variable came forward, which contributes to artificial enlargement of first line ground rather than to footprint reduction:

- Vertical SRA border is recommended as there is enough ground at landside to turn on in first line ground (i.e. enough lot depth).

Warehouse building design variables

The cargo handling process is performed inside the warehouse. Section 3.2.2 showed that the most appropriate shape for a warehouse building is the I-shape, with no exceptions. Warehouse footprint reductive design variables which emerged in section 3.2.2 are:

- Increase mechanization level in handling process is recommended to a certain extent, as not all cargo is suitable for mechanized handling
- The number of warehouse layers is recommended to certain extent, as not all cargo is suitable for vertical transport
- FTF is recommended, as it handles large volumes in a more efficient way than individual fast tracks

The cargo handling process is performed inside the warehouse. In section 3.2.2 came forward that the most appropriate shape for a warehouse building is the I-shape, with no exceptions. Warehouse footprint reductive design variables which emerged in section 3.2.2 are:

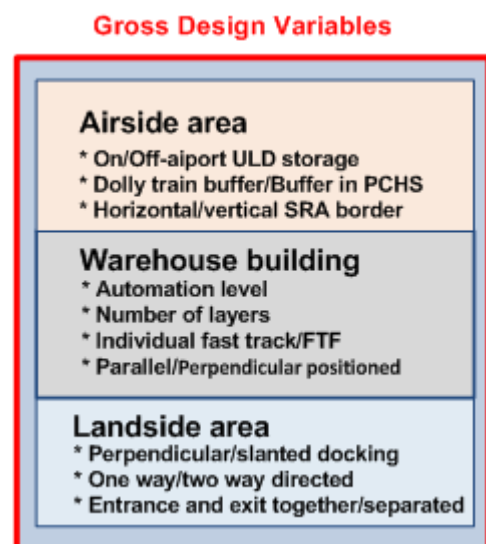


Figure 32 Gross warehouse design variables per warehouse section (Author, 2016)

- Particular positioned warehouses are recommended

Landside design variables

The function of the landside area is to enable truck supply. The following dedicated footprint reductive design variables emerged in section 3.2.3:

- Slanted truck docking is only recommended under extreme ground scarcity problems
- One way directed landside areas are always recommended
- Separate truck entrance and exit are always recommended

3.3.2 Combining warehouse design variables for the case study

Many warehouse designs can be created by combining the gross variables and therefore a structural method is required to systematically establish a total warehouse design. A useful design method which could be applied to investigate different solutions in a complex design, is the morphological analysis created by F. Zwicky. A method for investigating the totality of relationships contained in multidimensional, non-quantifiable problem complexes (Ritchey, 1998). In general, a morphological analysis is multidimensional and analysed by computer. However, in this research software is lacking and therefore the possible combinations will be performed per step, two dimensional.

The basis of the IATA and Districon ratios are on the mechanization rates, although expressed in automation level or number of warehouse layers. As the mechanization rate determines to a large extent the handling capacity, this research will handle a productivity ratio based on the mechanization level, determined by handling equipment combinations. This research, starting from scratch, offers the possibility to implement radical step-change improvements (Johnston, Fitzgerald, Markou, & Brignall, 2001), without external restrictions e.g. as for an existing building. The equipment combinations will be therefore firstly be combined with the warehouse infrastructure, together forming the warehouse building design. This design will then be combined with the interface areas; landside and airside. As the focus is on the warehouse designs, the airside and landside design will be adapted to the warehouse design, taking the schematic design principles and variables into account. Figure 33 visualizes the steps which will be performed to establish a total warehouse area design.

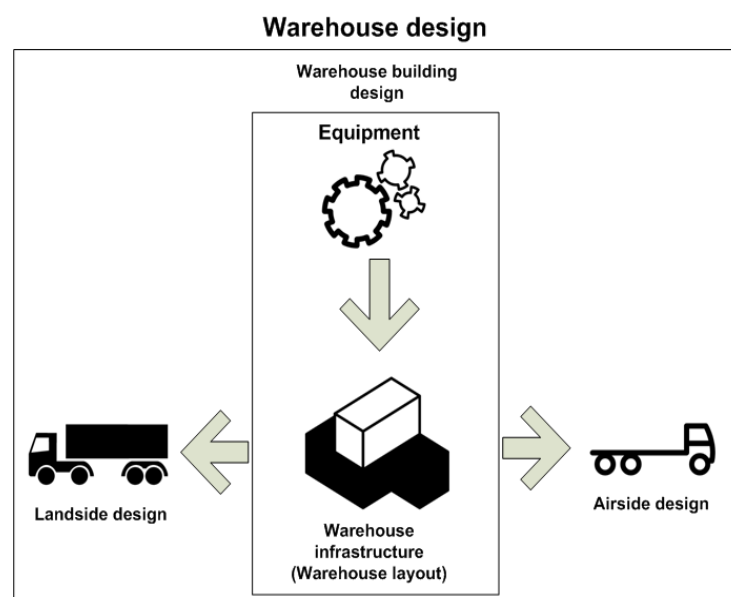


Figure 33 Morphologic approach of this research (Author, 2015)

4. Case study Amsterdam Airport Schiphol

This chapter documents the case study of this research, focusing on the Schiphol situation. This case study is built up according to the System Engineering Process steps framework of Grady (1998), shown graphically headlines in Figure 34. The first two steps are addressed in this chapter 4, the validation step in chapter 5 and the evaluation step in chapter 6.

The framework of Grady is used as overall framework. To study the framework steps of Grady in depth, other specialized frameworks are used. These frameworks are introduced in the sections where they are addressed. The total methodology of the case study is shown in Appendix D1

The objective of this chapter is to present warehouse design alternatives based on literature that meet the system criteria. Literature presented in chapter 3 forms the basis for this and local criteria are added. The definition of system requirements is addressed in section 4.1, with first the identification of the critical stakeholders (section 4.1.1) followed by the determination of the design criteria (section 4.1.2). The design and development phase starts in section 4.2. Since there are many design options, it is necessary to narrow the amount of design option into a couple feasible designs. This downsizing process is done in three steps based on the Stage-Gate model of Cooper (2002). Section 4.2.1 starts with an initial screen, followed by an identification of the solution space in section 4.2.2. This chapter 4 ends with a couple of feasible designs in 4.2.3.

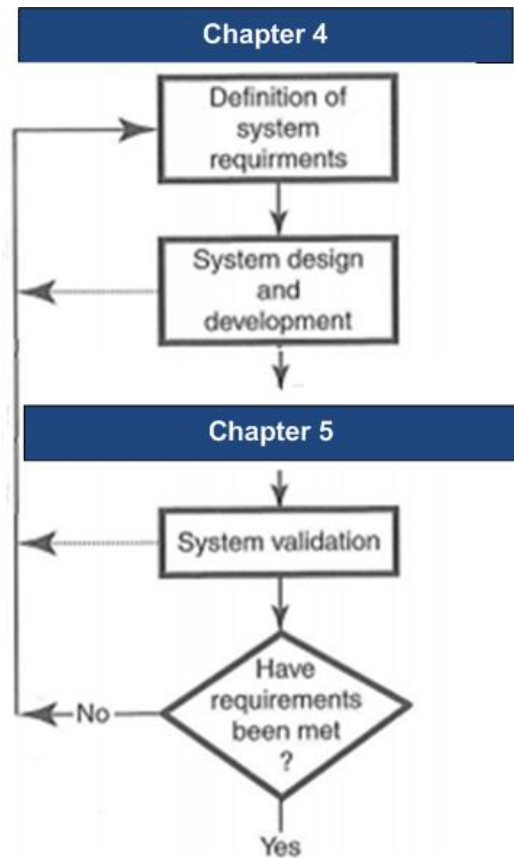


Figure 34 Overall framework of chapter 4, 5 and 6: System Engineering Process steps. Adjusted from (Grady, 1998)

4.1 Definition of system requirements

Literature from chapter 3 forms the basis for this and local criteria are added. These local criteria can only be identified once the core stakeholders are known. Therefore, this chapter starts with an identification of the core players in section 4.1.1. After that, the system environment is studied in section 4.1.2. Section 4.1, with the generation of Schiphol's specific KPIs in 4.1.3.

4.1.1 Identification of Schiphol's core players

The stakeholders who are physically involved (taking part in the handling process) or legally involved (having a contractual or public/private relationship) in the actual handling operation and development were identified in Chapter 2. Different and sometimes discrepant interests must be considered (Olander & Landin, 2005). However, some stakeholders are more critical than others. A suitable stakeholder mapping technique is to perform a power/interest analysis and place the different stakeholders into a power/interest grid (Sharma, 2010). By grouping the stakeholder into

this grid a better picture of how communication and relationships between stakeholders has affected the project and its implementation (Olander & Landin, 2005). Following stakeholder are considered:

Schiphol Real Estate (SRE)

SRE develops and manages real estate at the airport premises. Without commitment of SRE it is impossible to develop new warehouses (Laurey, 2015). This makes SRE a stakeholder with high power and high interest.

Schiphol Security and Policy (S&P)

The main interest and concern of S&P is the design and security of the SRA border over which they have the approval power (Lowijs, 2016). As such they have no particular interest in the design of the actual warehouse. S&P is a gatekeeper with high power and low interest.

Customs

Customs are physically as well as legally involved in the warehouse process. With the Joint Inspection Centre and the Smart Gate concept, Dutch customs try to streamline the handling process in collaboration with the handler and show commitment to the industry (section 2.4.2). Goods are monitored and controlled throughout the chain. Based on the cargo nature supervision can be determined. Checks at Schiphol can be executed with the aid of mobile scanners and a remote scan (ground handlers performs the check and the customs could watch via a camera) (Schweig, 2015). Warehouse designs do not have major influences on these checks. This makes that the customs do not benefit from specific warehouse design optimization. The commitment to the air cargo industry and the fact that customs do not benefit from specific warehouse designs, makes that they are categorized as stakeholder with low interest. However, the customs do have high power as they should approve the warehouse design. The design should meet certain requirements, stated by law (Hockemeijer, 2016). (These requirements are not taken into account in this research as these are more important for detailed designs e.g. separation of import and export flows etc.). Customs are identified as gatekeeper with high power and low interest.

Ground handlers

Ground handlers are to a large extent depend on warehouse design, as this impacts on processes, throughput time, handling efficiency, and ultimately on business results (Koet, 2015). The customer-provider relationship with SRE gives handlers high power. It is not assumed that they will do it, but the ground handlers are free to leave Schiphol to locate on another airport (Laurey, 2015). SRE should therefore closely manage the relationship with ground handlers. Especially the larger handling operators as they have the largest impact on the demand side of the local market for cargo warehouses. This makes the larger handling parties at Schiphol high powered with high interests. The smaller ground handling parties are also high interested. However, as their impact on AAS is smaller, they are categorized as low powered.

Trucking operator

The interest of the trucking operators aligned with those of ground handlers when it comes to fast truck turnaround times. However, lack of a contractual relationship, with the airport operator or with the ground handlers, and strong competition among trucking operators makes them a low powered party, who are not able to enforce requirements and interests. But for innovative, synergetic projects like as eLink, commitment between the trucking operators and ground handlers is necessary (Roupe van der Voort, 2015). In most cases innovations also requires investments, what makes it harder to achieve commitment between these parties. It should be kept in mind that the power of the trucking operator is low, but commitment could not be enforced. However, commitment is the only way to make innovations, where trucking operators are involved, a success (Kervezee, 2015). This makes trucking operators a party with low power, but high interest in optimizing the process. The outcome of the actor criticality analysis is presented in the Power versus Interest grid in Figure 35.

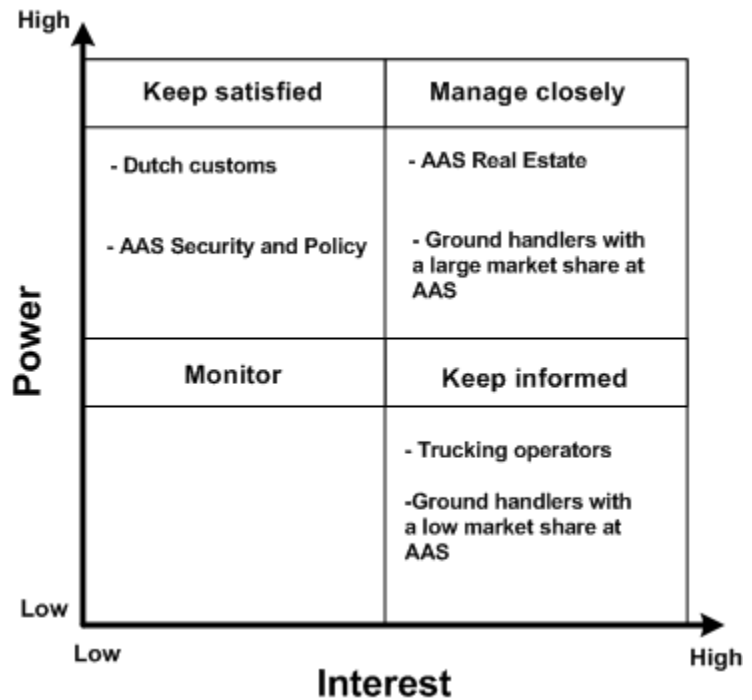


Figure 35 Power versus Interest grid. (Author, 2015)

4.1.2 Design criteria for Schiphol

Future warehouses should be designed in such a way that they are able to function in their environment (van der Donk, 2015). Knowledge from critical stakeholders is required to investigate their demands and limitations w.r.t. the warehouse and its operation. The system environment can be divided into two parts: the “hard” environment including physical and legal aspects and the “soft” environment including multiple interests, behaviors and resources. The influence of an environment on the design of a project or organization can be translated into objectives, constraints and requirements for the design (Dym & Little, 2009):

- Requirements define what the system must do and how well it must do those things, also referred as functional requirement (Grady, 1998).
- Constraints are boundary conditions within the designer must remain while satisfying performance requirements (Grady, 1998).
- Objectives are specific results that a system aims to achieve within a time frame and with the available resources (BusinessDictionary, n.d.).

Requirements and constraints are those that have to be satisfied in the result produced to come to functionally feasible alternatives. Objectives or soft requirements are those for which satisfaction can be relaxed during the research, although their relaxation should be minimized (Liu, 1995). Thus,

objectives are not knock-out criteria but are suitable for comparing the alternatives to each other. Figure 36 visualizes the coherence between the system environment and the feasible designs, and the influence of the objectives on the final alternative.

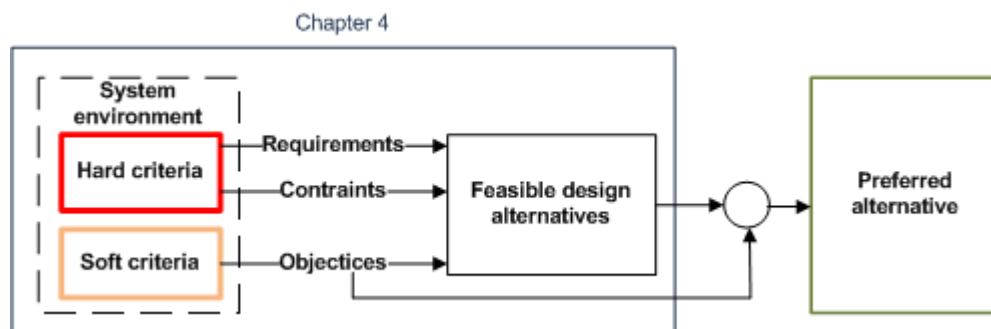


Figure 36 Coherences of the system environment on the feasible designs and the influence of objective on the final selection of an alternative (the circle) (Author, 2016)

The system environment of potential future warehouses at Schiphol is analyzed in different ways: interviews, literature and field research. The system environment of this research is compared to other system environment analyses from researches that show similarities with the warehouse development environment, e.g. the CPD research of van der Donk, de Wit and Lubbe. In both cases the main goal is to handle 3 million ton cargo per year. Also, a both cases have several stakeholders in common.

Some criteria are case specific i.e., criteria set up especially for this research, others are general i.e. widely applicable. This is an important distinction to take into account for future research at Schiphol. The general criteria can be inherited and the case specific requirements should be reviewed on accuracy. The full system analysis can be found in Appendix D4. Outcomes of these analyses are described in the following sections.

Designs constraints (hard criteria)

Strict policies are maintained on the airport ground with regard to ground scarcity. As air cargo warehouses fulfill the transshipment function between airside and landside, the warehouses are bounded to a location along the SRA border. The only location left for the development of cargo warehouses is on Schiphol South-East. Thus, the warehouse designs are restricted to this specific area (Laurey, 2015).

Security poses another constraint, i.e. all persons and objects on the platform have to be security cleared in order to get access to the restricted area. A safe SRA border has to be guaranteed in the warehouse design (Lowijs, 2016).

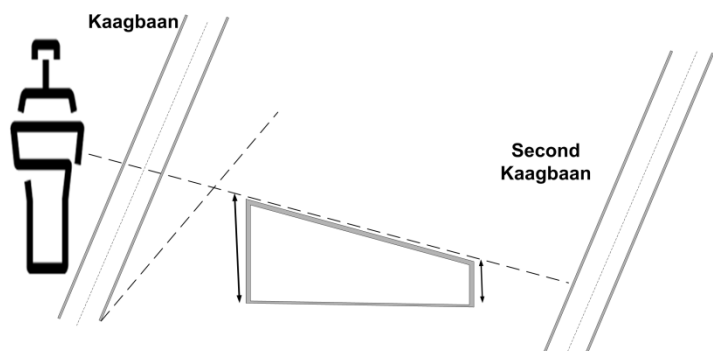


Figure 37 Schematic representation of the two influences on the height (Author, 2015)

Another constraint is safety, which limits building height. All aircraft areas should be visible from the control tower

(Timmerman, 2015). The sight lines are not a restrictive factor in the current situation. However, AAS is looking at possibilities to expand runway capacity. To manage all aircraft movements in the future, a reservation is made for a potential runway parallel to the Kaagbaan, at the other side of the prospective building lots A and B (Ministerie van Infrastructuur en Milieu, 2013). Another height restrictive factor is around the runway as no obstacle may block air operations. However, this is not the most critical height restriction at lot A and B (Timmerman, 2015). The height restriction lines are visualized in Figure 37.

Table 3 Stakeholder constraints (Author, 2015)

Stakeholder	Constraint	Case specific constraint?
SRE	The warehouse buildings should be developed within the given area at Schiphol South-East	Yes
SRE	The warehouse buildings may not exceed the maximum height	No
AAS S&P	Security Restricted Area	No

In this research the constraints which were described above may not be exceeded under any circumstances. Although the height constraint will remain the same, AAS could influence the surface constraint by purchasing more land at Schiphol South-East for future expansions. This makes the height constraints independent (not case-specific) and the surface constraint dependent (case-specific).

Design requirements (hard criteria)

The first requirement is given by Schiphol Cargo. Predictive analyses show growth in future cargo volumes at Schiphol. The scenario reckoned with is a volume of 3 million ton cargo per year. It is likely that 3 million ton will be reached within 40 years. The average lifespan of a cargo warehouse is 40 to 50 years (Timmerman, 2015). The designs should therefore be calculated using this yearly volume. However, it should be kept in mind that the current warehouses located at Schiphol South-East will stay. This implies that the 3 million ton cargo should be divided over the exiting warehouses and new warehouses at South-East. Taking a standard productivity rate for a manual operation (10 ton/m²) for the existing warehouses results in a remaining volume of 2,2 million ton for the new warehouses.

Another requirement is given by the ground handlers. The cargo arrival rate at Schiphol is not equally spread over time. Cargo volume peaks and dips can be identified over the year. This has to do with the general production week (Monday-Friday) and special occasions (e.g. Valentine's day with a lot of flower import). As it is not expected that the mentality of the production industry will change, it is assumed that the peak times will remain, an assumption also made by van der Donk (2015). However, it should be investigated to which extent the peak times will smoothen out, taking the runway capacity into account. Nevertheless, total peak shaving is not expected and therefore the new warehouse designs have to be able to handle cargo on peak times.

Table 4 Stakeholder requirements (Author, 2015)

Stakeholder	Requirement	Case specific requirement?
AAS Cargo	The Warehouse designs shall make sure that 2,2 million ton cargo per year can be handled by the new designs	Yes
Ground handler	The warehouse design shall make sure that the peaks in cargo volumes belonging to a yearly cargo volume of 3 million ton can be handled adequately	Yes

The scenario of 3 million ton cargo handled at Schiphol is based on several analyses. However, past forecasts about cargo volumes did not always turn out to be correct. The analyses are refined annually. If this research will be continued in the coming years it could be possible that the yearly volumes will be different from now, making this requirement case dependent (case-specific).

Design objectives (soft criteria)

To keep an overview, the system objectives are classified in different categories: productivity, financial and flexibility.

Productivity objectives; Productivity is a well-known KPI in air cargo warehouses. Air cargo warehouse performance benchmarks are based on the productivity rate expressed in handled ton/m² per year. The productivity rate gives an indication of the handling efficiency. The higher the productivity rate, the lower the handling costs per unit, which is an important indicator for the ground handlers (Ankersmit, 2013).

With the productivity the required warehouse surface can be determined, an important factor for the warehouse developer SRE. A Higher the productivity rate means a smaller the required warehouse footprint, making it an important factor regarding the increasing ground scarcity. Multi-level warehouses have positive influence on the warehouse footprint.

Trucking operators have to deal with congestion on the landside areas, what reduces their productivity. Less trucking movements means less congestion on the landside terrains and a higher efficiency for the trucking operators.

Financial objectives; Costs and cost savings are important criteria, since it gives an indication of the efficiency increase for all stakeholders (Cai, Liu, Liu, & Xiao, 2009). The financial objectives consist of four different aspects. The building costs are for SRE (Laurey, 2015). These costs should be in line with the rent earnings (Bakhuijsen, 2015). Another important factor for SRE is the ground utilization. The smaller the footprint of the cargo warehouses, the more ground surface will remain for other developments.

As the ground handling industry is not a very profitable industry, the financial objectives from the ground handlers are mainly focused on cost minimization, for both investment and operating costs (Kervezee, 2015); (Koet, 215). The rental price per square meter reduces in the case of a more layered warehouse. However, mechanization is required in the case of vertical transport (Districon, 2015). The equipment costs have to be paid by the ground handlers themselves (Laurey, 2015). Ground handlers are therefore looking for a balance between the warehouse rent and the required equipment.

Flexibility objectives; Flexibility is expressed in two ways: operational and rental flexibility. The warehouse operation flexibility is important for the ground handlers as air cargo is very diverse. A higher mechanization level leads to less operational flexibility (Koet, 215). For SRE warehouse flexibility is important, because custom made warehouses are difficult to rent out to successive tenants. There should be sought for a general warehouse design suitable for different air cargo handling operations (Laurey, 2015).

Table 5 Stakeholder objectives (Author, 2015)

Stakeholder	Objective	Case specific requirement?
SRE	Standardization of the warehouses	No
SRE	Minimize warehouse footprint	No
SRE	Minimization of the building costs	No
SRE	Maximization of the rental income	No
Ground handler	Faster cargo handling	No
Ground handler	Maximization of the ground utilization	No
Ground handler	Minimization of the operational costs	No
Ground handler	Minimization of the investment costs	No
Ground handler	Operational flexibility	No
Trucking operators	Minimization of truck movements for air cargo at Schiphol area	No

The given objectives are generic, as they are not location or time specific. This makes as objectives not case-specific.

4.1.3 Creation of Schiphol specific KPIs

First the domain objectives are classified into one of the matching KPI categories, obtained from literature (section 3.2). Thereafter the categorized objectives are converted into measurable actions in order to monitor entity performance and business processes (Ke, Li, Rui, Qiu, & Guo, 2010). The methodology of the KPI setup is shown in Figure 38.

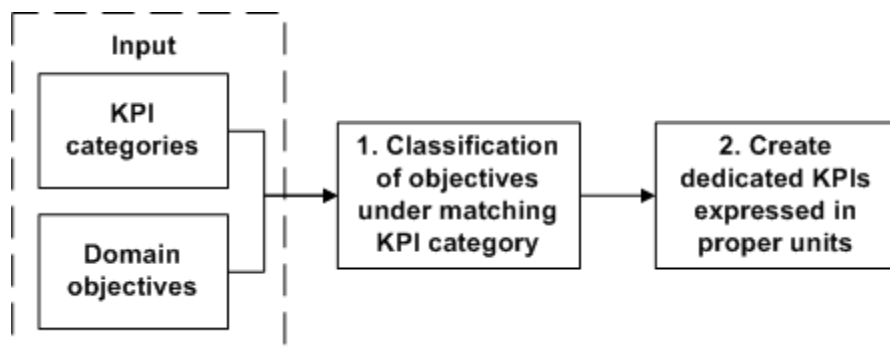


Figure 38 Methodology of the case specific KPI set-up (Author, 2016)

The total set-up of the case specific KPIs is shown in Appendix D5. Most KPIs are quantitative; however, the flexibility and SCR KPIs cannot be expressed quantitative as they are too complex. In this research these two KPIs are qualitative evaluated on a binary scale. In this research it is only to compare the alternatives with respect to each other. Therefore has been chosen for a rating without numbers as that could suggest that there is an arbitrary zero point. In Table 6 the results are presented.

Table 6 performance indicators for alternatives (Author, 2015)

KPI	Unit	Important for
Productivity		
Total capacity	Ton per year	Ground handlers
Total warehouse floor	m ²	Ground handlers
Footprint productivity	Ton/m ² per year	Ground handlers
Total warehouse footprint	m ²	SRE
Financial		
Building investment costs	€	SRE
Equipment investment	€	Ground handlers
Rent price	€/year	Ground handlers/SRE
Flexibility		
Warehouse operation	Qualitative	Ground handlers
Warehouse rent ability	Qualitative	SRE
Social Corporate Responsibility		
CO2 emission	Qualitative	Schiphol Group/ Ground handlers

4.2 System design and development

The system design and development is done on the basis of a simplified Stage-Gate Model of Cooper (2002). The aim of this model is to come systematically to an alternative selection, by the aid of Stage-Gates. Stage-Gate divides the selection process into a series of activities (stages) and decision points (gates). Every stage ends with a decision to reduce the number of alternatives and come to a final number of design options (Cooper, Optimizing the Stage-Gate Process: What Best Practice Companies are Doing - Part two, 2002).

This section starts with an initial screen of warehouse design variables in section 4.2.1. In section 4.2.2 the solution space for the alternatives is determined. The last step of the Stage-Gate model is addresses in section 4.2.3 with the development of the schematic designs. The build up of this section is visualized in Figure 39.

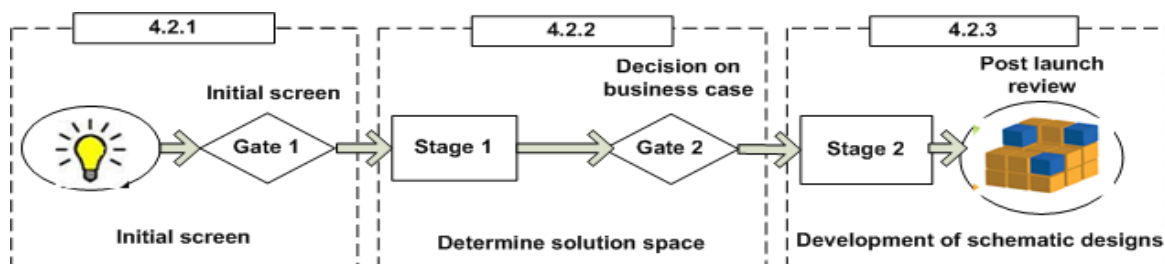


Figure 39 The built up of the system design and development section on the basis of the Stage-Gate model, adjusted from (Cooper, Optimizing the Stage-Gate Process: What Best Practice Companies are Doing - Part two, 2002)

4.2.1 Initial screen of warehouse design variables

In this section the first screening towards design alternatives is shown. Standard variables are e.g., depths per area and required warehouse heights per process in the warehouse. These variables form the basis for the schematic design development in 4.2.3. The input variables are discussed per warehouse area.

Input variables for airside areas

Airside depth; the airside acts as a buffer for in- and outgoing ULDs and as storage for empty ULDs. In general this requires a depth of 30-50m (Districon, 2015). Most ground handlers at Schiphol have an airside depth of 30m. If there will be no footprint reductive variables implemented, an airside depth of 30 meters is maintained in the warehouse designs to meet the footprint constraints.

Input variables for warehouse buildings

Productivity rate; IATA and Districon productivity ratios determine overall productivity rates. Chapter 3 has shown the influence of the import-export distribution on the productivity ratio (export requires more surface than import). However, for the warehouse design productivity rates at Schiphol will not distinguish between import and export, as import and export flows are equally divided (almost 50-50 distributed (de Wit, 2015). Therefore it is not necessary to separate the areas to determine overall productivity. Table 7 shows the current and maximum productivity rates of Schiphol, together with benchmark rates and a recommendation planning parameter for Schiphol.

Table 7 Productivity rates at Schiphol and benchmarks (Districon, 2015)

Current planning parameter Schiphol	
Current realisation Schiphol	8 ton/m ² per year
Maximum realisation Schiphol	10.6 ton/m ² per year
Benchmark	12 ton/m ² per year (one layer) 28 ton/m ² per year (two layers)
Recommendation planning parameter Schiphol	10 till 14 ton/m ² per year

The recommended planning parameter for Schiphol has a large range. However, no further specifications are given by Districon for the 14 ton/m² per year. It can be questioned into which extent 14 ton/m² per year is a reasonable/feasible planning parameter for warehouses at Schiphol, as the current maximum at Schiphol is only 10,6 ton/m² per year. For the creation of robust design alternatives a productivity rate of 10 ton/m² per year will form the basis. The robustness of productivity rates of the alternatives are checked on the basis of sensitivity analyses.

Free height clearance of the warehouse; free height clearance in warehouses is usually between 7 and 8 meters. However, during a meeting with Districon and a few stakeholders it became clear that these height requirements are not scientifically proven or legally established. According to literature (Rotteveel & Timmermans, n.d) only storage requires more height. This indicates that there should be possibilities to lower the roof clearance for the build-up and cargo receiving areas. The maximum height of a ULD is around 3 meters. Taking a margin of 2 meters, results in a warehouse roof clearance of 5 meters. The same applies to the receiving area. For the Schiphol warehouse design the following minimal roof clearance heights are taken into account:

- Receiving area: 5m
- Storage: 6m
- Build up and break down: 5m

Fast track; Increasing volumes together with ground scarcity requires a fast and efficient cargo handling process. Fast tracks contribute to this requirement. At Schiphol, large cargo import volumes are suitable for fast track handling (Kallen, 2015). Therefore, fast tracks will be implemented, individual or a FTF.

Input variables for landside areas

Landside depth; landside areas for docking requires a depth of 35m. Within this area the trucking operator is able to manoeuvre, dock and drive. This landside area depth is only appropriate if the trucking operators are able to dock immediately, otherwise extra depth is required for parking (50m) (Districon, 2015). The ground handlers at Schiphol are not able to receive trucks on demand, which indicates a required landside depth of 50m if nothing changes. Therefore the following landside depths are taken into account in this research:

- 30m for a on demand truck process
- 50m for non-on demand truck process

4.2.2 Determine solution space for warehouse designs

In chapter 3 the morphological approach (MA) has been introduced as method to investigate different solutions in a complex design (Zwicky, 1967). Basically, all systems are composed of a various number of sub systems, each of which can be shaped in different ways. MA identifies various shapes of the subsystems, combines these shapes into all possible alternatives the system may adopt within the solution space. In this way it is possible to model complex problems in a non-quantitative way (Yoon & Park, 2005). The design variables are retrieved from literature (chapter 3) observations and interviews. The variables are divided into 3 main sections: airside design, warehouse design and landside design. With the warehouse design further subdivided into equipment variables and warehouse infrastructure variables as shown in Figure 33 (chapter 3).

It is not feasible to work out all possible warehouse designs. To reduce the number of alternatives a selection of elements from the various morphological sectors of categories is made. A benefit of this approach is that it reduces the number of impractical combinations generated. A drawback to this approach is that it clearly limits the consideration of many ideas, especially unconventional ones (Sage & S William, 2009). The aim of this design study is to retrieve diverse and broad information on various design options. On the basis of a well-chosen morphological category, a variety of design options can be investigated, without spending too much time in selecting alternatives in this exploratory phase. This makes it a useful approach.

As equipment determines the handling capacity, the designs are varying in the level of mechanization (Section 3.3.2). In general mechanized solutions are required to overcome vertical transport and therefore along with the number of warehouse layers (chapter 3.2.2). The decision to vary the alternatives based on the element mechanization level offers opportunity to create alternatives in multidimensional objective corners, to retrieve a clear insight in the stakeholder's preferences. To reduce the extremity between the alternatives, a medium alternative will be introduced. The decision variable and important objective associated are shown in Figure 40.

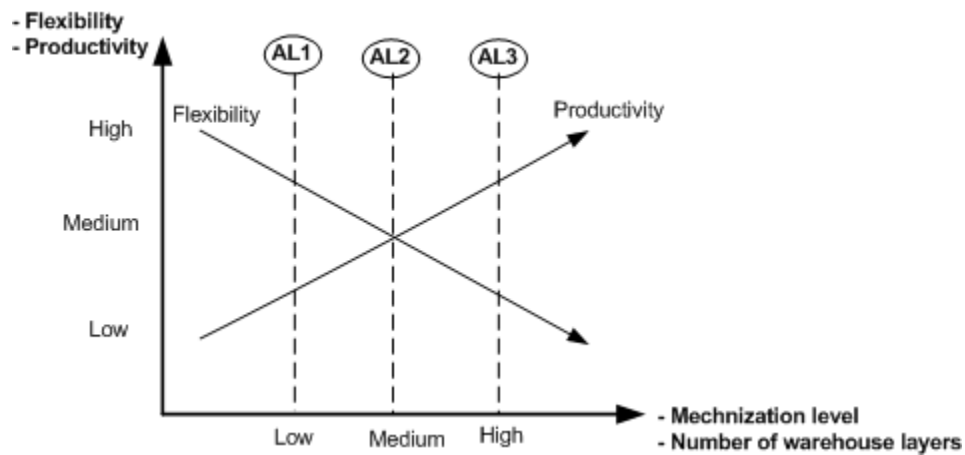


Figure 40 Decision variables, number of warehouse layers and mechanization level, and the associated objective for the three alternatives. This figure is an visualization and is not on scale (author, 2016)

The equipment selection per alternative based on mechanization level is shown in Appendix D8. The following alternatives came forward:

Alternative 1 – Basic warehouse solution

This alternative will be the most simplistic solution. The aim of this warehouse design is to create the most flexible design in both the handling operation as rental flexibility. This can be achieved by keeping the mechanization level low. The mechanization rate of the current warehouses will form the base, as it is not feasible to lower the mechanization rate regarding the ground scarcity. The only full mechanized process in the current warehouse operation is the PCHS system for the storage of ULDs. It is up to the ground handlers to design their own inner warehouse distribution (distribution of different cargo flows).

Alternative 2 – Semi-advanced warehouse solution

Alternative 2 forms the middle alternative by a medium level of mechanization with the process divided over two warehouse layers. The aim of this warehouse design is to find a balance between flexibility and productivity.

Alternative 3 – Advanced warehouse solution

This alternative will be most advanced, with a high mechanization rate and the handling process divided over 3 warehouse layers. The aim of this design is to increase the productivity. A higher mechanization rate allows a higher productivity rate. However, this should be compromised by both the handling operation as rental flexibility.

4.2.3 Development of schematic warehouse designs

All alternatives should meet the requirements and must not exceed the constraints. The designing is done in iterations to test the designs every step on their feasibility. Every iteration step is based on a concept derived from literature. In these iteration steps, the preferences of the system environment are taken into account to improve the usability of the designs (Nielsen, 1993). The iteration steps and the final alternatives are presented in the following sections. The complete analysis can be found in Appendix D9. Final designs are visualized at the end of the alternative steps.

Alternative 1 – Basic warehouse design

The base design has been modelled as a process similar to the current warehouse operations at Schiphol. Goal of this design is to minimize the mechanization level and to handle all operations on one single floor. The following solution space inputs from section 4.2.1 have been applied:

- Airside depth: 30 meters.
- Free height clearance of the warehouse: 7 meters (standard height).
- Landside depth: 50 meters, suitable for truck parking.

The following steps within the solution space have been taken to come to a final schematic design:

A. Copy of the current warehouse designs

First step is to consider a one-on-one implementation of the current warehouses: I-shaped warehouses parallel to the runway. This would result in a low ground utilization due to odd wedge-shape of lot A and due to the low utilization of the area depth of lot B. The consequence of this underutilization of the ground is that the one-on-one implementation of parallel, I-shaped design does not meet the productivity requirement.

B. Position warehouses perpendicular to the platform

To increase the ground utilization, the next step is to rotate the warehouses. Although rotation of the warehouses enables more warehouse surface (and thus capacity), it is still not enough to meet the productivity requirement.

C. Implementation of a general Fast Track Facility

The third step is the implementation of a general FTF, enabling general import handling of BUPs (Kallen, 2015). Kallen created two types of FTFs: manual and automated. Both designs enable the same handling capacity (Appendix B2). However, the differences are in the required footprint and operational process. Keeping the main objective of this alternative into account (minimize mechanization level), there has been chosen for a manual operated FTF, requiring an area of 6460m². Although this is a large surface, the left side of lot B is perfectly suited for the manual operated fast track facility dimensions. However, even with the implementation of a FTF the required productivity is not reached.

D. Double layer warehouse

The final step is inserting an additional floor to create a double layer warehouse. So far this has been avoided to stay away from mechanisation requirements for vertical transport. Generally, processes in multi-layer air cargo warehouses are divided in 2 levels (Sanders, 2015). However, for this design has been chosen for a strict process separation between the two levels. To enable supply at the first floor two one-direction truck ramps on the land side and a long dolly train ramp (max. 1.1° inclination) on the air side allow full access to the first level (Vonk, 2003), without the requirement for mechanized lifting.

E. Final design - Basic warehouse

The combination of manual operated warehouses, partly perpendicular orientated to the runway and partly double layer and completed with a FTF, results in enough capacity to handle the required tonnage. Alternative 1 is visualized in Figure 41, Figure 42 and specified in Table 8. Last check has been performed in Table 9, by checking if the design meets the hard criteria. The complete iteration process with all visualizations can be found in Appendix D9.1.

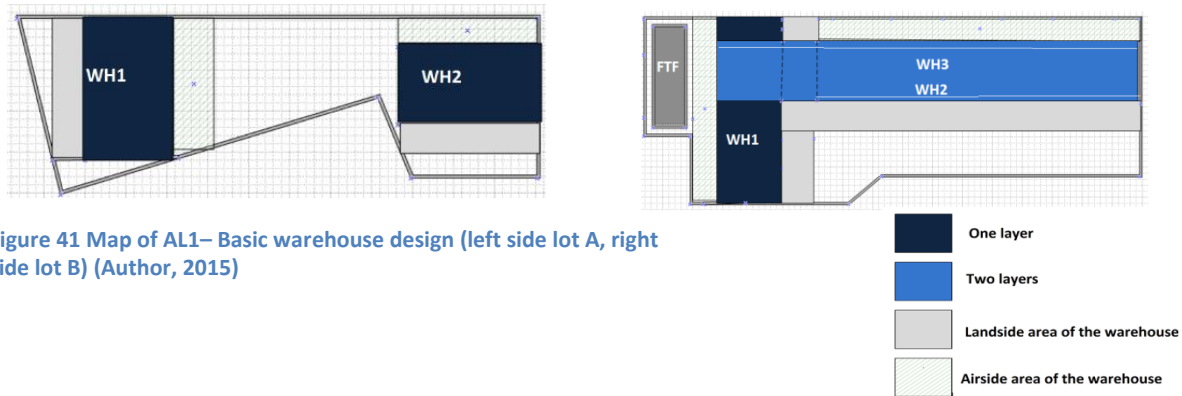


Figure 41 Map of AL1– Basic warehouse design (left side lot A, right side lot B) (Author, 2015)

Table 8 Basic warehouse design key dimensions (Author, 2015)

Key dimensions of basic design	Lot A	Lot B	Total
Warehouse footprint	34,100 m ²	85,100 m ²	119,200 m ²
Total warehouse floor surface	34,100 m ²	155,100 m ²	189,200 m ²
Assumed productivity rate	10 ton/m ² per year	10 ton/m ² per year	
Required warehouse capacity with a FTF			1,848,462 ton per year
Total capacity	341,000 ton per year	1,551,000 ton per year	1,892,000 ton per year

Table 9 Hard criteria checklist basic design (Author, 2016)

Requirements/constraints	Fulfilled?	Validated by
Enough handling capacity	Yes	Researchers own calculation
Within height restriction	Yes	Bakhuijsen, van der Kooij
On given ground surface	Yes	Bakhuijsen, van der Kooij
Secured SRA border	Yes	Lowijs, Bakker

f. Productivity robustness analysis

The basis productivity rate for this design is 10 ton/m² per year. The operation of this design is similar to the operation of the current operations at Schiphol. It is assumed that this productivity ratio is reasonable, taking the fact into account that 10 ton/m² per year already has been proven at Schiphol (shown in Table 7). Therefore has been decided not to take a large productivity margin, as shown in Table 10. The lowest productivity rate to reach the required yearly tonnage is 9,7 ton/m² per year.

No warehouses on lot A is the most positive scenario. This could be enabled by a production rate of 13 ton/m² per year or higher for all warehouses on lot B. Although, this productivity ratio is not assumed, it is recommended to construct first all warehouses in lot B, whereupon can be determined if the warehouses on lot A are required.

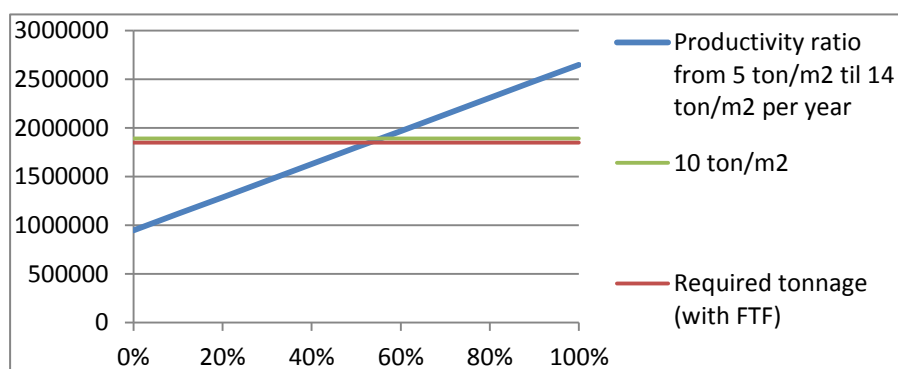


Table 10 Basic design productivity ratio robustness analysis. The blue line shows 5 ton/m² per year ratio on the left side and the right side a ratio of 14 ton/m² per year (Author, 2016)

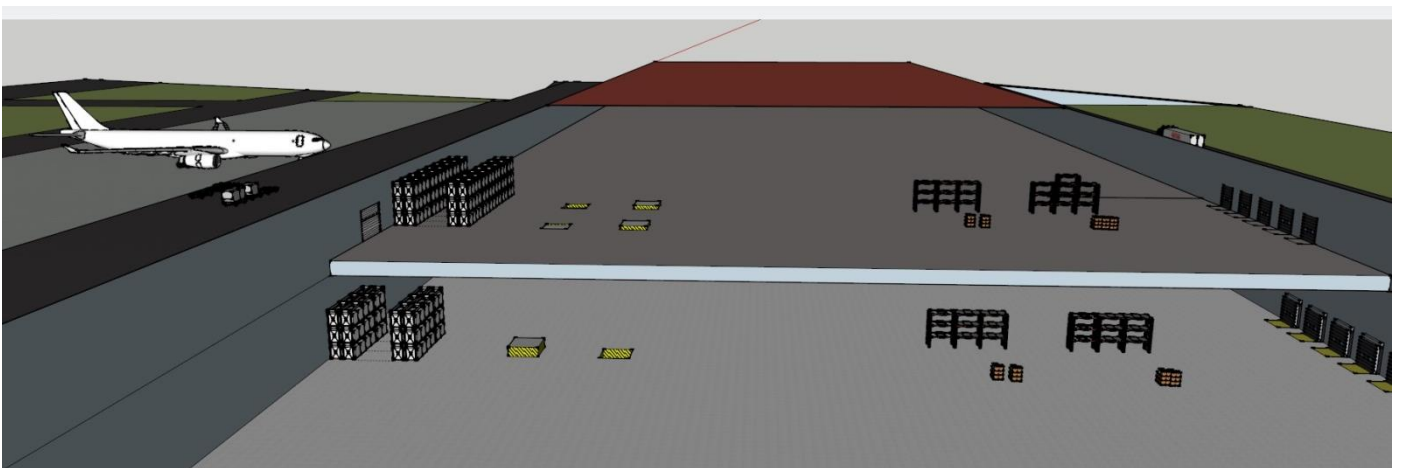
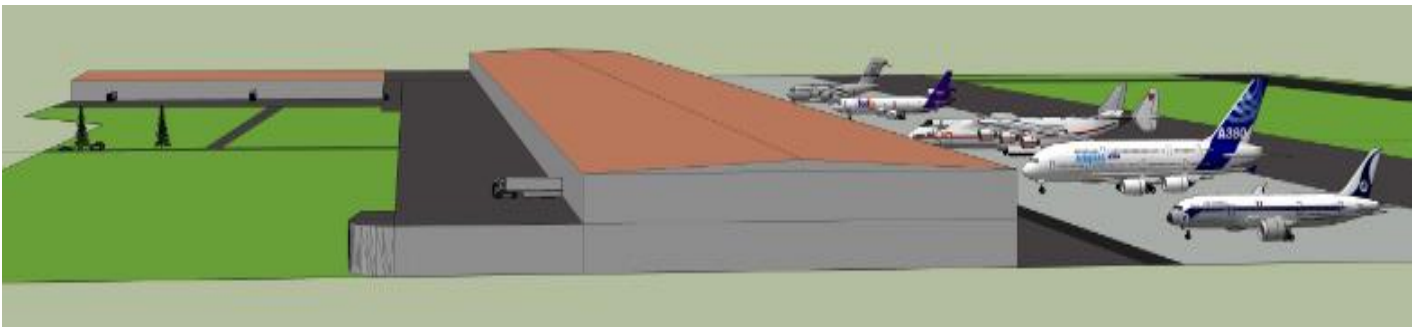
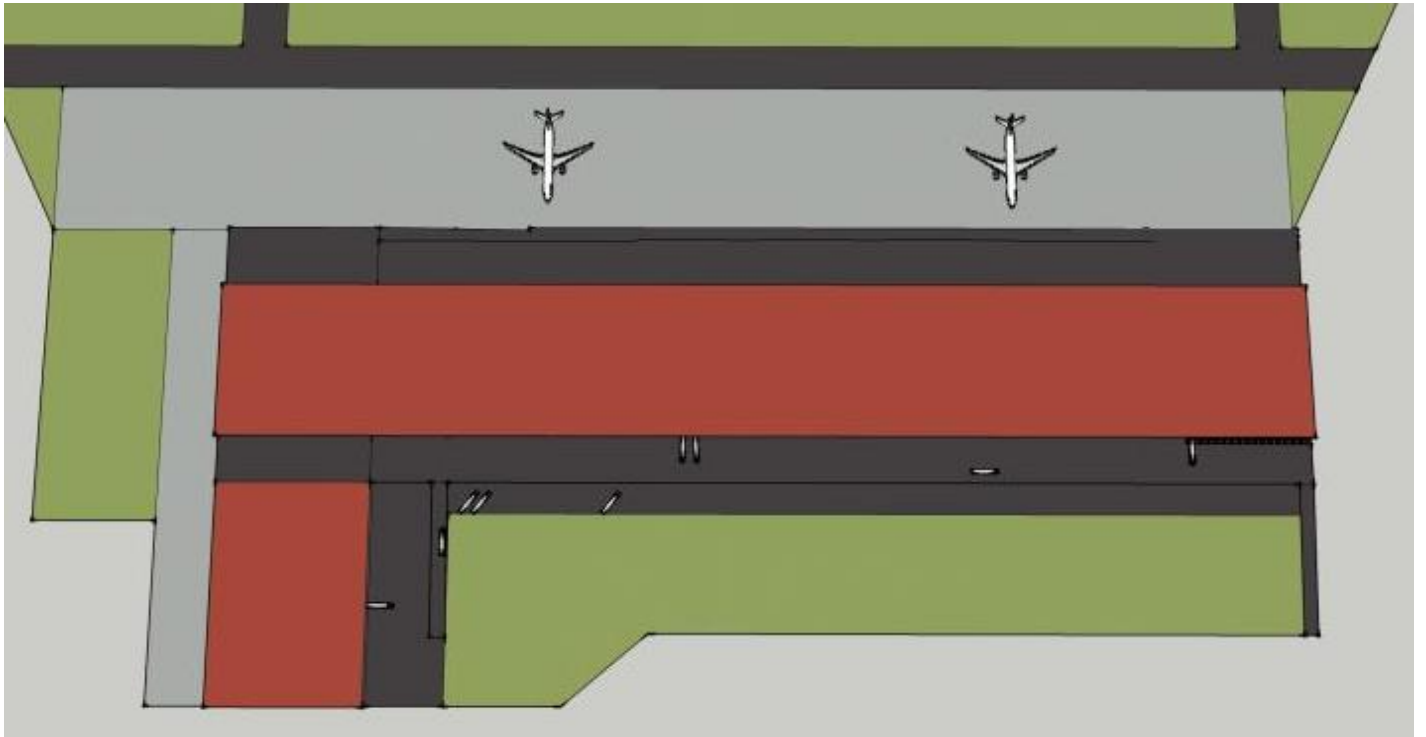


Figure 42 (Author, 2016)

1. Overview, lot B (Author, 2015)

2. Side view, lot B (Author, 2015)

3. Cross section. Multi-level warehouse, lot B

Alternative 2 – Semi-Advanced warehouse design

Alternative 2 is a semi-advanced warehouse design. It is based on the current warehouse design and operation, but with an operation separated over 2 layers. The following solution space inputs from section 4.2.1 have been applied:

- Airside depth: 30 meters.
- Free height clearance of the warehouse:
 - 7 meters build up and storage (standard height).
 - 5 meters for receive.
- Landside depth: 50 meters, suitable for truck parking.

The following steps within the solution space have been taken to come to a final schematic design:

A. Position warehouses perpendicular to the platform

On Lot B, four 2-layer warehouses are projected perpendicular to the runway over the full depth of the plot. However, to comply with height restrictions it is not possible to construct a multi-level warehouse over the whole area depth of lot B. rotation of warehouses on lot a do not add value. On lot A is therefor chosen for a double layer warehouse parallel to the platform

B. Assigning functions to the layers

Storage and build-up require a lot of surface. Therefore the choice has been made to locate these on the ground floors (available over the total building length). The truck docks require less surface and height and are therefore located on the first layers. An additional advantage of trucks assigning to the first floor is that trucks require less height enabling optimal height utilization (Figure 43).

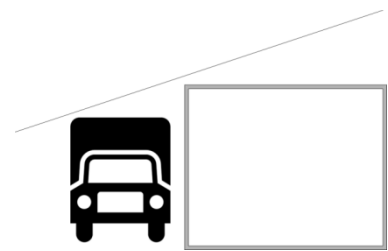


Figure 43 Optimal height utilization (Author, 2016)

C. Final design– Semi-advanced warehouse design

This design offers enough capacity to handle the total required yearly tonnage, without the implementation of a general FTF. The warehouse depths are in total 110 meters divided over the first floor (30 meters) for the truck supply and the ground floor (80 meters) for storage and build up. On the first floor (the roof) remains a landside area of 50m deep, what is enough to facilitate truck docking and parking. The map in Figure 45, clarifies the previous statements. The semi-advanced design visualized in Figure 41, specified in Table 11 and checked on correctness in Table 12. The complete iteration process with all visualizations can be found in Appendix D9.2.



Figure 44 Airside view one warehouse on lot B (Author, 2015)

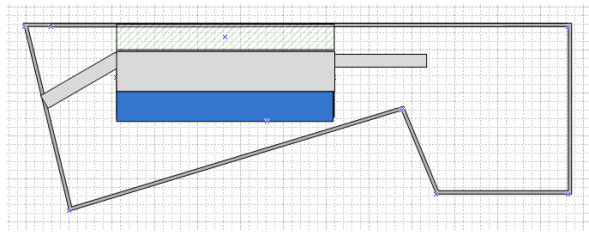


Figure 45 Map of semi-advanced warehouse (left side lot A, right side lot B) (Author, 2015)

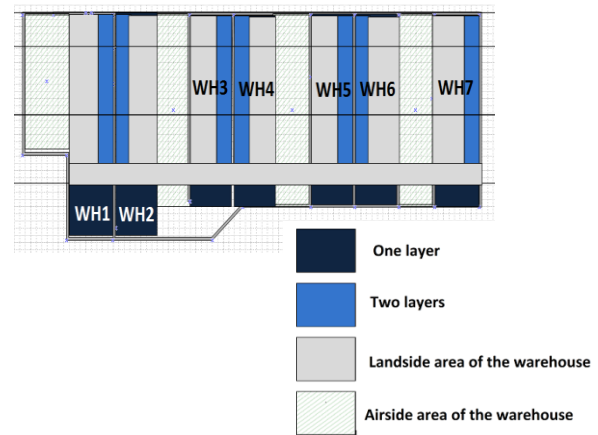


Table 11 Semi-advanced warehouse design key dimensions (Author, 2015)

Key dimensions Semi-basic design	Lot A	Lot B	Total
Warehouse footprint	24,000 m ²	156,880 m ²	180,880 m ²
Total warehouse floor surface	32,100 m ²	196,570 m ²	228,670 m ²
Assumed productivity rate	10 ton/m ² per year	10 ton/m ² per year	
Required warehouse capacity without FTF			2.240.560 ton per year
Total capacity	321.000 ton per year	1.965.700 ton per year	2,286,700 ton per year

Table 12 Hard criteria checklist semi-advanced design (Author, 2016)

Requirements/constraints	Fulfilled?	Validated by
Enough handling capacity	Yes	Researchers own calculation
Within height restriction	Yes	Bakhuijsen, van der Kooij
On given ground surface	Yes	Bakhuijsen, van der Kooij
Secured SRA border	Yes	Lowijs, Bakker

D. Productivity robustness analysis

The operation of this design is similar to the operation of the current processes at Schiphol. However, a vertical transportation step is added in the warehousing process. Theoretical is 10/m² a feasible production ratio for Schiphol, according to Districon as shown in Table 7. The vertical step could negatively influence the productivity rate. Though, it has been chosen to take basis ratio as basis due to the fact that the operation does not change, except the extra vertical transportation step. This alternative is less robust compared with the basic design due to the fact that the vertical transportation step adds uncertainty on the productivity ratio. However, if 10/m² per year is not reached, a FTF could be added in future (shown in Appendix D9.2). The risk of under-capacity is hereby excluded.

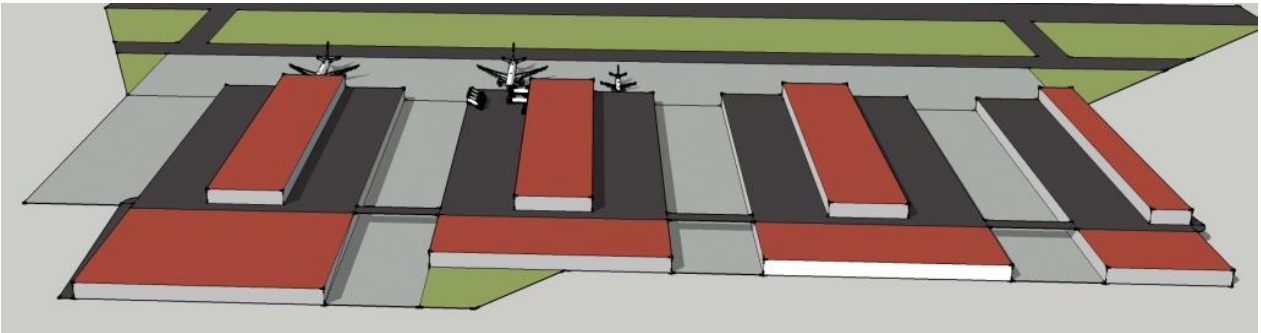
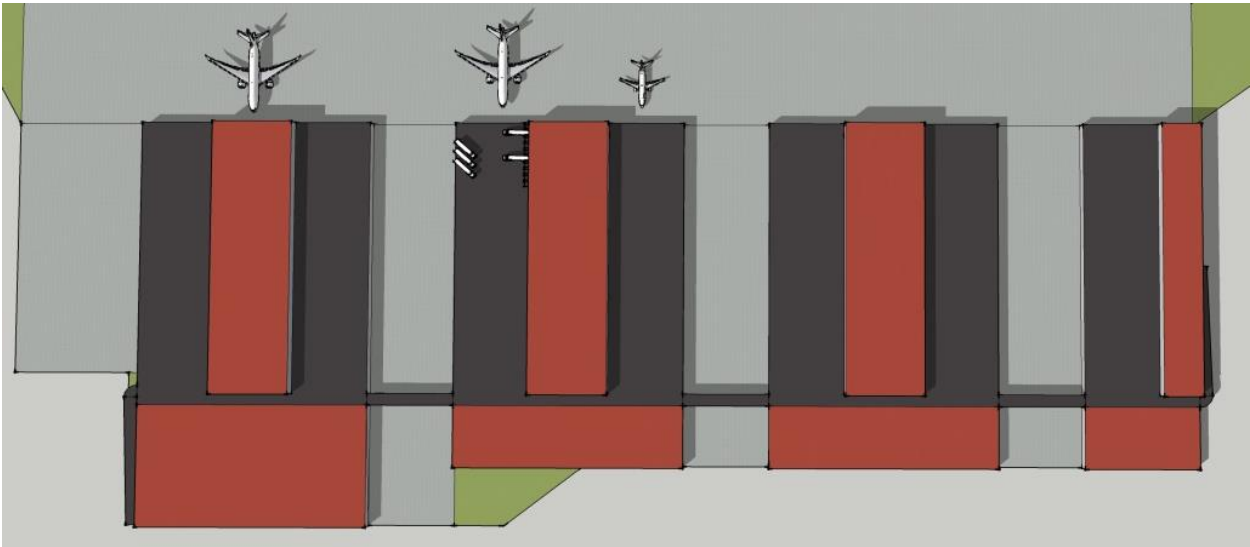


Figure 46 Semi-advanced design
 1. Overview warehouse, lot B
 2. Land-side view, lot B
 3. Cross section of the warehouse

Alternative 3 – Advanced warehouse design

Alternative 3 is an advanced warehouse design. This design is based on the most advanced air cargo warehouse operations in the world: the HACTL building in Hong Kong. The HACTL building has six layers and is highly mechanized. Two layers are dedicated to each of the following processes: receive, storage and build-up. The following solution space inputs from section 4.2.1 have been applied: Airside depth: unknown

- Free height clearance of the warehouse:
 - 5 meters for build up
 - 6 meters for storage
 - 5 meters for receive.
- Landside depth: 30 meters, trucks are coming on demand

The following steps within the solution space have been taken to come to a final schematic design:

A. Number of warehouse layers and location of the warehouses

Under the height restrictions at Schiphol a 6-level warehouse is not feasible. However, it is possible to realize a 3-level warehouse, with the same dedicated functions per floor as within the HACTL building. Due to the height restrictions the only location for a 3-level building is along the platform (Figure 48).

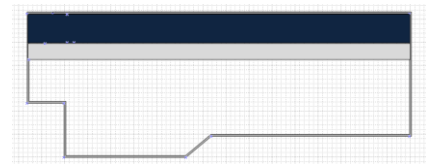


Figure 48 Three layer full automatic warehouse on lot B (Author, 2016)

B. Increase mechanization level

Bulk storage function will be enabled by a Box Storage System (BSS) (Appendix D8.9) and loaded ULDs will be stored in a PCHS, which is able to load dolly trains directly, taking away the buffer function of the airside area (no airside area required) (Appendix D8.12). A mechanized process is able to handle large volumes of general cargo on a relatively small footprint. However, the process should also be able to handle all types of cargo (Rotteveel & Timmermans, n.d). It is not feasible to handle specials in a three layer warehouse. The highly mechanized warehouse does not utilize the total depth of lot B, which enables the construction of another building behind the highly mechanized warehouse. The special cargo building will be of the traditional dimensions with a depth of 100m and a landside (30) and airside (30m). However, a conflict arises concerning the SRA border, as the airside of the specialties warehouse will be crossed by trucks which supply the general cargo warehouse.

C. Cargo Satellite design

To solve the landside-airside conflict, the cargo satellite design of Vonk (2003) will be implemented (explained in section 3.2.1). This results in a truck supply on the third floor of the general cargo warehouse, totally isolated from the airside of the specialties warehouse. Within the general cargo warehouse there will be a horizontal SRA border. The SRA border for the specialties is as the traditional at the end of the airside area of the warehouse. The vertical and horizontal borders are visualized in Figure 49. However, even with a special cargo warehouse behind the general cargo the productivity requirement is not met.

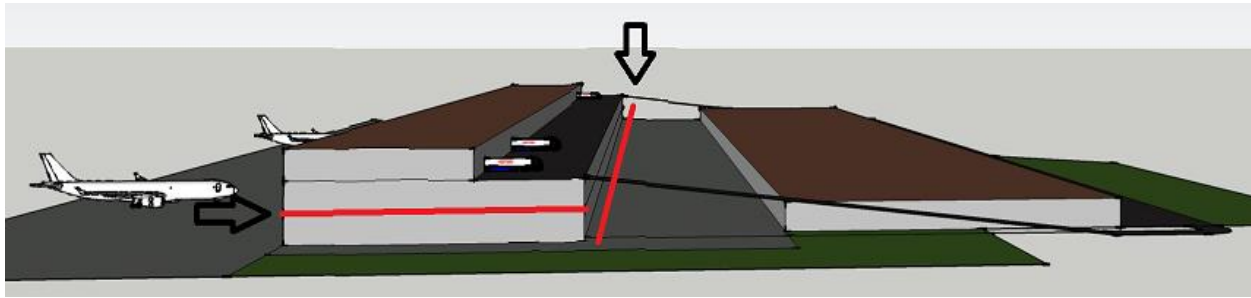


Figure 49 The SRA borders, on the left side the vertical SRA border in the general cargo warehouse and on the right side a traditional horizontal SRA border (Author. 2016).

D. Implementation of a general Fast Track Facility

To increase the total handling capacity there has been chosen for the implementation of an automatic FTF. The general cargo warehouse, the specialties warehouse and the FTF are able to handle the required capacity, only on lot B.

E. Final design - advanced warehouse design

Together, the three buildings (general cargo warehouse, a specialties warehouse and a general FTF) have enough capacity to handle the required tonnage on lot B only. The advanced design is visualized in Figure 52, Figure 51, specified in Table 13 and checked on correctness in Table 14. The complete iteration process with all visualizations can be found in Appendix D9.3.

F. Productivity robustness analysis

The basis productivity rate for this design is 10 ton/m² per year. As stated in the basic alternative is 10 ton/m² per year a reasonable productivity for a standard warehouse. This production ratio is assumed for the standard warehouse in this alternative. However, the operation of the advanced warehouse is not comparable with any operation of the current operations at Schiphol, what makes the productivity ratio uncertain. A footprint productivity ratio of 30 ton/m² per year (3 layer building), seems too positive. Therefore it is decided to assume the proven production ratio of the HACTL building as the advanced warehouse has been constructed as the HACTL (26 ton/m² per year). Assume a fixed productivity ratio for the standard warehouse, results is a required productivity ratio of 7 ton/m² per year for the advanced warehouse (11% range relative to the production ratio of the HACTL operation) (Figure 50). This marge is very important to take into account to create a robust alternative with many uncertainties.

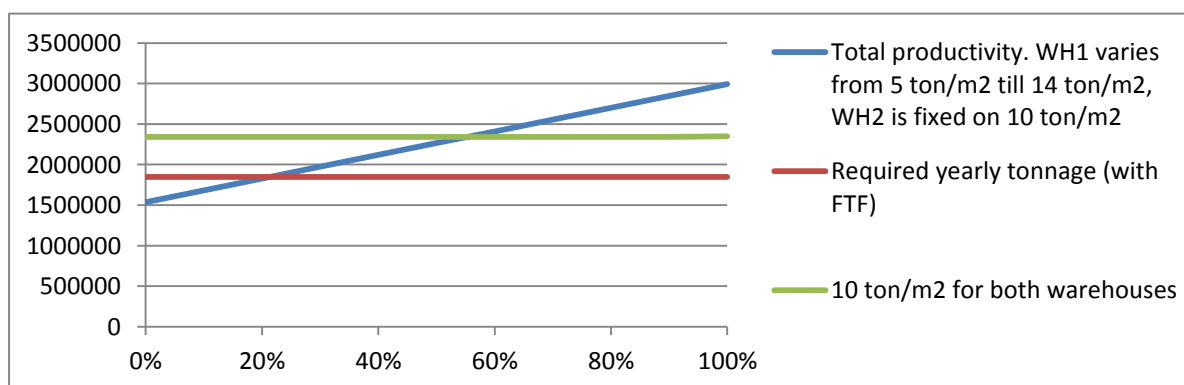


Figure 50 Advanced design productivity ratio robustness analysis. WH1 is fixed on 10 ton/m² per year ratio (shown on the left side) to 14 ton/m² per year ratio (right side) (Author, 2016)

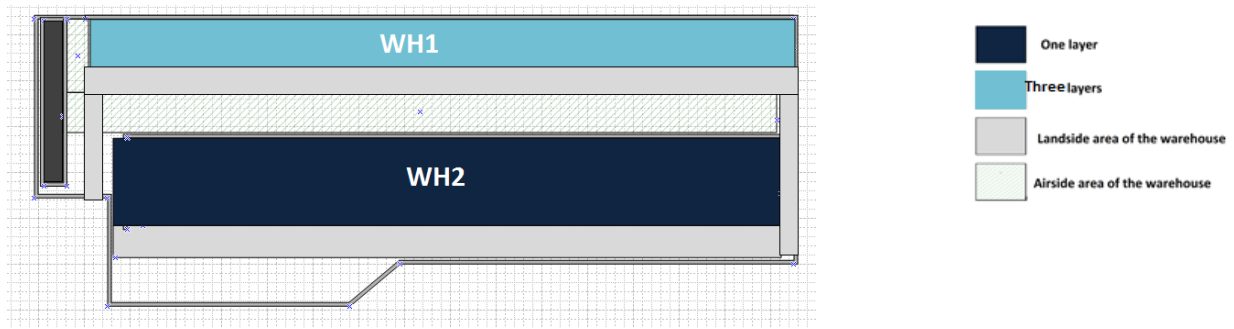


Figure 52 Map of advanced warehouse lot B (Author, 2015)

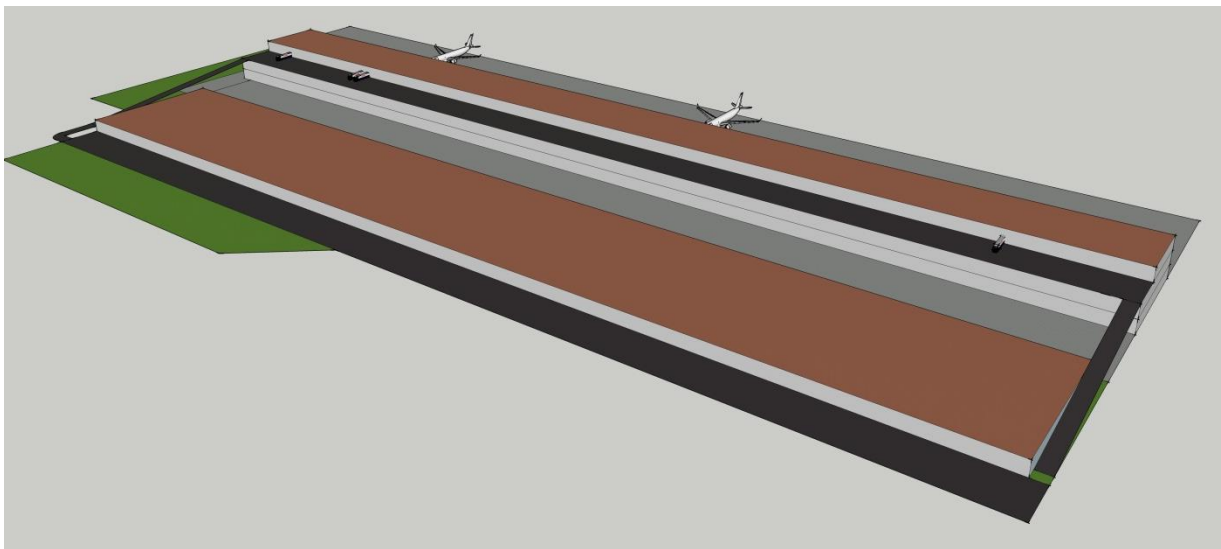


Figure 51 Advanced design (Author, 2015)

1. Overview (without FTF), lot B
2. Cross section, 3 layer building

Table 13 Advanced warehouse design key dimensions (Author, 2015)

Key dimensions of basic design	Lot A	Lot B	Total
Warehouse footprint	-	134,699 m ²	134,600 m ²
Total warehouse floor surface	-	234,700 m ²	234,700 m ²
Assumed productivity rate	-	Advanced warehouse: 8,8 ton/m ² per year Normal warehouse 10 ton/m ² per year	
Required warehouse capacity with FTF			1,848,462 ton per year
Total capacity	-	2,152,960 ton per year	2,152,960 ton per year

Table 14 Hard criteria checklist advanced design (Author, 2016)

Requirements/constraints	Fulfilled?	Validated by
Enough handling capacity	Yes	Researchers own calculation
Within height restriction	Yes	Bakhuijsen, van der Kooij
On given ground surface	Yes	Bakhuijsen, van der Kooij
Secured SRA border	Yes	Lowijs, Bakker

5. Case study results and validation

In this chapter the results and validation of the design alternatives are presented, the last step of the systems engineering process of Grady (1998). As validation is a broad concept, the Stage-Gate process by Cooper (2008) is used to structure this chapter. This chapter focuses on the last stage decision: which alternative is feasible and which is not.

The Stage-Gate model consists of a series of stages during which information is gathered and the design progressed, followed by a Go/Kill decision (Cooper, Perspective: The Stage-Gate Idea-to-Launch Process – Update, What’s New and NexGen Systems, 2008). The activities stage is discussed in 5.1 by showing the KPI scores per alternative. During the Integrated Analysis the alternatives are validated in section 5.2. In section 5.3 the integrated results of the analysis are presented by investigating the critical stakeholder acceptance. This forms the input for the conclusion of this chapter based on the Go or Kill decision for the alternatives.

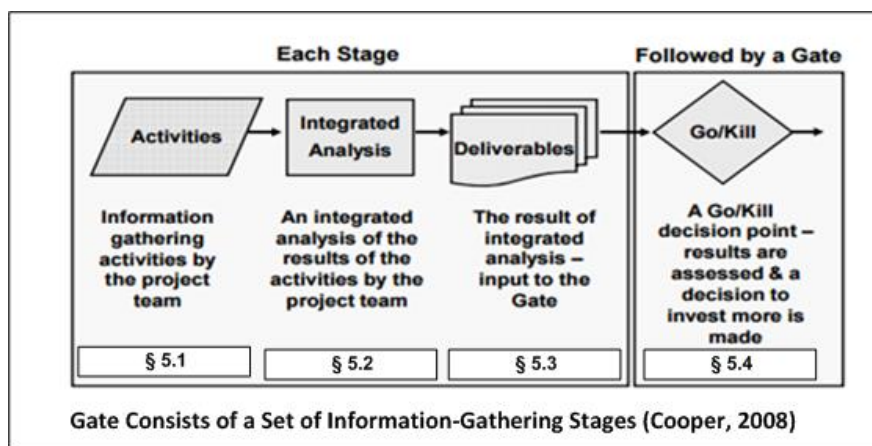


Figure 53 Gates Consists of a Set of Information-Gathering Stages (Cooper, Perspective: The Stage-Gate Idea-to-Launch Process – Update, What’s New and NexGen Systems, 2008)

5.1 KPI scores of the designs

In chapter 3 the importance of KPIs has been addressed and the need for well-chosen KPIs. General important KPIs for supply chain are: productivity, costs, flexibility and Corporate Social Responsibility (Cai, Liu, Liu, & Xiao, 2009). The KPI scores are presented in Table 15 KPI scores per alternative. Descriptions and explanations per KPI are given in the following sections.

Table 15 KPI scores per alternative

Productivity	Basic design	Semi-advanced design	Advanced design
Total capacity per year	1,892,000 ton (+FTF:392,098 ton)	2,286,700 ton	2,152,960 ton (+FTF:392,098 ton/year)
Total warehouse floor	189,200 m ²	228,670 m ²	234,700 m ²
Footprint productivity per year	10 ton/m ²	Multi-level 13 ton/m ²	Multi-level: 26,4 ton/m ² Single-level: 10 ton/m ²
Total warehouse footprint	119,200 m ² +FTF ³ : 6,460 m ²	180,880 m ²	134,600 m ² +FTF: 2,200 m ²
Financial	Basic design	Semi-advanced design	Advanced design
Building investment costs (SRE) ⁴	€ 205,585,546	€ 230,788,394	€ 225,063,270
Equipment investment costs (Handler)	€ 23,845,000	€ 41,286,000	€ 25,123,800
Rent price (year)	€ 22,704,000 FTF € 775,200	€ 24,573,000	€ 22,134,000 FTF € 775,200
Flexibility	Basic design	Semi-advanced design	Advanced design
Handling flexibility	+	0	-
Rent flexibility	+	+	-
Social Corporate Responsibility	Basic design	Semi-advanced design	Advanced design
CO2 emission	0	-	+

5.1.1 Productivity

The productivity rates of the alternatives are determined by the equipment selection. Table 15 shows the results of the productivity (ton/m²) and required warehouse footprints of all three alternatives. All designs enable the required productivity (2,240,560 ton/year). Two alternatives are designed with a FTF to reach this productivity level. The basic design scores best on the objective “footprint reduction”. However, the remaining land has been divided into fragments. The advanced design requires more footprint, however, the utilization of lot B is better exploited, leaving lot A for other developments. The semi-advanced design scores the worst on footprint. This could be explained by fact that this is the only alternative without a FTF. Total evaluation can be found in Appendix D10.1.

5.1.2 Financial

The building costs range from 205 million till 230 million euro. The basic design has the lowest building costs and the semi-advanced alternative the highest building costs due to the amount of buildings. As the basic design also has the lowest equipment cost, this alternative scores best on investment costs for SRE as well as for the ground handlers. Remarkable are the outcomes of the equipment costs. The basic and advanced designs have almost the same equipment costs. A highly mechanized (automated) warehouse enables faster cargo handling, what relatively reduces the amount of equipment (e.g. more ton per dock or working station handled). The semi-advanced design scores the worst on equipment cost, due to the fact that all cargo requires vertical transport by lifts. The process itself has not been designed more efficient. Low efficiency leads to lower

³ Different surfaces required for FTFs, dependent on operation (manual vs automated) (AppendixB2).

⁴ In consultation with R. Bakhuizen has been decided not to take land purchase into account, as the land is already in possession of SRE.

equipment utilization rates and requires therefore more equipment to handle total yearly tonnage. Total evaluation can be found in Appendix D10.2.

5.1.3 Flexibility

The flexibility aspects are reviewed on a qualitative way, compared with each other on an ordinal scale without an absolute zero point (Appendix D5.2). Handling flexibility can be accomplished by flexible floor space (low mechanization rate) and reduction of vertical transportation (Koet, 215). The basic design is most flexible due to the one-level operation with a low mechanization level. Although, warehouses are partly double layered, the operations are totally separated. The required vertical transportation is covered by ramps on land and airside. The operation of the semi-advanced design is comparable with the basic design. However, in the semi-advanced design the handling operation is divided over 2 layers, resulting in vertical transportation which makes the operation less flexible. The advanced design is categorized as lowest regarding handling flexibility, as the operation is in one warehouse is highly mechanized and the process is separated over 3 locations (FTF, Advanced warehouse and the standard warehouse).

The other important flexibility factor is the rental flexibility: how easy is it to rent the warehouse building to different ground handling operators over time (Bakhuijsen, 2015). As the operations of the basic and semi-advanced designs are similar; general cargo as well as specialties could be handled in the same building without much mechanization. These warehouses are quite easy to rent out to different all-purpose handlers. The advanced design on the other hand is less flexible for rental to different operators. The handling operation of general cargo and special handling is separated over two buildings. If a ground handler leaves, the successive party should have the same general cargo – specialties distribution. However, it is not said that this distribution is the same over all ground handling parties. The basic and semi-advanced designs are flexible in the way that the ground handler is able to handle all cargo in one building and could make the general-special cargo distribution themselves. For the advanced design this distribution is fixed.

5.1.4 Social Corporate Responsibility

Two general design indicators could indicate the truck CO2 emission in this research. Firstly the road grade as road grade can have significant effects on the fuel economy of vehicles (Boriboonsomsin & Matthew, 2009). The second important indicator is the potential congestion level. Vehicles spend more time on the road due to congestion and have relative high emissions during low speeds (Boriboonsomsin & Matthew, 2008) (Appendix D10.4). Especially congestion on slanted roads could have a negative influence on the CO2 emission.

All designs have slanted access roads. In the advanced design trucks are coming on demand, what reduces the probability of congestion. The advanced design has therefore the most positive influence on CO2 emission. The basic and semi-advanced designs do not have trucks on demand. The semi-advanced design is rated as worst due to the fact that all truck supply is done on the first floor. In the basic design only a fraction of the truck supply is done on the first floor.

Remark: The qualitative ratings might be subjective from the point of view of the researcher. An objective KPI result can be gained by running a dynamic model with empirical outcomes. However, a more detailed design is required to perform a dynamic simulation. For now these ratings give an indication.

5.2 Validation

Validation is defined as determining that the design is ‘reasonable’ and that the design’s output has sufficient accuracy for the intended purpose (Sargent, 2005). Two kinds of validations can be distinguished: theoretical and empirical validation (Loconsole, 2002). The alternatives can not be empirically validated as the validation is based on conceptual design what does not exist or is not modelled (TU Delft Wiki Systeemmodellering¹, 2014). Different non-empirical validation methods are performed for justifying the alternatives, on the basis of answering two standard validation research questions (Wieringa, 2010):

1. Are the design alternatives correct? (5.2.1)
2. Are the design alternatives sensitive for different contexts? (5.2.2)
3. Do the design alternatives contribute to stakeholder goals? (5.3)

Question 1 is answered on the basis of face validation. Face validity shows that processes and outcomes are reasonable and plausible (correct) within the frame of theoretic basis and implicit knowledge of system experts or stakeholder (Klügl, 2008). Question 2 is tackled in section 5.2.2 by means of an external robustness analysis⁵ in section 5.2.1. A robustness analysis is an approach to structure problem situations in which uncertainty is high, and where decisions can or must be staged sequentially (Rosenhead & Mingers, 2001). Robustness traditionally has not been considered as validation method in the strictest sense, since it is usually investigated during the design development, once the method is at least partially optimized (Krull & Swartz, 2008). This robustness check is not performed to investigate the robustness per alternative design, but to compare the robustness of the alternatives against each other, useful to choose between different alternatives (Krull & Swartz, 2008). The last question is answered on the basis of feedback from critical stakeholders in section 5.2.3.

5.2.1 Face validation of the designs by experts

The experts in the field of warehouse design development at Schiphol are parties which were already indicated in the Power/Interest grid in section 4.1.1. First an overall face validation of the Schiphol Group Cargo department is presented. Thereafter, a face validation by SRE with the focus on development of cargo warehouse is presented. The last performed face validation performed by S&P concerning the security of the alternatives.

Schiphol Cargo (problem owner)

Schiphol Cargo performances an overall face validation. All air cargo warehouses have been investigated during a presentation and feedback session with the whole cargo department. The majority of the participants have major concerns on the semi-advanced design regarding blockages on airside and landside due to dead ends and the safety hazards that this entails. Therefore, this design is not an option in their opinion. There are also doubts about the advanced design concerning non-proven technology. The majority of the Cargo department sees the advanced design as a high risk design.

⁵ Different from internal robustness analyses in chapter 4. In chapter 4 internal robustness has been evaluated. In this chapter the external robustness is checked, the robustness of the alternatives on external influences.

Schiphol Real Estate

SRE develops and manages real estate at the airport ground and thus is also responsible for the still to develop warehouse buildings. On behalf of SRE, W. van der Kooij (property manager SRE) and R. Bakhuijsen (portfolio manager SRE), have approved that all warehouse designs are within the constraints (height and surface). The rough cost estimations seem reasonable according to them. They raise concerns about the high mechanization levels and the shared FTF as it is the question how this will work out for the target market: all-purpose ground handlers. Furthermore, they are worried about potential blocking on air- and landside of the semi-advanced design.

Schiphol Security& Policy

The department 'Security&Policy' is responsible for the enforcement of the SRA border. On behalf of S&P R. Bakker and T. Lowijs approved all the warehouse designs. However, they noted that it is harder to guarantee the security level for the semi-advanced (i.e. more adjustments should be done to supervise the areas). Alternative 3 has great potential as labour costs could be decreased due to the cargo satellite designs. However, regulations need to be adjusted for this alternative, to enable an airside area and landside area above each other. Probable this would not form an impediment.

5.2.2 Robustness analysis of the designs

The robustness check is done by changing a single variable at a time. This method is recommended when models are constrained (Saltelli & Paola, 2010). In this case is the model constrained by the absence of empirical data. As it can not be computed other method with changing more variables at a time are not applicable.

An unoccupied warehouse is a waste of investment for SRE. Therefore, there is looked to the building flexibility over time of the three alternatives. So, first the total freight volumes are changed. The second variable that is changed is the cargo commodity distribution. Appendix D6 shows the case of the IAG Ascentis warehouse (Heathrow). This building is mostly dedicated to the handling of general cargo. The success lagged behind as the demand for special cargo increased. The success of the handling operation is in this case the flexibility to respond to the market demand. Both robustness analyses are done on a qualitative manner with intervals without an arbitrary zero point (Appendix D5.2).

Lower total freight volumes

Table 16 shows the results of a lower total growth and the ability to adapt the warehouse constructing expansion on demand. The construction flexibility is the best for the semi-advanced design as this concept exists of modular stand-alone buildings. The building flexibility of the basic design is rated as average, as the buildings at lot A are modular. However, the buildings on lot B are intertwined, what requires constructing of the warehouses all in one time. This fact also applies to the advanced design, as the handling process is divided over different buildings (general cargo, BUPs and specials). Building the highly mechanized general cargo warehouse goes along with the building of the warehouse for special handlings.

Table 16 Robustness analysis for lower total cargo volume growth (Author, 2016)

Lower total growth	Alternative 1	Alternative 2	Alternative 3
Construction flexibility	0	+	-

Commodity growths adaptability

Table 17 shows the results of divergences in commodity growths and the adaptability of the warehouse designs on these fluctuations. The basic design is, with all operation on the same level, the most flexible warehouse. A growth in specials or general cargo could easily be realized by restructuring the floors. The same applies for the semi-advanced design. However, a vertical movement in the handling process and less surface on the ground floor makes this alternative to some extent less flexible. A growth in special cargo will, in the first instance, not form a problem for the advanced design, as there is a large warehouse area totally dedicated to special handling. Although, when the special handling exceeds the capacity of the dedicated warehouse, the adjustment of the other building will be hard to achieve due to the handling equipment for handling general cargo in mechanized warehouse. Thereby, is special cargo handling over three layers not desired. Conversely, would the advanced design the best alternative when it comes to a growth in general cargo. The highly mechanized warehouse is able to handle high volumes general cargo, and general cargo could eventually also be handled in the special cargo handling building. The basic and semi-advanced designs are able to handle more general cargo by changing the warehouse divisions. However, these alternatives are not able to handle the volumes as the highly mechanized warehouse of advanced design.

Table 17 Robustness analysis for commodity growths adaptability (Author, 2015)

Commodity growths adaptability	Alternative 1	Alternative 2	Alternative 3
Special cargo Growth	+	0	-
General cargo growth	0	0	+

5.3 Critical stakeholder acceptance

In this section the critical stakeholders give a review on the three created design in the chapter 4. By comparing the objectives of the stakeholders with the KPI results, an indication of the stakeholder's preferences can be given. However, the KPIs never include all criteria. Therefore, a stakeholder review is important to evaluate the warehouse designs from different perspectives. The reviews have been conducted from interviews and feedback session. The following sections elaborate on the review per actor.

5.3.1 Schiphol Cargo (problem owner)

Some innovative cargo warehouse designs in the world are staying behind in their productivity rates as the innovations do not work as designed. Because of this Schiphol Cargo realizes the importance of implementing only design concepts that has been proven in other warehouses. This makes the Cargo team tending to the basic design. However, they also recognize the innovations in the industry and thus at their competitors. Implementing the basic design has the risk of staying behind on the competition in the future. For that matter should the advanced design be a better option. They prefer the advanced design, with the precondition that all design concepts are proven. Otherwise

alternative 1 will be on rank 1. Taking their boundary condition into account, the result of the group voting based on plurality resulted in the following ranking:

Schiphol Cargo Ranking	Design	Positive elements	Negative elements
1	Advanced design	High productivity level Trucks one way directed	Non-proven concepts
2	Basic design	Proven concept Trucks one way directed	
3	Semi-advanced design		Horseshoe design (land and airside)

5.3.2 Schiphol Real Estate

The property and portfolio managers of Schiphol Real Estate have reviewed the designs too. The outcome of the review is remarkable. SRE gave as input the following important KPIs: costs, rental flexibility and footprint reduction. However, they merely based their decision on rental flexibility and costs, and did not take the footprint reduction into account. SRE came to the following ranking:

SRE Ranking	Design	Overall positive elements	Overall negative elements
1	Basic design	Proven concepts Flexible for renting Low mechanization rate Trucks one way directed	
2	Semi-advanced design	Possibility to construct in phases	Horseshoe design (land and airside)
3	Advanced design	Innovative	Non-proven concepts Separation of handling process

The rental inflexibility of alternative 3 was decisive for giving this alternative the lowest rank. As the operation of alternative 1 is similar to the current handling operation at Schiphol this seems the safest option, what led to a number 1 rank for alternative 1. SRE considers alternative 3 as a distant future alternative with too many uncertainties to implement in the near future.

5.3.3 Ground handlers

The ground handlers' reviews⁶ are obtained from interviews with the parties: SwissPort, SkyLink, WFS and Dnata⁷. The main preferences of ground handlers for a specific alternative are different between alternative 1 and 3. Some ground handlers prefer a safe design with a proven warehouse concept (basic design). Others seem to see the advantages of faster cargo handling by more mechanization and less manpower (advanced design). The last group also takes the life span of a warehouse building into account. They stated that they will lack behind on the competition at other airports if there will be chosen for a traditional warehouse design. All ground handlers agreed that the semi-advanced design has no added value in comparison with the basic design.

An explanation for the different preferences could be explained by the differences in job functions of the interviewed ground handlers. The more conservative responses came from the higher management and the more innovative responses from operational managers. Higher management

⁶ Due to confidentiality, did the handlers not receive the calculated KPIs. Their opinions are purely based on the sketches.

⁷ Former Aviapartner

has more insight in the required equipment investments, what leads to a preference for the basic design. The operational managers seem to see the importance of mechanization in the process, not taking the investment costs into account. The following rankings for the different management groups came forward:

Ground handlers ranking (higher management)	Design	Overall positive elements	Overall negative elements
1	Basic design	Proven concept Low mechanization rate	Non-proven concepts Shared facility
2	Semi-advanced design	Total handling operation on one location	
3	Advanced design	Innovative	Non-proven concepts Horseshoe design (land and airside) General FTF Separation of handling process

Ground handlers ranking (operational management)	Design	Overall positive elements	Overall negative elements
1	Advanced design	High productivity Less human labour (probably) General FTF	
2	Basic design	Proven concept General FTF	No innovation
3	Semi-advanced		

5.4 Conclusion on basis of Stage-Gate method

It is essential to take the feasibility of alternatives into account. Study of an unfeasible design into further detail is waste of time and money (Cooper, Perspective: The Stage-Gate Idea-to-Launch Process – Update, What’s New and NexGen Systems, 2008). Remarkable in this context is the score of the semi advanced design on the KPIs, validation and critical actor ranking. The KPI scores of alternatives are not outstanding, what also showed off in the critical actor ranking. The semi-advanced design always scores lower than the basic design. Thereby, the semi-advanced design was also the biggest cause for concern in the face validation. Previous feedback taken into account, it can be concluded that alternative 2 is not a feasible design and is not included anymore⁸. Face validation on the advanced design also shows points of concern. However, this is not decisive enough to eliminate this alternative. Thereby, it has been shown in the critical actor feedback that some actors see the advanced design as best option.

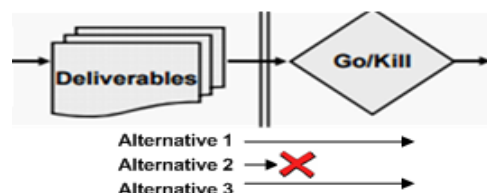


Figure 54 Stage decision of the alternatives retrieved from (Cooper, Perspective: The Stage-Gate Idea-to-Launch Process – Update, What’s New and NexGen Systems, 2008)

⁸ Remark: during the feedback session with the Cargo department and SRE, wrong building costs have been presented for the semi-advanced design. However, this alternative has been rejected on other reasons than costs. Therefore, it has been decided not to redo the face validation.

6 Case study evaluation and improvement

The aim of this chapter is to provide feedback on the case study and investigate if actions should be taken in order to achieve the initially specified objectives. This chapter is organized as follows. It begins by describing a general case study in section 6.1. It then goes on to providing an additional design suggestion in section 6.2. Finally, a validation is performed and conclusions are drawn in section 6.3.

6.1 Case study evaluation

The evaluation is twofold. Firstly, the preferences of the critical stakeholders are evaluated. Secondly, the contribution of literature to this case study is reviewed.

6.1.1 Critical stakeholder preference evaluation

There are different opinions regarding the best design. One part of the critical stakeholders would like to have absolute certainties and therefore chooses the safest option: the basic design. The other part of the stakeholders also keeps an eye on the competition. The average life span of an air cargo warehouse building is 40-50 years. Choosing for the basic design brings the risk of falling behind on competition in the future. The impact of this risk is emphasized by a benchmark. A benchmark is a continuous process of measuring products, services and practices against the toughest competitors, or those companies recognized as industry leaders (Camp, 1993). Since the alternatives are theoretical rather than empirical it is hard to compare the alternatives in an empirical benchmark. However, the designs are based on fundamental theories. This allows comparing the results of the designs with results that are expected from theory (TU Delft Wiki Systeemmodellering1, 2014). The basic and advanced designs are compared with leading air cargo handling operation in total output and in footprint productivity, shown in Table 18.

Table 18 International benchmarks compared with The basic and advanced designs (Author, 2016) (Districon, 2015)

	Basic design	Advanced design	HACTL	MASKargo	Turkish Cargo Istanbul
Total productivity [ton/year]	1,892,000 ton (+FTF:392,098)	2,152,960 ton (+FTF:392,098)	3.500,000	750,000	1,200,000
Maximum footprint productivity rate* [ton/m ²]	10	26,4	56	19	28

*maximum footprint productivity is the highest productivity that can be achieved. E.g. the advanced design has different footprint productivity rates, but only the highest rate is mentioned in this table.

Figure 55 illustrates the current benchmarking plan. This figure shows the current status in terms of some level of performance, the status of the major competition, and the desired objective. It can be assumed that the competitor is also involved in a benchmarking effort and has a higher goal. Thus, for the system in question, a plan must be developed that will enable one to follow path A-B in lieu of path C-D (Blanchard, 2008). The basic design will not have a positive influence if the goal is to reach the future benchmark of the competition. It can be concluded that differences between the basic and advanced designs are significant. Both alternatives form risks. The risk of the basic design is falling behind on competitors. The risk of the basic design is falling behind on competition. Risk of the advanced design is failure of the non-proven concepts and lack of adaptability of the ever shifting market demands.

6.1.2 Literature evaluation

In order to achieve footprint reduction multi-layer buildings and high mechanization rates are recommended in literature. The literature is dedicated to the overall warehouse innovation without specific details. There is a large gap between theory and practice. This leads to distrust from the industry, which has also come forward in the stakeholder reviews. The air cargo market has to deal with strong competition and a mistake in the

warehouse design could be fatal for a ground handling company. There is demand for warehouse innovations. However, stakeholders are restrained due to the large uncertainties of the innovative concepts. More detailed research could provide a solution by eliminating uncertainties.

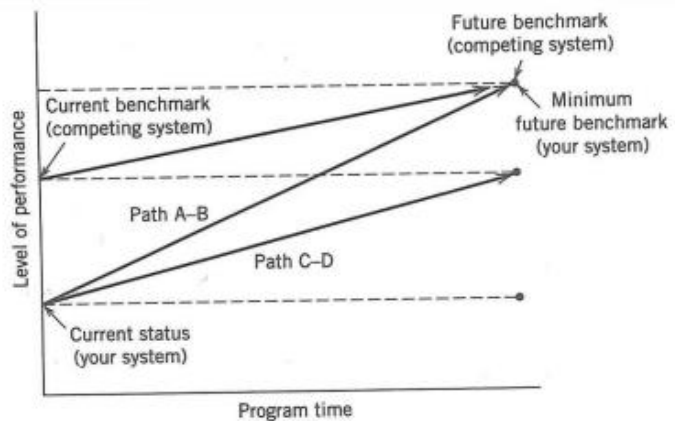


Figure 55 Benchmark (Grady, 1998)

6.2 Case study improvement

The aim of this chapter is to provide feedback and investigate if actions should be taken to achieve initially specified objectives. It has been clear that a forced choice between the basic and advanced designs will not lead to a desired outcome of this case study. To offer a more suitable design for Schiphol a new alternative is provided: alternative 3 'light', with priority on innovation and muting the risk of un-proven concepts.

6.2.1 Alternative 3-light solution space

To increase the stakeholder acceptance this section starts with a summary of feedback on the previous designs. The design elements that are appreciated by different stakeholders are: the Cargo satellite concept (horizontal SRA border), and the elements which improved the smoothness of the process, such as the one way directed airside and the PCHS adapted to the dolly trains for immediately loading. Less valued design elements are: dead-ends at both landside and airside, and the relative new techniques for air cargo handling, such as automatic bulk storage and trucks on demand.

Furthermore, are ground handlers not keen on a separated handling process as in alternative 3, where general cargo and specials were handled in different buildings. They see the advantages of a general fast track facility. However, they are not in favour of a shared facility for BUPs, since the market at Schiphol is very keen on maintaining confidentiality (clients and cargo types).

Therefore, the following proven concepts are taken into account in the 3-light solution:

- All landside areas are one-way directed
- As little mechanization as possible
- Truck will not come on-demand
- Total handling operation in one building
- Cargo satellite design to increase first line handling capacity
- (Partly) no airside required (immediate dolly loading from PCHS)

6.2.2 3-light design

It should be noted that this design is designed in detail. However, less thoroughly and with less elaboration than the alternatives in chapter 4. The warehouse buildings in the 3-light design are divided over both A and B lots. On lot A, a double layer warehouse has been placed with a total width of 120m (ground floor 90m, first floor 30m). There is no airside area, as the dolly trains are immediately be loaded from the PCHS. A total security clearance on the ground guarantees seamless transition between the warehouse area and platform.

On lot B a multi-level warehouse with the cargo satellite concept is implemented as well. For the same reason as on lot A. Furthermore, this is implemented to increase the first line handling capacity, as it enables building another warehouse behind the two layer building (explained in section 3.2.1). The warehouse behind the 'satellite' building is a standard warehouse with standard air- and landside terrains.

The warehouses are flexible in inner design, due to the low mechanization rate. Only the ULD storage and where needed the vertical transportation are mechanized. The low mechanization rate enables the handlers to design their inner process, with all operations under one roof: general, specials and BUPs handling. All truck movement in this design is one-way, in order to avoid blocking due to truck crossing lines. As trucks will not come on demand, all landside areas have a depth of 50m enabling parking and docking. The maps of both lots are shown in Figure 56 and the visualizations are shown in Figure 57.

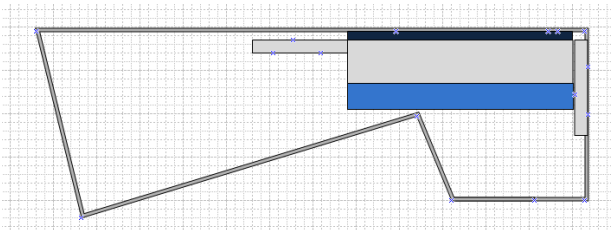
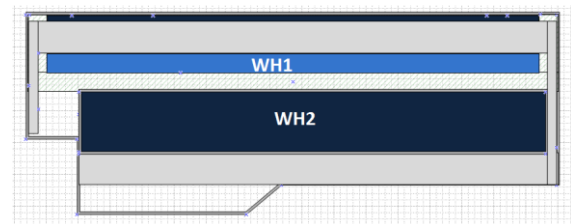


Figure 56 map of 3-light design (author, 2016)



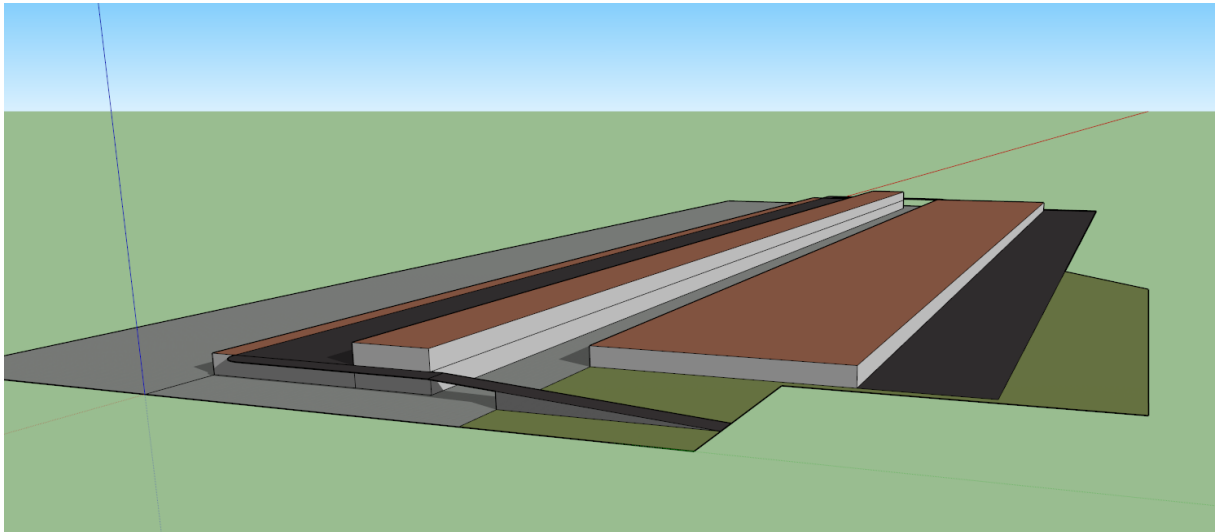


Figure 57 3-light warehouse design (Author, 2016)
 1. Overview warehouse design on lot B (Author, 2016)
 2. Cross section of the cargo satellite building on lot B

Productivity robustness analysis

The basis productivity rate for this design is 10 ton/m² per year. The operation of WH2 on lot B is similar to the operation of the current process at Schiphol. It is assumed that this productivity ratio is reasonable for this operation, taking the fact into account that 10 ton/m² per year already has been proven at Schiphol (shown in Table 7). However, a vertical transportation step is added in the other warehouse operations, what could negatively influence the productivity rate. Though, 10 ton/m² per year will be assumed taking the following facts into account:

- Not the all cargo is handled in a multi-level warehouse, as there is still a standard design. This reduces handling capacity uncertainty.

- This design enables expiation possibilities on lot A, if the productivity rates will be lower than 10 ton/m² per year. Although, extra constructions would raise the investment costs of SRE, it eliminates the probability of overcapacity at Schiphol.

These substantiations above and the fact that 10 ton/m² per year is the lower bound of the suggested productivity rate of Districon (10-14 ton/m² per year) leads to the conclusion that this is a robust design.

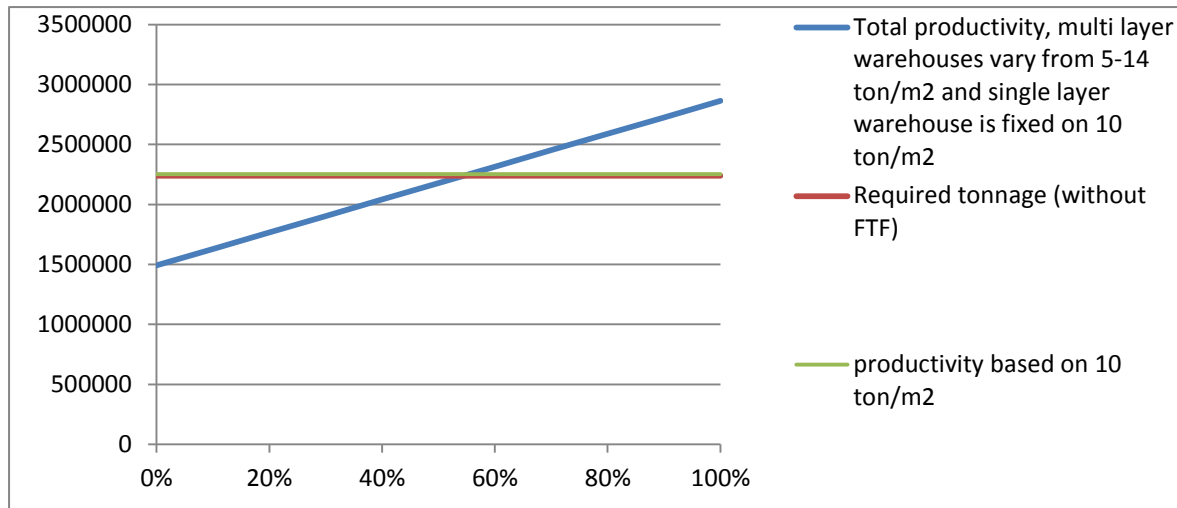


Figure 58 3-light design productivity ratio robustness analysis. Single layer warehouse is fixed on 10 ton/m². The productivity ratio of the multi-layer warehouses vary from 5 ton/m² per year ratio (shown on the left side) and 14 ton/m² per year (right side) (Author, 2016)

6.2.3 Results and evaluation of 3-light design

The KPI scores of the basic, advanced 3-light designs are presented in Table 19.

Table 19 KPI scores of the basic, advanced and 3-light designs (Author, 2016)

Productivity	Basic design	Advanced	3-light design
Total capacity per year	1,892,000 ton (+FTF:392,098 ton)	2,152,960 ton (+FTF:392,098 ton)	2,254,000 ton
Total warehouse floor	189,200 m ²	234,290 m ²	225,400 m ²
Footprint productivity per year	10 ton/m ²	Multi-layer WH: 26 ton/m ² One layer: 10 ton/m ²	Multi-layer WH: 13 ton/m ² One layer WH: 10 ton/m ²
Total warehouse footprint	119,200 m ² +FTF: 6460 m ²	134,320 m ² +FTF: 2200 m ²	182,800 m ²
Financial	Basic design	Advanced design	3-light design
Building investment costs (SRE)	€ 205,585,546	€ 225,068,270	€ 232,265,860
Equipment investment costs (Handler)	€ 23,845,000	€ 25,123,800	€ 37,689,000
Rent price (year)	€ 22,704,000 FTF € 775,200	€ 22,134,000 FTF € 775,200	€ 24,762,000
Flexibility	Basic design	Advanced design	3-light design
Handling flexibility	+	-	+
Rent flexibility	+	-	+
Social Corporate Responsibility	Basic design	Advanced design	3-light design
CO2 emission	0	+	-

Productivity

The productivity scores of the 3-light design are average compared with the basic and advanced designs. However, the required footprint is relatively high. This could be explained by the fact that the 3-light design is the only design without a general FTF. This means that all BUPs are handled individually by the ground handlers, which requires more warehouse surface and thus more footprint is required. Although, extra footprint is required for this design it contributes to the positive design element “Total handling operation on one location”.

Financial

The building costs of the 3-light design are highest. However, the rental costs are also higher. Higher building costs are not a problem as long as the rental income is in line with the investment costs (Bakhuijsen, 2015).

The investment for equipment costs are significantly higher compared to the other two designs. This can be explained by the fact that all warehouses operate their own fast track and 55% of the total cargo handling is handled in double layer warehouses, requiring mechanized vertical solutions.

Flexibility

The handling flexibility is rated as average relative to the other two designs. First the 3-light design is flexible in the way that all cargo can be handled on the same location (no general FTF etc.). However, on the other hand 55% of all cargo handling takes place over 2 layers, reducing the operational flexibility. The 3-light design will always be more flexible than the advanced design, with dedicated warehouses to special cargo types. Thereby the warehouses are suitable for successive tenants, as the whole warehouse module is suitable for all kinds of handling, the same as in the current warehouse operations.

Social Corporate Responsibility

The 3-light design is ranked as worst on CO2 emission compared with the other two designs. Firstly there is a risk of congestion formation as trucks do not come on demand. The same applies to the basic design. However, the warehouses in the 3-light design are more concentrated, increasing probability on congestion.

6.2.4 Validation of 3-light design

The face validation of the 3-light design is performed by Schiphol Cargo and SRE.

Schiphol Cargo (problem owner)

The overall face validation on behalf of Schiphol Cargo has been performed by H. Ritsema (Director Strategic Development at Schiphol Cargo). The 3-light warehouse design is by itself a feasible design for Schiphol, according to Ritsema. The one-way directed landsides together with sufficiently wide ramps are considered as positive design elements. However, Ritsema wonders how well a multi-level design will be adopted by the market (Schiphol's ground handlers) and if the used elements are proven technology in an air cargo environment.

Schiphol Real Estate

The face validation on behalf of SRE has been performed by R. Bakhuijsen (Portfolio manager SRE). He stated that the design would be appropriate for rental to different handler as it is rent-able in total modules, comparable with the current situation at Schiphol. Another positive point remarked

by Bakhuijsen is the fact that this design consist of 3 modules that can be constructed independently. In this way the construction can start when the market demand is sufficient.

6.3 Conclusion of case study evaluation and improvement

In the conclusion of chapter 5 is decided that on the basis of the go or kill principle of Cooper (2008) the semi advanced design will no longer be taking into account. This is due to lack of support from the stakeholders and negative face validation feedback. However, in this chapter it has become clear that a decision between the basic and advanced designs does not satisfy the initially specified objectives. Therefore, a new intermediate design has been introduced in this chapter: the 3-light design. It has been tried to combine all design elements which has been marked as positive in chapter 5, and leave out all negative evaluated design elements.

Taking feedback on the case study into account, it is expected that this design will receive a broader stakeholder support compared to the basic and advanced designs. Table 20 shows the feedback the researcher expects on this design. Taking this into account it is recommended to investigate this promising design into more detail.

Table 20 Expected feedback on the 3-light design

Design	Overall positive elements	Overall negative elements
3-light design	Flexible for renting Trucks one way directed Total handling on one location No shared facilities innovative	Non-proven concepts Mechanization rate

7. Conclusions and recommendations

Ground scarcity is a growing problem for airports. More efficient first line cargo warehouses are required to handle the increasing cargo demand. Several warehouse design variables are investigated in order to answer the following problem statement:

How to increase handling capacity using warehouse design variables under footprint constraints?

Section 7.1 summarizes the conclusions on generic aspects of infrastructure layout and footprint reduction variables. Section 7.2 continues on the consequences on stakeholder impact, the degree of mechanization as the main discriminator between three alternatives and conclusions of the KPI evaluation. The intermediate conclusion is that none of the three suggested design alternatives meet stakeholder expectations and a fourth alternative, called the 3-light design, is introduced. Sections 7.4, 7.5, and 7.6 respectively cover the contribution of this research warehouse design literature and recommendations for further research and work to realize the required Schiphol warehouses.

7.1 Conclusions from literature

1. What is an appropriate air cargo warehouse infrastructure layout?

Based on a literature study it is concluded that three main factors are of influence on the warehouse layout:

- The warehouse shape
- The warehouse orientation relative to the platform
- Secured Restricted Area (SRA) border location

The best warehouse layout concluded to be an I-shape, parallel to the platform with a traditional SRA-border along the platform. Although, the I-shape is a given, variations in warehouse orientation and an SRA border location are recommended to improve the ground utilization.

The warehouse shape

In terms of internal travel distance and productivity the I-shape is most appropriate warehouse shape. This conclusion is drawn from cross dock literature as literature on warehouse lay-out is not widely available. Cross dock operations are similar to air cargo warehouse operations on several aspects. The basic principle for shape determination is minimizing the internal travel distance (Cusumano, 1994). In the absence of space constraints this exercise will generally lead to preference for an I-shape, with the shortest transport distance perpendicular to the longitudinal axis of the building. Exceeding 150 docks will bring other shapes and sizes become interesting, as the internal travel distance becomes too large (Bartholdi & Gue, 2004). However, the differences between cross docks and air cargo warehouses should be taken into account. Cross docks generally have one flow, from inbound to outbound, they can be seen as one homogeneous, unidirectional operation (van Belle, Valckenaers, & Cattrysse, 2012). Air cargo warehouse operations handle more flows, e.g., import and export, which can be seen as two operations in one building. In a manual operated warehouse the import and export flows are separated, which divides the warehouse into two “separated processes” and decreases the number of docks per process. Therefore, it can be concluded that the I-shaped warehouse layout will remain the best, even when the number of docks exceeds 150 (Section 3.2.2). In terms of productivity is the I-shape also the most appropriate profile.

An important principle in cross dock layout designs is that corners reduce the efficiency due to lower usable space for (un)loading in the corners (Bartholdi & Gue, 2004).

Warehouse orientation

Traditional warehouses are positioned parallel to the platform. This is the most appropriate orientation given the truck-aircraft travel distance and security operation. However, a warehouse rotation of 90° creating an orientation perpendicular to the platform, improving the ground utilization as the depth of the lot is better used. A trade-off should be made between the internal travel distance together with the security options and the utilization of first line ground.

SRA border location

Traditionally the SRA border is vertical with parallel warehouses along this border, allowing good sight on the border for security services. However, the first line area could be increased by making this border horizontal, between warehouse layers, enabling a vertical (traditional) border further backwards (towards landside) (section 3.2.1). A precondition for this concept is a total isolated upper layer accessible by a bridge or ramp (Vonk, 2003).

2. Which footprint reducing design variables can be obtained from literature?

Airside area

Footprint reduction of the airside area can be achieved outsourcing its function to other locations with the following variables:

- ULD buffer function executed by the Pallet and Container Handling System (PCHS)
- Off-airport storage of empty Unit Load Devices (ULDs)

An effective solution is to remove the buffer function from airside, by buffering the ULDs in the PCHS in the warehouse. Instead, the PCHS should be designed such that dolly trains are enabled to immediately unload the ULDs into the PCHS. An off- airport empty ULD storage can be added. However, this is only recommended under extreme ground scarcity conditions, as it is an expensive solution with a relatively small impact on the footprint reduction.

Warehouse building

Footprint reductions inside the warehouse can be achieved by:

- Mechanization of the warehouse process
- Increasing the number of warehouse layers
- A general Fast Track Facility (FTF) outside the warehouse area

Mechanization is useful to reduce warehouse's footprint, as mechanized systems can overcome longer distances easier and are able to optimize height usage. However, mechanization is only applicable to a certain extent as not all cargo types are appropriate for mechanized handling. Moreover, the mechanization of the process is expensive and therefore only applicable in larger operations (economies of scale). The same applies to a multi-level warehouse as it is able to achieve higher footprint productivity. However, it can not be assumed that the footprint productivity will double, as vertical transportation adds slack in the process (Districon, 2015). Another variable to obtain footprint reduction is to bundle all individual fast tracks: roller bed from airside direct to landside for Build Up Pallets (BUPs), which do not require further handling in the warehouse. A general FTF increases the utilization rate by combining the BUP transport of more handlers and does not require warehouse surface (Kallen, 2015). It should be investigated per individual airport how a general FTF will work out, as ground handlers are not keen on sharing facilities due to confidentiality issues.

Landside area

Footprint reduction of the airside area can be achieved by:

- Smoothing the process
- Trucks on demand
- Slanted docks

Smoothing the landside process by separating processes is a relatively simple manner to reduce the landside footprint, and therefore recommended in any design. The same applies to trucks on demand. However, lack of commitment could block this implementation. Slanted docking is only suggested in extreme ground scarcity areas, as it negatively influences the unloading process.

3. Which factors influence the required warehouse surface determination?

Based on a literature study it is concluded that the warehouse surface determination is based on three factors:

- Mechanization level
- Warehouse levels
- Market demand

The IATA has based the productivity ratios on the level of automation; the more the warehouse operation is automated, the higher the productivity rate per warehouse level (IATA, 2015). Automation is only applicable if the operation is already mechanized. Therefore, forms mechanization level the basis of productivity ratios of the IATA. Generally the vertical distances are bridged by mechanized solutions. The level of mechanization therefore aligns with the number of warehouse layers. Districon bases therefore their productivity ratio on the number of warehouse layers (Districon, 2015). However, both ratios are calculated based on a 100% warehouse occupation and do not take the market demand into account. A highly mechanized warehouse is able to handle large general cargo volumes, but the actual productivity will be determined by the market demand. Local design influences as a general FTF are not taken into account in the production ratios nor mentioned by IATA or Districon. According to Kallen (2015) does a general FTF has major influence on the productivity rates within the warehouse building. It is recommended to already take these kinds of local influences into account in an early design state.

7.2 Conclusions Schiphol Case

4. How do stakeholders drive the development of new air cargo warehouses?

Next to Schiphol Cargo, the larger ground handlers and SRE have been identified as critical stakeholders (Section 4.1). An important stated requirement of Schiphol Cargo is that the warehouses design shall make sure that 3 million ton cargo per year can be handled at Schiphol, taking into account the handling peak times. The existing cargo warehouses at South-East will remain, which means that the new warehouses must be able to handle 2,2 million ton in total. The physical boundary conditions for the warehouse designs are imposed by the area and height restriction at Schiphol.

Objectives of the critical stakeholders are those for which satisfaction can be relaxed during the research, although their relaxation should be minimized (Liu, 1995). Objectives retrieved from

interviews and field research are classified in important KPI categories obtained from literature, suitable for comparing the alternatives in respect to each other.

5. Which warehouse configurations are feasible after applying local constraints?

The mechanization rate has been chosen as basis to determine the different alternatives, as the mechanization rate determines into a large extent the handling capacity. (The mechanization level is also taken as base in the productivity rates of Districon and IATA). Three alternatives have been set up. Two extremes and one intermediate alternative, presented in Table 21.

Table 21 Design alternatives Schiphol (Author, 2016)

Alternative	Number of layers	Automation level	General Fast Track Facility?	Remark
1. Basic warehouse design	1	Low mechanized	Yes – manual operated	Objective: maximize operational flexibility Operation similar to current operation at Schiphol (whole operation on one level)
2. Semi-advanced warehouse design	2	Medium mechanized	No	Objective: balance operational flexibility & footprint productivity. All warehouse operations divided over two levels
3. Advanced warehouse design	3	Highly mechanized	Yes – automated	Objective: maximize footprint productivity. Operation spread over 3 buildings (FTF, General cargo Building and special cargo building)

The alternatives are reviewed on the basis of KPIs, divided into four important KPI categories, derived from literature (Cai, Liu, Liu, & Xiao, 2009); (Samson, 2015): productivity, financial, flexibility and Social Corporate Responsibility. Many overall KPI evaluation methods are applicable. However, an overall KPI evaluation allows the researcher to (unintentionally) manipulate the importance of the KPI (Panusuwan, 2008). To avoid manipulation by overall ratings, the KPIs are presented on KPI level in Table 22.

The alternatives are reviewed on the basis of KPIs, divided into four important KPI categories, derived from literature (Cai, Liu, Liu, & Xiao, 2009); (Samson, 2015): productivity, financial, flexibility and Social Corporate Responsibility. Remarkable is the footprint productivity of the basic design compared with advanced design, as advanced design is designed with the concept of height optimization. The higher footprint of the advanced design can be explained by the fact that it also includes a large ‘standard’ one layer warehouse. Another remarkable outcome is the score of the advanced design on the equipment costs. The highly mechanized warehouse of the advanced design requires a lot of equipment. However, as the process is much faster than a manual operation, there is a relatively lower amount of equipment required for the advanced design. The advanced design scores the worst on both flexibility KPIs, as the operation is divided over 3 locations: FTF, General cargo Building and special cargo building. This increases the handling complexity and rent ability of the warehouses.

Table 22 KPI scores for three mechanization levels alternatives (Author, 2016)

Productivity	Basic design	Semi-advanced design	Advanced design
Total capacity per year	1,892,000 ton (+FTF:392,098 ton)	2,286,700 ton	2,152,960 ton (+FTF:392,098 ton)
Total warehouse floor	189,200 m ²	228,670 m ²	234,700 m ²
Footprint productivity per year	10 ton/m ²	Multi-level 13 ton/m ²	Multi-level: 26,4 ton/m ² Single-level: 10 ton/m ²
Total warehouse footprint	119,200 m ² +FTF: 6,460 m ²	180,880 m ²	134,600 m ² +FTF: 2,200 m ²
Financial	Basic design	Semi-advanced design	Advanced design
Building investment costs (SRE)	€ 205,585,546	€ 230,788,394	€ 225,063,270
Equipment investment costs (Handler)	€ 25,405,000	€ 41,286,000	€ 25,123,800
Rent price (year)	€ 22,704,000 FTF € 775,200	€ 24,573,000	€ 22,134,000 FTF € 775,200
Flexibility	Basic design	Semi-advanced design	Advanced design
Handling flexibility	+	0	-
Rent flexibility	+	+	-
Social Corporate Responsibility	Basic design	Semi-advanced design	Advanced design
CO2 emission	0	-	+

For justification the alternatives, different non-empirical validation methods have been performed, on the basis of answering three standard validation research questions (Wieringa, 2010):

1. Are the design alternatives correct? During the Phase validation by experts, the semi advanced design came forwards as not feasible due to the potential of blocking caused by dead ends in the designs.
2. Are the design alternatives sensitive for different contexts? This question has been answered on the basis of a robustness analyses. First the flexibility in building construction has been investigated. The basic design scores better in the way that is consists of more modules than the advanced design. The second robustness analysis that has been performed is about the adaptability on commodity growth (general and special cargo). The advanced design is most robust on a general cargo as it is specialized in it. However, the basic design is more robust in the case of a growth in specialties due to the total flexibility of the design (1 layer operations, with a low mechanization rate).
3. Do the design alternatives contribute to stakeholder goals? The semi advanced warehouse design does not contribute to the stakeholders' goals. The opinions among the Basic and Advanced designs are divided. All stakeholders realize the importance of proven concepts and warehouse flexibility. However, sticking to a standard design could have negative consequences on the future competition position.

Based on the validation and stakeholder feedback is decided to take the semi-advances warehouse design not into account anymore. However, the stakeholder opinions on the remaining basic and advanced design are mixed. Choosing for the basic design would bring the risk of staying behind on the competition in the future. However, choosing for the advanced design would bring the risk of implementing unproven design concepts. To conclude: the case study did not have the desired outcome. Therefore, a new alternative has been set up: Alternative 3-light. In this alternative proven concepts which obtained positive response are taken into account:

- All landside areas are one-way directed
- At least as possible mechanization
- Truck will not come on demand
- Total handling operation in one building
- Cargo satellite design to increase first line handling capacity
- No airside required (immediately dolly loading form PCHS)

The 3-light design does not score well on the productivity and financial KPIs (Table 23). However, it includes much desired warehouse design elements. The overall face validation of the 3-light design has been performed by H. Ritsema (Schiphol Cargo) and R. Bakhuijsen (Schiphol Real Estate). According to them is the 3-light design by itself a feasible design for Schiphol. The one-way directed landsides together with sufficiently wide ramps are considered as positive design elements. However, Ritsema wonders how well a multi-level design will be adopted by the market (Schiphol's ground handlers) and if the used elements are proven technology in an air cargo environment. Further feasibility studies for this design are recommended.

Table 23 KPI scores of the basic, advanced and 3-light designs (Author, 2016)

Productivity	Basic design	Advanced design	3-light light design
Total capacity per year	1,892,000 ton (+FTF:392,098 ton)	2,152,960 ton (+FTF:392,098 ton)	2,254,000 ton
Total warehouse floor	189,200 m ²	234,700 m ²	225,400 m ²
Footprint productivity per year	10 ton/m ²	Multi-level: 26,4 ton/m ² Single-level: 10 ton/m ²	Multi-level: 13 ton/m ² Single-level: 10 ton/m ²
Total warehouse footprint	119,200 m ² +FTF: 6,460 m ²	134,600 m ² +FTF: 2,200 m ²	182,800 m ²
Financial	Basic design	Advanced design	3-light light design
Building investment costs (SRE)	€ 205,585,546	€ 225,063,270	€ 232,265,860
Equipment investment costs (Handler)	€ 25,405,000	€ 25,123,800	€ 37,689,000
Rent price (year)	€ 22,704,000 FTF € 775,200	€ 22,134,000 FTF € 775,200	€ 24,762,000
Flexibility	Basic design	Advanced design	3-light light design
Handling flexibility	+	-	0
Rent flexibility	+	-	+
Social Corporate Responsibility	Basic design	Advanced design	3-light light design
CO2 emission	0	+	0

7.3 Overall conclusion

How to increase handling capacity using warehouse design variables under footprint constraints?

Handling capacity can be increased in different ways by implementing different warehouse design variables. These variables will be divided over 3 categories:

1. Variables which are relatively easy to incorporate in a warehouse design.
 - 90° rotation of the warehouse to improve the ground utilization.

- A double layer warehouse. Two levels do not complicate the process that much. It is even possible to create a horizontal warehouse separation, with elimination of vertical transportation requirements (e.g., alternative one of the case study).
 - Smoothing variables. Fewer blockings in the process offers opportunities to increase the handling capacity
 - Landside: one way directed landside with a separate entrance and exit.
 - Warehouse: by designing an I-shape warehouse with the optimal width, aligned with the handling process.
 - Airside: by buffering full ULDs in the PCHS
2. Variables which are more complex to incorporate in a warehouse design
 - Construct three or more layers. Although it complicates the handling process, it is a very effective factor regarding handling capacity.
 - High mechanization level. Relative to manual operations are mechanized processes able to operate faster and increase the height usage and thus the handling capacity.
 - Creation of a horizontal SRA. It increases the handling capacity by increasing the available land for air cargo warehouses.
 3. Variables that only should be implemented under extreme ground scarcity conditions.
 - Off-airport empty ULD. An expensive implementation with a relative low effect on the handling capacity.
 - Slanted docking. An effective variable, but with a negative influence on the unloading process.

7.4 Relevance to literature

This research has a special focus on the case study of Schiphol Group with specific environmental criteria. However, to come to the specific designs a lot of literature has been consulted. Literature used was generally written for cross dock buildings, as there was a lack of papers discussing the warehouse variables and the best shape for a warehouse in detail. Air cargo warehouses are to a certain extent comparable with cross docks. This study identified the warehouse design variables based on cross dock literature, but it also indicates into which extent cross dock literature is not relevant for air cargo operations. A lot of what is identified in this research is already performed in real life. However, this research scientifically underpins the real life observations. In this way the air cargo industry can be understood better, which can be considered as relevant for air cargo warehouse design literature.

7.5 Recommendations for further research

First it is recommended to investigate local influences on the productivity rates. The standard ratios based on level of automation and numbers of warehouse layers are quite general. It could be useful to specify these ratios with typical influences e.g. the distribution of import and export, the presence of a fast-track within or outside the warehouse and commodity distribution as these could be of major influence on the production rate.

Second it is recommended to study the impact of mechanization/automation on the operational costs and particular on labor costs, dedicated to the air cargo industry. Operational costs were not

taken into account in this study due to lack of available information. However, this is a factor which could have major influence on the decision to mechanize/automate a handling process.

7.6 Recommendations for Schiphol

A couple of general factors concerning Schiphol's business model of warehouses should be further investigated:

First the rental price of a multi-layer warehouse should be reconsidered. In cooperation with SRE, a rough estimation of rental prices has been made for the first and second layers. The suggested price should be arithmetically checked on accuracy.

One of the objectives for SRE was a flexible warehouse design which could be rented out to different successive handlers. Different options for realization of flexible rent options have been discussed. However, there has not been a specific outcome yet. This is of great importance on the future warehouse building designs. It is recommended to prioritize this topic as it is input for the schematic designs.

The last recommendation is to reconsider the possibility of purchasing ground of Mr. Poot, creating a rectangular lot for area A. It is recommended to investigate what prevails:

- Take the current lot into account with the risk of a less flexible ground handling operations and more costly buildings *or*
- Consider a rectangular lot, with an expensive land purchase, enabling a more appropriate warehouse layout for the operation as well for the building costs.

In the case of option 1, further research to the actor's preferences and benchmark studies are recommended. Based on the current feedback it is recommended to elaborate the basic and 3-light design into further detail. If land acquisition is contemplated, the recommendation is to design new, less complex, schematic designs. However, the literature, non-case specific criteria and the design method of this case study still forms a good framework for potential new designs.

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