An experimental multi-domain model for material handling system design

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Master‘s thesis

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Graduation project

Baggage handling system of the future

Subject

Vanderlande is marketleader worldwide in the design, supply, maintenance and operation of baggage handling solutions. Specific domain knowledge combined with operational and logistic concepts (abstract methods) and deployed by quality products are key succes factors over the last two decades. In order to maintain its leading position Vanderlande is investing in new products driven by applying new technologies, but also innovating with operational and logistic concepts. Creating more and/or additional business value for airport stakeholders is driving this quest. Business parameters as space, footprint,performance aspects, cost (investment and operational costs) play a role, but also the so-called ilities(maintainability, flexibility, etc.) Last but not least, a new question is on the table, whether the total supply chain of baggage handling (door-to-door) needs to or will change.

Assignment

The assignment is to develop the baggage handling system of the future together with a multidisciplinairy team using a model based approach. Different parameters from different domains (technology,performance, business) create a multi-dimensional optimalisation problem. What is impacting what,what is influencing what, etc. Work has been done in the past to support system design (cost domain in combination with space and functions). We learned that modeling the multi-domain problem not only provides a platform for experimentation and knowledge building about the dependencies, but also gives new insights and ideas that enable innovation at conceptual and product level.Direct result of the assignment would be a defined and implemented multi-domain model that allows the team to explore and experiment with different parameter settings, that is build upon a basis of logistics performance modeling. As part of this work, research will have to be done for scoping decision(abstraction level, which details, what theoretical base exists maybe elsewhere that can be (re)used) and validation purpose.

Start	September 2014
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Abstract

In this research a first step is made towards a multi-domain model that should assist Vanderlande Industries in the design of material handling systems. The report covers a company profile and literature on the design of material handling systems. Afterwards is discussed how the system of the distinct business domains are generalized to a generic material handling system, which consists of five generic functions. Lastly, due to research on both process and material flow diagram this research resulted in defined functional attributes, TSU attributes, and interfaces that are used to construct process flow diagrams.

Definitions and abbreviations

Definitions

Performance
Capacity Throughput in general, the number of units that can be processed per hour.
Design capacity The theoretical capacity of individual equipment, on basis of speeds or cycle times.
In-system time The minimal time for a product to go from a system entry to an exit.
Availability The percentage of time a function or system is able to perform according to the requirements Vanderlande and its customer agreed on.
Redundancy The duplication of critical components or functions of a system with the intention of increasing reliability of the system.
Convey-ability The ability to be conveyed by a material handling system, usually indicated with a range of dimensions and weight.
Irregulars Products that are not able to be transported by the regular system. In some cases a separate system is build to handle irregulars.
Non conveyable Products that can not be transported by a conveyor (e.g. fishing rods or live animals) unless placed in a carrier.
Crossdock The transshipment of an unloading dock directly to a loading dock.

Economical
Capital expenditure Acquisition costs such as equipment cost, project execution costs and costs for initial spare parts.
Operating expenditure Cost involved to operate the system through its life cycle such as, maintenance and labour costs.
Total cost of ownership The sum of Capital and Operating expenditure, the total cost involved through a systems life cycle, or other defined period of time.

Building
Footprint The amount of floorspace required to place a piece of equipment.

Quality
Mishandled The delivery of a unit to the wrong destination, this may result into a penalty cost.
Lead time The time between the placement of an order, and the loading in a vehicle.

Abbreviations

VI	Vanderlande Industries
PFD	Process flow diagram
MFD	Material flow diagram
OOG	Out of gauge
SKU	Stock keeping unit
TSU	Transport and storage unit
ICS	Individual carrier system
KPI	Key performance indicator
STD	Scheduled time of departure

G	Generator
U	Unloading
T	Transformation
S	Sort
ST	Store
L	Loading
E	Exit

Contents

Chapter 1

Introduction

1.1 Research context

Being one of the market leaders in material handling systems, Vanderlande offers material handling solutions for the domains: Parcel and postal, Baggage handling and Warehouse automation. And for each of these solutions, decisions need to be made involving performance, volumetric, economical and quality related parameters.

To guide engineers, Vanderlande applies the 4-step design process to go from customer requirements to system design concept. With each step taken, more detail is given to the design, reducing the inaccuracy in estimations. In the design process the engineer will first develop a "process flow diagram", subsequently followed by a "material flow diagram" and a "layout". However, due to lack of resources and time an engineer is not able to review all alternatives in the scope, and thus can not guarantee the design qualitatively is the best concept for the customer.

To be able to consider all alternatives Vanderlande is searching for a "multi-domain model" that allows them to explore and experiment with different parameter settings. The multi-domain model aims to embody all three Vanderlande domains in a single model instead of three separate models, to offer synchronization between the distinct domains.

By means of synchronization, it is intended to further standardize the way of working in both the sales and design process. Furthermore, by generalizing the terminology, it is believed that communication between departments improves, making the multi-domain model a platform for knowledge sharing.

As a result of this knowledge platform, the generic multi-domain model, ultimately facilitates synchronization between the distinct domains and offers opportunities for technical cross-overs. Assisting to use technologies and/or logistical concepts from one domain in the others.

1.2 Scope

In this study, a first step is made towards the multi-domain model that should assist design engineers to develop system concepts. Therefore, it was firstly necessary to define a generic terminology to embody the domains in a single model. The goods handled by material handling system are generalized in “transport and storage units”, which enables the discovering of generic functions that are carried out by material handling systems.

The functions that resulted from research on process flow diagrams and material flow diagrams are then formalized with attributes and interfaces, such that process flow diagrams can be constructed.

In construction of a process flow diagram it is firstly intended to construct a minimum process flow diagram as a starting point. The minimum PFD solely embodies the functions that are required to form a feasible process flow diagram, in which arriving goods are unloaded correctly and build up again to have the correct shipment. Furthermore, the minimum PFD includes the operations that are important for the process of the customer, like the screening of a bag or the storing of goods to hold inventory. Additionally, these operations are positioned such that they are applied on the correct type of goods.

By introducing more relevant attributes or requirements, one can extend the minimum PFD to more constrained PFDs. That in further research can be extended to material flow diagrams.

1.3 Report structure

This report firstly familiarizes the company Vanderlande to the reader. Chapter 2 introduces the three domains, process and material flow diagrams, and both the processes of sales and concept design applied by Vanderlande.

Secondly, Chapter 3 discusses literature that was embarked on the start of this research.

Thirdly, Chapter 4 examines the derivation of the generic material handling system and discuss both a generic description of Transport and store units, and the behavior of material handling systems.

Then, in Chapter 5, the framework of attributes and interfaces is introduced that is required for the construction of process flow diagrams. Additionally, this chapter demonstrates a case where in a process flow diagram of a Vanderlande system is reconstructed using the attributes and interfaces.

Lastly, Chapter 6 depicts the conclusions of this research along with recommendations for future work.

Chapter 2

Vanderlande Profile

This chapter is intended to familiarize the reader with Vanderlande. First a brief overview of the company's history is displayed, followed by a description of the different domains in which the company is active, the sales procedure and the process of concept designing. After reading it should be clear what kind of company Vanderlande is and how they get to a system design concept, which is essential to understand the scope of this research.

Information displayed in this chapter is mostly obtained via personal communications with Vanderlande personnel[1] and via the internal database Vikipedia [2].

2.1 History

Vanderlande was founded in 1949 by Eddie van der Lande[3]. It started as a family company consisting of a machine factory and a construction workshop. At that time Vanderlande produced amongst others, machinery for production, hoisting cranes, and transport systems. In 1963 the company was bought by the American company Rapistan, which lead to the focus on internal transport systems. In 1971 the company moved to their current location in Veghel and a couple of years later, in 1988, the van der Lande family bought the company back from Rapistan and went on as an independent company.

Currently Vanderlande is market leader worldwide in the design, supply, maintenance and operation of material handling solutions. With about 3000 employees worldwide the company is active in the markets for Parcel & Postal, Baggage handling, and Warehouse Automation domains. Thereby, focusing on improving the customer's business processes and increasing their logistical performance, now and through the entire life cycle.

To achieve this, the company has a wide product range and industry knowledge. Vanderlande also possesses capabilities in relevant disciplines that range from system design and engineering, through supply chain management to customer services.

2.2 Domains

In this paragraph the three domains, in which Vanderlande is active, are described. Starting with Parcel & Postal respectively followed by baggage handling and warehouse automation. First some background is delivered followed by a process description and solutions offered by Vanderlande[3].

2.2.1 Parcel and Postal

From letters to pallets to cars, all around the world goods are transported from A to B. Depending on the weights and lead times these are all different processes, carried out by distinct companies. Figure-2.1 demonstrates the different areas of transport and also indicates the scope in which Vanderlande is active. As indicated, Vanderlande is active in both the postal- and express segment that primarily transport parcels.

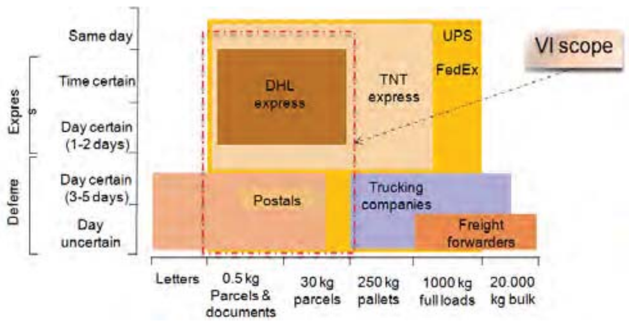

Figure 2.1: The scope of Vanderlande in the moving goods market

On a daily basis millions of parcels are delivered worldwide. And due to the growth in e-commerce it is expected this amount is going to increase. The challenge is to handle all these parcels and deliver them to the correct location and in time. Through a network of several depots and hubs, parcels are eventually delivered to the customers' door. Although the depots and hubs differ in size and automation levels, the basic process is approximately the same, as is explained in the **Process** sub-subsection.

Process

Typical for the Parcel and Postal market is the fact that sites are only open for a couple of hours, leading to high peak capacities. Independent of the size of the depot each parcel goes through the same process that is demonstrated in Figure 2.2.

Firstly, parcels are unloaded from a van, trailer or plane and placed on the system. Secondly, the parcels are identified by scanners to determine the destination, weight and/or volume of the parcel before they are sorted (manually or automated) to an end destination. There the parcels are loaded into another vehicle that delivers the parcel to another depot or to a customer. When parcels are already presorted on a pallet or a roller container they are directly transferred from the unloading dock to the loading dock without system interaction, this is called cross-docking.

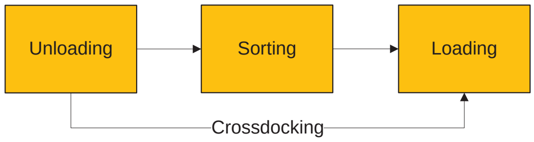

Figure 2.2: Basic process flow diagram of a parcel and postal depot

Solutions

Despite the basic process is similar, the required solutions differ depending on the demanded capacity. Table 2.1 hands an overview of the typical parcel and postal solutions, for different capacity ranges. As the demanded capacity increases, the automation level also increases. Below, the different solutions are briefly described to give an indication of these systems.

Table 2.1: Parcel and Postal depots and their typical solution

Depot	**Solution**	**Capacity (Parcels per hour)**	**Automation level**
Depot	Manual sorting	2000 - 5000	Low
Automated depot	Single line or loop sorter	5000 - 13.000	Medium
High capacity hub	Multi-sorter (lines and/or loops)	13.000 - 40.000	High
Airhub	Multi-sorter (lines and/or loops)	40.000 - 300.000	High

Manual sorting With manual sorting parcels are unloaded from vans or line haulers and placed on a long conveyor, and are then picked by operators when it belongs to their destination. Mostly the parcels are loaded in roller containers, which are subsequently loaded in vans. To make better use of the vans it occurs that containers are loaded in the transporters from which parcels were unloaded.

Line sorter As the flow of parcels increases, it becomes more lucrative to invest in a sorter to increase efficiency and reduce mishandled parcels. One of the options is a line sorter, a straight sorter that transfers parcels to the destined chutes. As line sorter Vanderlande employs the Posisorter that transfers the parcels by the movement of black shoes. Figure 2.3 depicts a Posisorter that sorts a parcel to the right, into a chute that can be seen in the figure. Parcels enter at the beginning of the sorter and end in a disposal chute when they are not sorted to a destination. Parcels that end up in this disposal chute are sorted to their destination by hand.

Figure 2.3: (L-R)A Posisorter sorting a parcel to the right, and a roller chute

Loop sorter An alternative for a single sorter solution is a loop sorter. For which Vanderlande offers the Crossorter, which basically is a long belt of conveyors with their transport direction perpendicular to the transport direction of the belt. When a parcel is inserted or sorted to a destination the motor of the conveyor is turned on to rotate the conveyor in the proper direction. Since the sorter is orientated in a loop it is possible to insert parcels at various points of the sorter. In general, most depots that have this sorter also have unloading docks on multiple sides of the building, which is not the case for line sorters.

To increase efficiency of the loading and unloading process of line haulers, an extendable conveyor is deployed, to decrease the walking distance of the operators[1]. An example of such a conveyor can be seen in Figure 2.4.

Figure 2.4: (L-R)A Crossorter and an extendable conveyor

Multi-sorter In multi-sorter projects the number of parcels to be handled is too big to be handled by a single sorter. In such projects multiple sorters are combined to handle these large parcel flows. The multiple sorters can be orientated alongside one and other or stacked on top of each other. In the case the sorters are stacked; the sorters sort out on spiral chutes. In Figure 2.5 one can see these spiral chutes from which the parcels are loaded in the vehicle.

Figure 2.5: Spiral chute, connected to multiple sorters

[1] The belt conveyor is also usable for line sorters

2.2.2 Baggage handling

In the world today it becomes more common to travel by plane. Passengers are flying more frequently and further away. Studies from the international air transport association (IATA) showed 2.98 billion passengers traveled by plane in the year 2012 and is expected to grow to 3.91 billion passengers in 2017. This growth in volume leads to a lot of possibilities for Vanderlande. Airports are expending and many new airport ports are deployed that all need baggage handling solutions.

In the baggage handling market, Vanderlande makes a distinction between three types of airports. Increasing in size and passenger volume they consider regional airports, international airports and intercontinental airports, also called air hubs. Although the airports handle different passenger volumes, the processes a bag will be subjected to are approximately the same, as is explained in the **Process** sub-subsection. Nevertheless the solutions for these airports differ. The different solutions are briefly described in the **Solutions** sub-subsection.

Process

As mentioned, a distinction is made between different airports. However, independently of the airport‘s size the processes are rather identical. Figure 2.6 demonstrates the process flow for an airport, including both a departure and arrival process.

For a departing flight, passengers first deliver their bags to a check-in desk or at a self bag drop, from which the bags get onto the system. Subsequently the bags are checked for explosives and other dangerous goods at the screening machines, often called (hold baggage) screening. Screening became a trending topic in 1988 due to the Lockerbie bombing and even became more important after 9-11. With several screening levels airport personal ultimately dispose hazardous bags, preventing them to enter an airplane. Once a bag has been cleared it either goes to the early bag store or will be sorted to the make-up point of a flight, depending on the departure time of the aircraft. In the storage the bag awaits the moment it is needed at the make-up point, where bags are prepared for the loading of a departing flight.

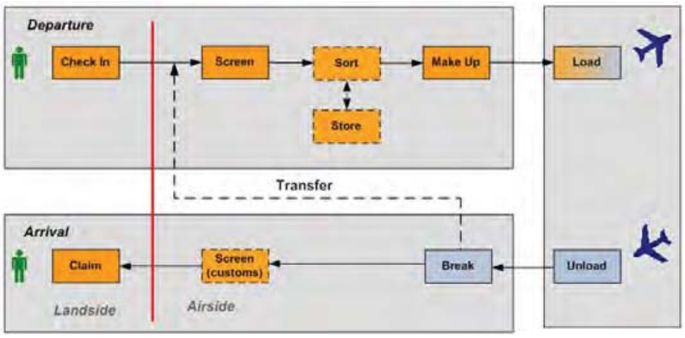

Figure 2.6: Process flow of an airport

When arrived on the targeted airport, the bags are unloaded from the plane and brought to the reclaim carousels, in case the passenger is on its final destination. Otherwise, when the passenger has a connecting flight, the bags are transferred to the baggage handling system where they undergo the same process as departing bags.

Solutions

Depending on the size of the airport, Vanderlande offers a different solution. As a rule of thumb each airport category has a typical solution, as demonstrated in Table 2.2. The bigger the airports, the higher the automation level, costs and footprint.

Table 2.2: Airports and their typical solution

Airport	**Capacity (Bags per hour)**	**Solution**	**Automation level**
Regional Airport	100-2400	Checkin-Triplanar	Low
International Airport	2400-6000	Checkin-Sort	Medium
Intercontinental Airport (HUB)	>6000	Checkin-Hub or Individual carrier system	High

Checkin-Triplaner Regional airports are often equipped with a Checkin-Triplaner system; A simple system that consists of check-in desks, screening processes if necessary, and make-up carousels. From these carousels, seen in Figure 2.7, bags are manually carried to a baggage train that transports the bags to the plane. Once the bags arrive on site they are loaded in the plane.

Figure 2.7: Make-up carousel

Checkin-Sort A baggage handling system of an international airport mostly is a raw baggage system. The main difference with Triplanar solution is presence of a sorter and a simple early bag store (Long lanes of conveyors). The sorter collects the bags from different entries and delivers the bags to destined make-up points. By tilting the tray or by pushing a bar the bags are transferred to chutes, where operators collect the bags. Note that the use of carousels is still optional, but the use of chutes decreases the likeliness of errors. (make-up carrousels are still optional.)

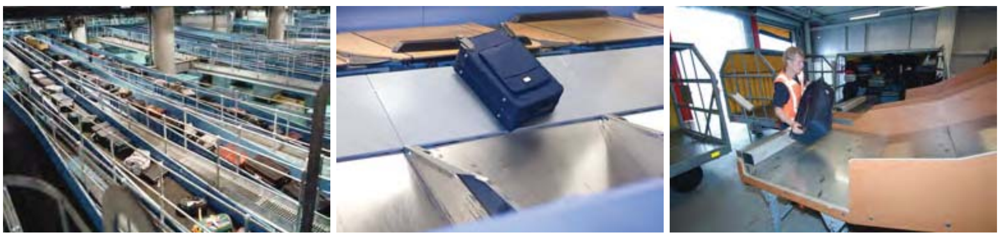

Figure 2.8: (L-R) a lane based early bag store, a bar sorter and a chute

Checkin-hub The Checkin-hub solution basically is an upscaled version of the Checkin-Sort, the capacities are higher, multiple terminals can be serviced and the bag store can be implemented as a rack based store, which is explained in next paragraph.

Individual carrier systems Individual carrier systems are often installed at Air-hubs. By transporting bags into carriers called tubs, higher speeds can be achieved then with a conventional conveyor, which is necessary to cover the large distance between different buildings. Also by linking the bag‘s ID to its tub, it simplifies the tracking of baggage in the system, further reducing the possibilities of errors. In addition, the tubs allow for more efficient storage solutions. The tubs are placed in racks by a crane and stay there until they are needed at the make-up point. Because of the individual tracking of the bags, the bags leave the bag store in a controlled/sequenced way that allows the efficient use of robots at the make-up points.

Figure 2.9: A rack based bag store with tubs, and a loading robot

2.2.3 Warehouse automation

Practically any item that can be bought in a store or ordered on the Internet was once in a warehouse, either as raw material or as an end product. According to Vanderlande almost 90% of these warehouses are manually operated with fork lifts and static racks. But it is expected that this percentage is going to decrease in the future. To increase service levels, reduce lead times and costs; more companies are investing in automated solutions.

Vanderlande delivers automated warehouse solutions world wide for finished goods associated with food and non-food retail, fashion, and parts and components that all have specific demands concerning freshness, trends and Lead times. Aside from the market segments, warehouses can also differ in picking concepts, either the operators go to goods, which is called ”man to goods”, or the goods go to operators, which is called ”goods to man”. Both these concepts are explained below in the **Process** sub-subsection. And also depending on the number of items in the warehouse, and the required order pick capacity this results in different solutions as is explained subsequently in the **Solution** sub-subsection.

Process

In contrast to the other two domains, a warehouse needs do keep an inventory to fulfill customer demands with a certain service level. This leads to a slightly different process, but contains the same functions as in the other domains. The process flow diagram of a warehouse is displayed in Figure-2.10 and is explained below.

To refresh inventory, goods are unloaded from trucks and are subjected to a quality control to confirm the correctness according to the placed order. Subsequently, the pallets or boxes are brought to bulk storage, where they stay until they are required for picking. Then depending on picking process the pallets are transfered as a whole or separated in batches to the pick storage. In case the pallet is depalletized the products are often stored in totes, which simplify the handling process. Products are then picked by an operator, according to ”man to goods” or ”goods to man”. When a man to goods policy applies, an operator moves through the racks and collects the products necessary. Under a ”goods to man” policy the operators stay stationary while the goods are brought to them. By means of automated solutions, totes are picked from the pick storage and arrive at a workstation. There an operator picks products from the tote and places the products in a roller container, pallet, carton or another tote. In case the tote still contains products it will be send back to pick storage, otherwise it will be send to the depalletize area. The picked items are consolidated and loaded in the next truck.

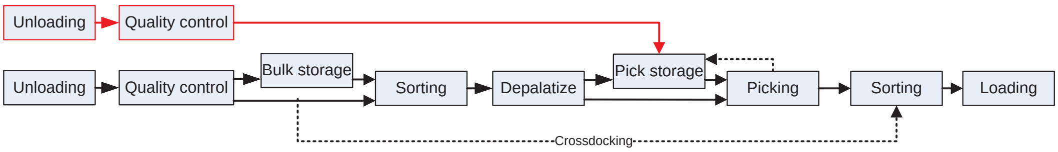

Figure 2.10: A typical process flow diagram of a Warehouse

Besides the regular flow of goods some warehouses also have a return flow. Especially in the E-commerce business approximately fifty percent of goods that go out, return to the warehouse. All these returns have to be handled as well. In the figure the route of these returns is indicated in red.

Solutions

In the other two domains the selection for a solution is mostly driven by capacity. For warehousing other parameters influence the choice for a solution. For instance, the number of stock keeping units (SKUs), product dimensions, and lead times are important factors. Therefore, it not simple to classify solutions as simple as for the other domains. In Figure 2.11 a decision graph is depicted and indicates which concept should be chosen based on capacity (in lines per hour) and number of SKUs. The picking concepts stated in the figure are described below.

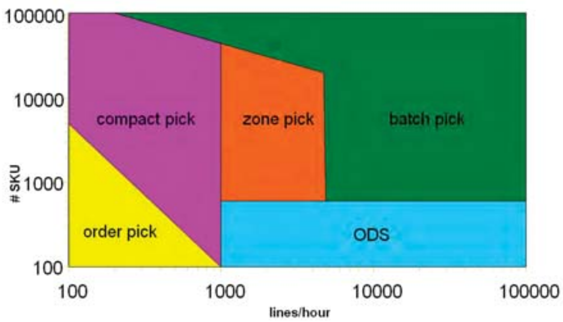

Figure 2.11: A decision graph for picking policies, by B van Wijngaarden [4]

Manual (multi-)orderpicking With this picking concept, operators travel through the racks. Collecting the items that are necessary for their order(s). Depending on the size of orders operators pick either order for order or multiple orders simultaneously. In Figure 2.12 an example for both cases are displayed. On the left, an operator is depicted that uses an order pick truck that lifts a pallet and on the right an operator uses a cart with multiple pockets in which orders are sorted.

Figure 2.12: Manual picking

Zone picking and Order distributed systems A zone picking system is a man to goods system in which an operator is dedicated to a couple of aisles, called a zone. Through the facility there is a transport system that transfers totes along the operators (Figure 2.13). When a tote arrives at an operator he picks the tote of the system and checks if the corresponding order needs an item that lies in their zone. The items are then picked and placed in the tote, which will be placed back on the system. Passing every operator they all together picked items for a single order.

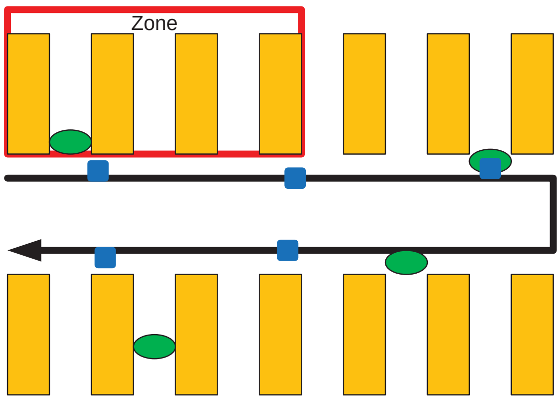

Figure 2.13: a layout of a Zone picking solution

An order distributed system has a similar layout as the zone picking system. However, this system is a goods to man system in which the products are transfered (in totes) over the system and the order totes are positioned at the operator. When the operator requires a product, it is picked from the belt and placed in the tote of the corresponding orders.

Batch picking Just like in a zone picking system operators are dedicated to aisles. The operators pick for several orders simultaneously and put the items on a conveyor that transports the items to a sorter as used in Parcel and Postal(the Posi- and Crossorter). The sorter sends items that belong to the same order to the same exit. In most cases more orders are linked to an exit and it is required that an operator performs final sorting.

Compact picking In this goods to man system, products are taken out of a storage by automated cranes or shuttles. Shuttles are small carts that travel along the racks on different floor levels. The shuttles are inserted by a lift and subsequently travel to an item location. Then the shuttle goes back to the lift area where it goes back into the lift that shifts the shuttle to ground floor where the items are released to a workstation or a robot that palletizes an order. At the workstation an operator picks item out of the totes, according to the instructions projected on a screen. Due to the reduced walking distances a higher capacity per operator can be achieved.

Figure 2.14: (L-R) Lift carrying a shuttle, a workstation

2.3 Sales

The sales procedure of Vanderlande can be divided in four steps, namely: Lead, Pre-bid, Bid and Closing. These steps cover the procedure from finding possibilities for projects, which are called leads, to the signing of a contract. Between each step a gate has to be passed before engaging in the following step. At the gate, a decision is made whether to engage to the next phase. A checklist of requirements has to be completed on which a decision is made to continue the process, or not.

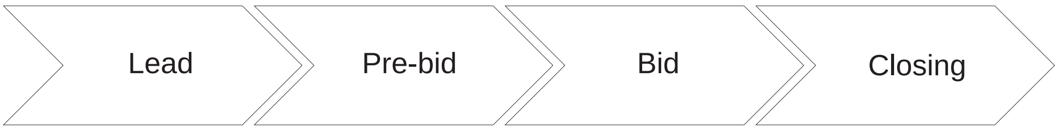

Figure 2.15: Overview of sales trajectory

First, during the lead phase, the goal is to identify and shortlist leads based on expected business potential and the fit with Vanderlande. The first step in the lead phase is a market analysis. Based on the input of media, personal networks and business intelligence, a marketing and business plan for the next fiscal year and for the medium term are prepared. These plans serve as a guideline to identify the possible leads. By visiting fairs, fast growing businesses, consultants and others, opportunities are identified and listed based on the fit with Vanderlande, the realistic chances to win and realistic potential for healthy profit. Based on these the decision is made to proceed to the Pre-bid step.

During Pre-bid it is most important to create a good and unique relationship with the decision making unit, to improve the position of Vanderlande and maximize win chances. To achieve this a feasibility study is conducted and a first system concept is configured. (How these concepts are derived is discussed in the next paragraph.) In the feasibility study legal terms and risks & opportunities are examined to determine whether to continue to the bid Phase.

Subsequently to the pre-bid phase, the customer publishes a tender on which all competitors have to place a Bid. The tender is a document with requirements that specify the features of the system. These requirements cover a wide range of customer‘s demands, amongst others it covers the responsibilities during the building phase, the dimensions of products to be handled and the eventual color of the material handling system. Important is the fact that the Tender can only be changed under extraordinary circumstances, therefore it is essential to have a good relation with the decision making unit.

Based on this tender, Vanderlande decides in the bid-phase how they are going to propose their system to the customer. In the case the tender is non-compliant with Vanderlande‘s solution, the sales team either has to calculate the price to implement the non-compliant, state why the Vanderlande is not going to fulfill the requirement, formulate a question to the customer or consider it as a risk. Then based on this response the customer and the competitors go into negotiations.

Finally, when the customer decides that Vanderlande is the winner, a contract is signed and the project is handed over to the project managers and the corresponding departments.

2.4 Concept design

As mentioned in the previous paragraph design of system concepts is in parallel to the sales process. The information obtained from the customer serves as input for the so-called four step design process, which is a structured method, developed by Vanderlande, to obtain a system concept. It can be used in the lead-phase, pre-bid and/or bid phase of a project. It often occurs that Vanderlande goes through this procedure multiple times, to implement newly obtained information in the design concept. The further in the sales trajectory the more detailed the system concept will be.

The "4 Step Design Model" consists of the following steps: "Analyse process", "Define concepts", "Select concept" and "Detail concept". Figure 2.16 portraits the design process, from left to right the four steps are taken to get from the customer question to a system concept. By conducting workshops with the customer and by analyzing their available data, information is obtained that serves as input for the design process. To clarify the process the four steps are briefly described below.

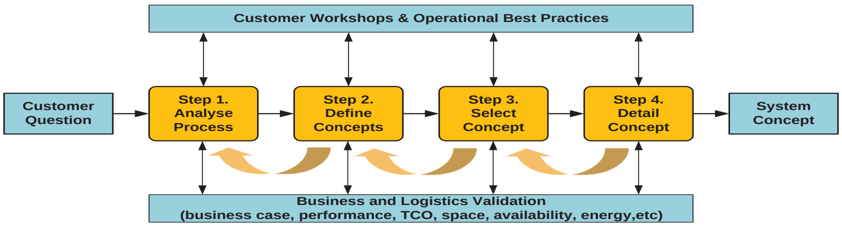

Figure 2.16: Overview of "four step design model"

Step 1: Analyse Process

During this phase Vanderlande analyses the available information from the customer. Also they capture the main processes of the system in a "Process flow diagram"(PFD) that are demonstrated in figures 2.2, 2.6 and 2.10. The processes in these diagrams only cover the systems functions, and in most cases no technical choices are made in this stage. Besides a PFD a deliverable from this step is a list of required volumes that need to be processed by the main processes.

Step 2: Define Concepts

The goal in the Define concepts phase is to develop solutions that meet the required volumes and process requirements. To achieve this, different technological choices need to be defined per process block. E.g. for a certain process there are two different technology options. There is a machine A with capacity X and a machine B with capacity two times X. To meet the required volume one machine will suffice, but also two machines of type A will do the job. Based on the requirements a number of configurations are deployed and displayed in Materials Flow Diagrams. Ultimately, the deliverables of this step are: one or more (high-level) Materials Flow Diagrams (MFD) with corresponding capacities, a budget estimated (+/- 10-20 %) and a controls architecture.

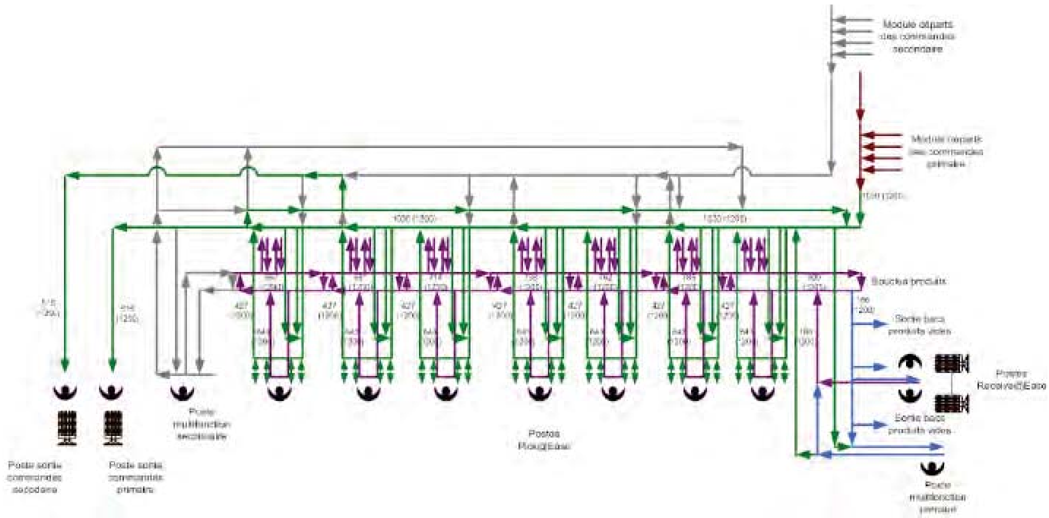

Figure 2.17: An example material flow diagram of a Warehouse automation project

Step 3: Select Concept

To properly decide which solution is the best valued system concept both quantitative and qualitative attributes are taken into account. Along with the customer it is defined which criteria are used and how heavy they are taken into account. Besides the criteria it is also important to gain insight in the offers of the competitors. If known, it can be determined how to distinguish the Vanderlande solution from the others. Furthermore, it might be necessary to perform simulations to test the performance of solution, especially when new concepts are going to be offered.

In the end, the chosen material flow diagram needs to be delivered along with an evaluation report that contains the motivation to choose the concept. This material flow diagram shall be the basis for the detailed concept. In Addition to the material flow diagram a new price must be estimated with an maximum anomaly of 10%.

Step 4: Detail Concept

Once the concept is chosen, it is going to be detailed. To do this the interface of the system with the building should be investigated. How will the system be configured so that equipment is easy accessible for maintenance and such. In addition, the complexity of the buildings should be taken into account. It might be that additional equipment is needed to make a good fit, compared to a rectangular shaped building. To be sure if the promised performance is met the system is simulated to validate capacities and other KPIs. Besides to system performance the operational use of the system must be investigated to make a proper calculation of the total cost of ownership.

2.5 Summary

In this chapter, an introduction into Vanderlande was given. By means of a historical overview and an introduction into the current business domains, one should be familiar with the origin of the company, the business processes of customers and solutions that Vanderlande offers to contribute to these processes.

In addition, an overview was handed considering the sales procedure that focuses on the Tender documents, in which customers formulate their requirements for a material handling system.

Furthermore, the 4 step design method was introduced which is applied by Vanderlande to design material handling systems. In four steps a system is designed from only requirements to a system concept. Going from a process flow diagram to a material flow diagram to a layout.

Supplementary information about system design is handed in the next chapter. In Chapter 3, literature is discussed that connects to the design of these material handling system and industrial systems in general. Subsequently Chapter 4 recurs on the three domains of Vanderlande, and discusses how the systems of these domains are generalized to form a single generic material handling system.

Chapter 3

Literature, Methodical design of industrial systems

In the previous chapter, the market segments of Vanderlande were described, along with the sales process and the “four step design method”. A method handled to translate the customers’ requirements to a system concept design. Based on requirements, the system design went through different abstraction levels, from a process flow diagram to a system layout.

A similar decision making approach is described by Brandts[5]. He considers a decision making cycle of the following steps: analyze, synthesize, evaluation and decision that, in essence, are similar to the four step design module of Vanderlande. Further in his research Brandts states that the process of system design can be captured in three aspects; he considers attributes, design abstraction and (sub-) systems, and models them in a “Design cube”(Figure 3.1).

Therein, the attributes represent amongst others the requirements of a customer, government and product specifications such as dimensions and weight. In particular, these attributes, and relations between them, form the constraints that have to be satisfied by the (sub-)systems. Furthermore, as the design process progresses the level of abstraction decreases and more parameters are taken into account. This is similar to the process of going from a process flow diagram to a system lay-out.

In this chapter, each section is dedicated to one of Brandts‘ design aspects and describes the aspect in further detail, with addition of literature.

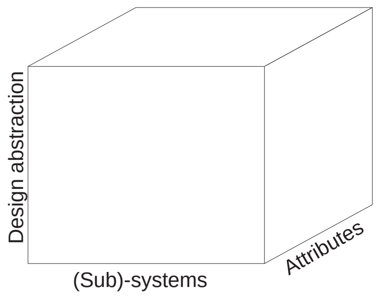

Figure 3.1: The design cube, portrait in Brandts’ research

3.1 (Sub)-systems

In his work Brandts states that an industrial system is build out of several sub systems. Figure 3.2 depicts the subdivision of these systems that is described in this section. The overarching system name is called the industrial system, which consists of collocation of products and corresponding production systems. In addition, the production system can be subdivided in a manufacturing, information and financial system. And lastly the information system can be split into a control system and a financial control system.

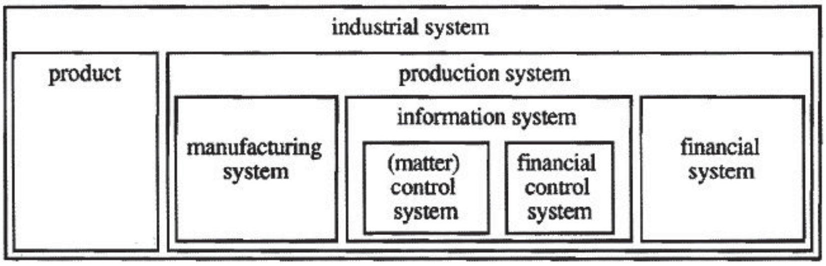

Figure 3.2: Coherence of sub-systems, according to Brandts [5]

In this terminology, the material handling system, along, with the material that being handled are considered as an industrial system and the physical system is depicted as the manufacturing system. In the manufacturing business the handling of materials is mostly seen as a supporting operation to their core business. However in the material handling domain these systems are core business. Considering the information and financial system no distinctions can be made with the material handling systems.

Brandts' sub-division enables the design of these sub-systems in series, in parallel or in a combination of the two, as is depicted in Figure 3.3. In practice, complete parallel design is unlikely to be implemented as there are many relationships between the distinct sub-systems. Therefore, it is more common that design of the sub-systems is done serial. However, to speed up the design process designers may choose to work both in serial and parallel, although this requires additional communication.

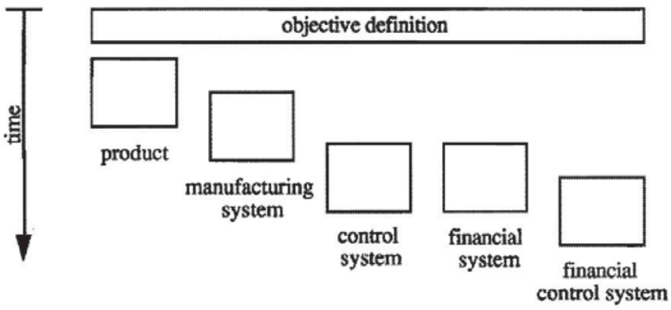

Figure 3.3: A serial and parallel design scheme of an industrial system [5]

This research focuses on the products and the "physical" system as these are the most relevant elements for system concept design, as is the case in the four step design method.

3.2 Attributes

Brandts examines a system design as a network of attributes that are interconnected and related to one another. Based on the known parameters, design choices are made, which result in values for other parameters. As example for this, Brandts uses the relation $Mass = Volume*Density$. Based on mass and volume requirements, a material with certain density should be chosen to fulfill the constraints. However, by choosing a material one should also consider parameters such as strength, corrosion resistance and costs. By evaluating on the combination of the relevant parameters can result in a weighted decision.

Due to all the interconnections between parameters it is difficult to fill in all these attributes. To add some structure to these networks, four categories were defined concerning material handling systems, namely, Performance, Economic, Building and Quality attributes. In Table 3.1 these categories are summarized with a description and example attributes.

To connect this to material handling systems, research has been conducted on design parameters of material handling system. From communications with personnel[1] and internal documentation [2] can be concluded that Vanderlande offers automated solutions to support a customer‘s process. For which, the system requires a certain performance that is mainly focused on capacity. In most cases a customer desires a system that is able to process a certain number of units per unit of time.

In addition to capacity, customers desire a high availability of their systems, because down-time often results in penalty costs. To prevent this from happening, critical parts are implemented redundantly such that in case of breakdown there is a back-up. Research conducted by Vlasblom et al.[6] investigated the relation of system availability with life cycle cost. The research investigated different system configurations, and concluded that redundancy, if implemented correctly, can lead to higher availability and lower life cycle cost. Apart from the down-time, there are other attributes that determine the life cycle cost of a system, such as investment cost, maintenance costs, operational costs.

Life cycle costs can also be refereed to as 'Total Cost of Ownership' (TCO), which represents the total costs that are involved owning the system. This TCO can be separated in capital expenses (CAPEX), representing initial investment costs, and operational expenditure (OPEX), which represent cost necessary to operate the system. With the TCO approach, cost of investment can be justified because it leads to savings on operational expenses in the long term.

Apart from performance and economic parameters, there also are volumetric parameters that need to be considered, since material handling systems require a certain amount of space in a building. The relation of equipment and buildings, is often referred to as Building Interfaces. In his work, Graste[7] determines building interfaces for raw baggage systems. In one example Graste demonstrates, a "volume envelope" of a carousel that, besides the physical equipment, included an operator area, and a parking and drive area for dolly transport. In addition, constraints were portrait for cases where multiple carousels are placed in parallel.

Other research, conducted by van Neerrijnen[8], focuses on the relation between the shape of a building and the sorter concept in parcel and postal systems. In his document van Neerrijnen mentions that elongated rectangular buildings, mostly benefit from line concepts, while for square building it is mostly beneficial to implement a loop concept. Besides the shape of the building, van Neerrijnen also mentions that the unloading and loading of parcels can be performed on multiple sides of a building.

Up till now, treated attributes were quantifiable with a certain measure. However, there also are attributes for which this is not the case, for instance the attribute sustainability. Which is considered as a positive trait but is often defined as: “the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance”[9]. Which makes it difficult to quantify, however Vanderlande is investigating methods to demonstrate the sustainability of their solutions.

Table 3.1: Material handling attributes, categorized into four parameter categories

Category	**Description**	**Examples**
Performance	Indicate the performance of the system and/or equipment	Capacity, Availability
Economic	Costs involved acquitting and operating the material handling system	Capital expenditure, operational expediture
Building	Volumetric parameters that define the interface of equipment with the building	Footprint, height, floors
Quality	Parameters that add value to the process of the customer	Sustainability, innovation

3.3 Abstraction

As mentioned in the introduction of this chapter, Brandts considered a design process similar to the four step design method. Starting from a high abstraction level one gets more details into the design as the process lapses, as is described in Section 2.4. This section first focuses on the abstraction level of a material, as most previous work on material handling system design is done on this level, and secondly it discusses process flow diagrams

In his PhD thesis, Schotborgh [10] demonstrates a methodology to automate design processes, which he amongst others applies on a baggage handling case of Vanderlande. As input for his method, Schotborgh requests a process flow diagram, which he adepts to a material flow diagram with the use of graph theory. The designed material flow diagrams are then evaluated on four key performance indicators, namely Costs estimation, Capacity, Redundancy, and in-system times. Indicators as, space efficiency were not taken into account as these indicators made the problem too complex to be handled by his methodology. Nevertheless, the feedback the research has received from Vanderlande was encouraging, according to Schotborgh.

Other research on the design of baggage handling systems was conducted by Grigoras and Hoede [11]. They also investigate the design of material flow diagrams with the use of graph theory, however Grigoras and Hoede do consider some building interfaces. The first step in their method is the mapping of a PFD on a *Geographical Constraint Graph*, of which a simple example is depicted in Figure 3.4, which is a virtual representation of rooms that are present on a floor. With design rules considering the multiplication and reduction rules, they succeeded to reproduce a material flow diagram of a baggage handling system. Lastly they mention, if floors should be added to the problem the complexity increases as it results into a NP-*hard* problem, making it more complicated to solve.

Both discussed methodologies request a process flow diagram as an input. However, the problem of process flow diagrams is the interpretation of a process. For one process, two distinct designers may come up with two different interpretations. A phenomenon also encountered by van Kempen[13],

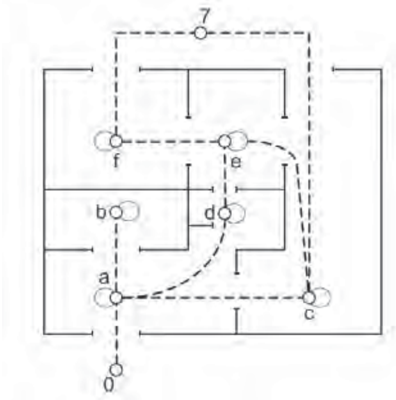

Figure 3.4: A example of a geometrical constraint graph, by Grigoras and Hoede [12]

who demonstrates seven different interpretations of a process flow diagram of a warehouse system in his research.

The demonstrated process flow diagrams differ amongst others on "freight forwarding" and transport. According to one designer "packing of goods" is part of freight forwarding, while others see this a separate process. In the case of Transport some designers represent transport by means of arrows, while others like van Kempen use a separate block and arrows for transport that represents transport between the processes, as is depicted in Figure 3.5.

Although they describe the same system, it can be described in various ways. For the multi-domain model, however, it is preferred that the processes are not open to interpretation. This means that a process should embody a single handling and not a compound that embodies multiple handlings.

Additionally, there are different names for similar processes in the three domains. So therefore, a generic description of material handling system is required to form a robust base for the design of material handling systems. The next chapter describes how this generic material handling system is deduced.

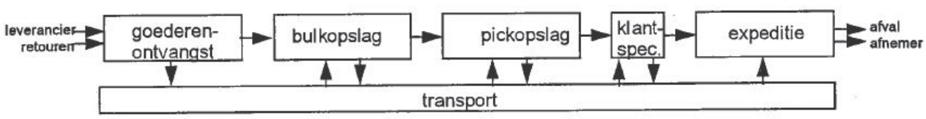

Figure 3.5: The process flow diagram of a warehouse system according to van Kempen[13]

Chapter 4

Generic material handling system

As presented in the Chapter 2, Vanderlande designs material handling systems for the domains: Baggage Handling, Parcel & Postal and Warehouse automation. Three domains, each with their own vocabulary, requirements and specifications. However, rather than building three specialized models, a generic approach that covers all domains was chosen. In addition, this multi-domain model should not be bound by current technology, as it is not intended to design the best conveyor system. The future might bring new technologies and logistical concepts, which should be easily embodied by the model.

Furthermore, the generic approach may positively contribute to the design process. By means of a platform with a generalized terminology the communication between engineers of different domains should be more simple, allowing knowledge sharing and synchronization in the way of working in sales and the design process. Due to the synchronization, the general platform could encourage the exchange of technology and logistical concepts between domains.

This chapter covers the derivation of the generic material handling system, which exists of two phases. First, section 4.1 describes generic transport and storage units that are used generalize PFDs and MFDs to one standard. Secondly, section 4.2 covers the generic functionality of material handling systems.

4.1 Generic transport & storage units

This section covers the categorization of transport en storage units that is used to generalize process and material flow diagrams. Instead of considering bags and parcels or roll-cages and pallets, considering these categories is beneficial to the identification of generic functions of material handling systems.

This research retains to four TSU levels named: bulk, containerized goods, carrier based goods and itemized goods, which are four categories that represent goods that typically have similar dimensions and weight. In Table 4.1 an overview is shown of the used TSU categories, which are also described below.

Firstly the category “Itemized goods” is considered. This category embodies single item flows such as baggage, parcels, clothes, CDs etc. Goods that typically weigh between a half and fifty kilo grams and can be handled manually or by a material handling system. Additionally, Itemized goods are considered to be the lowest aggregation level, which means they cannot aggregate other goods. In the case of bags and parcels, it is assumed their content is irrelevant for material handling and on the note that nothing happens to this content, bags and parcels are considered itemized goods.

The second TSU category considers carriers based goods and covers carriers that are either empty or carry one or multiple itemized goods. Carriers were introduced into material handling to simplify loading procedures, because the loading of loose items can be inefficient. Furthermore, one can increase conveyability of items by placing them into a carrier.

Like itemized goods, carriers can be handled manually and by a material handling system, assuming a filled carrier is not heavier than fifty kilos. Typical examples of a carrier are: Totes and Tubs. Additionally, cartons are considered as carriers as well. Although, cartons physically are the same as a parcel, the content of the carton is relevant for material handling and can possibly be altered before shipment, therefore it is considered as a carrier.

Thirdly there is the container TSU category that portrays carriers that are too big and/or heavy to be handled by regular material handling systems. However they can be handled on specialized "heavy material handling systems", or pulled or driven. In addition, containers can aggregate items or carriers.

The last TSU category named bulk, represents transport modalities that are used for logistics between depots. As consequence of being the highest category, Bulk units are allowed to aggregate all combinations of TSU aggregations of lower categories. In other words a truck may be loaded with parcels, but also with roll-cages holding trays that hold items.

Further in this research, these four categories are used to simplify the description of the generic material handling system. However, categories might change in the future as well as the number of categories. Therefore this should be taken into account to generically specify the model and terminology.

Table 4.1: TSU categories, with descriptive picture and typicals in that category

TSU Category	**Descriptive Picture**	**Typicals**
Bulk		Truck Van Ship Train Plane
Containerized goods		Pallet Roll-cage Dollie
Carrier based goods		Tote Carton Tub
Itemized goods		Parcel Baggage Item

4.2 Generic Behavior

To design systems for all the domains with a single methodology, it is desired to develop a generic system characterization. A characterization that preferably holds for multiple levels of abstraction, such that it holds on both system and equipment level. Eventually as the design progresses, the attributes of this characterization increase in detail as the level of abstraction decreases, limiting the search space for solutions.

For the characterization there was chosen to model material handling systems on a function level. Despite the different implementations of these functions, the functions themselves can be setup generically for the domains. Furthermore, the functions could be arranged in a format of process flow diagram, laying the base for system design similar to the 4 step design method. Later on, technological solution and logistical concepts should be coupled to these functions.

To derive the generic functions of a material handling system, research was conducted on both process and material flow diagrams. Also, inspiration was obtained from S.Haneyah et al. 2013 [14], who used a generic material flow diagram to develop generic controls for material handling systems. The generic material flow diagram applied by Haneyah consisted of six stages was based on systems corresponding to Vanderlande‘s material handling domains. In Table 4.2 the names of these stages are shown along with a stage description. Although, the characterization deployed by Haneyah sufficiently describes the occurring events in a material handling system, the terminology was a little unambiguous from a design perspective. Herewith it is intended that it is difficult to use this sequence on different abstraction levels. For instance, one could only use shipping to describe the loading of the transport modality and not for other loading processes.

Table 4.2: Material Stages from the generic MFD developed by Haneyah

Name of Stage	Stage description
Receiving	The receiving of goods and the breakdown to single items
Quality Control	To check the conformation of incoming goods to requirements and specifications
Storage	The stage where goods are temporary stored
Order Picking	Products are picked, and taken from the system
Consolidation	The picked goods are consolidated
Shipping	The consolidated goods are loaded in a transport modality

In order to translate the generic MFD to generic functions, there was looked into the basic functions of transport. According to P.J.J Renders and J.E. Rooda [15], there are twelve basic functions to distinct concepts of transport. Amongst others they consider: transport, transloading, divide, merge, storage, and identification and coding. Where transport is further divided in continuous or discontinuous transport, and horizontal, vertical or spatial transport. Furthermore they divide storage in short and long term storage.

To investigate which of these functions are relevant on the abstraction level of process flow diagrams research was conducted on process flow diagrams. In addition research was performed on material flow diagrams to determine for which functions technological and logistical concepts are selected. Combining these basic functions with the knowledge obtained studying PFDs and MFDs, five functions are defined for which technical or logistical concepts can be selected and are connected by arrows that represent transport.

Table 4.3 demonstrates the generic functions unloading, loading, sorting, transform, store, and transport. The table additionally depicts the functionality of each function and enlists the base functions embodied by the generic functions. Further below, each function is explained in more detail.

Table 4.3: Generic functions

Function name	Functionality	Embodied base functions
Unloading	Lower the level of aggregation	Transloading
Loading	Increase the level of aggregation	Transloading
Sort	Merges multiple flows & splits single flows into multiple flows	Divide, Merge
Transform	Adjusts products physically or virtually	Identification, Coding
Store	Store units for extensive amount of time	Long term storage
Transport	The movement of goods from A to B	Transport, short term storage (Accumulation)

The first two functions deal with the concept of transloading and are respectively called **unloading** and **loading**. The unloading function corresponds with concepts that lower the level of aggregation and loading with concepts that increase the level of aggregation. Considering a goods flow of carriers containing items, by unloading one obtains a goods flow of items and a goods flow of empty carriers. Vice versa, by means of a loading action, loading items into carriers results in a carrier goods flow containing items.

Secondly, the **sort** function is considered. Within Vanderlande the definition of sort is often coupled to the division of goods to multiple destinations. However, in this research the merging of goods is also considered as a sorting action.

To explain why merge is part of sorting, a T-junction is taken as an example. In a T-junction goods arrive in a single flow and have the option to go either left or right. The decision for the direction, left or right, is mostly based on an attribute of the goods. For instance, products with label “A” go left and products with label“B” go to the right, which results in the sorting of a mixed flow to an A and B flow.

Turning the example around, a T-junction is examined where two flows, flow A and flow B, converge to a single flow. Based on the product labels, either products labeled A or B have priority and may go first. The decisions that determine the order in which products are merged is considered as a sorting action. Hence that goods are ordered by means of criterion.

Therefore, the sort block is used as a connection block connecting goods from different origins to different destinations. Additionally, the sort function can separate TSUs based on a difference in attributes such as, product dimensions or weight.

The next function involves operations that are applied on goods. This can involve both physical operations like alignment or placing a label and operations that virtually change a product. An example of such a virtual operation would be the screening process in baggage handling, where bags are screened to get a cleared status to make sure there is no suspicious content. Since the term operation is ambiguous this function is named **transform**, to indicate the change of a product.

The fifth function is the **store** function, which represents the equipment used to store goods for an extensive amount of time. Short term storage, also called accumulation, is considered to be part of transport and shall not be embodied by the store function. In general, stores are used to decouple processes that are asynchronous in time by storing goods that arrive (too) early. A store allows warehouses to keep inventory, and grands airport the opportunity to forward the opening times of the check-in desks.

Lastly the transport function, is the function that connects the other five functions in a process flow diagram by means of arrows. There was chosen not to implement a transport block, like Van Kempen in Figure 3.5, since it was not used in almost every PFD and MFD of Vanderlande. Furthermore, the function of the transport block, can better be described as a sort function that merges multiple flows and distributes them amongst multiple exits.

As mentioned, the functions were defined such that technological/logistical concepts could be selected that carry out the specific function. To certify that the generic could completely capture the behavior of material handling systems, the functions have been “mapped” on material flow diagram to check no functionality was left out. Figure 5.2 depicts two material flow diagrams of an example baggage handling system. On the left is the initial MFD and on the right a MFD on which all functions are fitted. (Unloading in orange, loading in blue, sort in purple, transform in green, and store in yellow.) To explore how the mapping was performed one is referred to Appendix A.

Based on the material flow diagram mappings it is concluded the generic functions: unloading, loading, sort, transform and store are able to describe the behavior of material handling systems. To obtain a PFD-like approach the named functions are connected with arrows that represent transport. To explain how to build the process flow diagrams, the next chapter deliberates the implementation of these functions into the multi-domain model that shall assist in the design process.

Chapter 5

Multi domain model

In the previous chapter generic TSU categories are used to define the generic functions: unloading, loading, sort, transform and store, which define the behavior of material handling systems. This Chapter cover the further detailing of these functions and how they are supposed to be connected in the multi domain model

The goal of the multi domain model is to assist in the design process, by reviewing all alternatives in a short time period. Therefore it is necessary to develop a framework that could be used to construct all alternative process flow diagrams based on the same requirements.

This chapter discusses two methods investigated in this research. Section 5.1 examines the deployment of a generic process flow diagram, a method that uses a fixed configuration of the function to design process flow diagrams; while Section 5.2 discusses a methodology where functions are connected by a set of constrains, which are embodied by the so-called attributes and interfaces.

The interfaces and attributes that are introduced in Section 5.2 are also summarized in Appendix B.

5.1 Generic process flow diagram

It was believed that a fixed configuration of function blocks was beneficial for the design process. Similar to the generic material flow diagram used by Haneyah et al.[14] a generic process flow diagram was deployed, which is depicted in Figure 5.1. This depicted PFD is the final version of the generic PFD, where goods enter via an *unloading*, undergo a *transformation*, can be *stored* via a *sort* action and eventually leave via *loading*.

By using the generic PFD as a fundamental building block, details can be obtained by placing generic PFDs in series or in parallel, or by zooming in on a single block seeing again the generic PFD.

Unfortunately, the research performed showed that many unused blocks were added with every step, and thereby losing the essence of this schematic. Therefore elaboration of this method had been discontinued, and a scenario without a fixed configuration was chosen.

This new configuration consisting of attributes and interfaces is discussed in the next section.

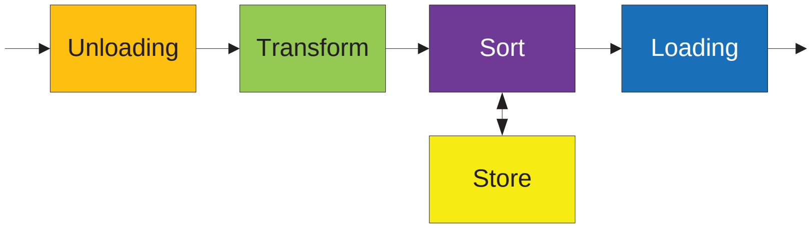

Figure 5.1: Generic process flow diagram

5.2 Attributes & Interfaces

As the fixed configuration of the generic process flow diagram resulted in an inconvenient method of constructing PFDs, a different approach was investigated, with a more flexible approach by applying a rule set for using functions blocks and connecting them to one another.

The selected approach can be compared to a jigsaw puzzle. An approach, wherein each function block is represented as a piece of the puzzle, with attributes that depict the contents of the piece, and interfaces that determine how blocks may be connected.

By fitting the generic functions, introduced in the previous chapter, on PFDs and MFDs of Vanderlande systems, it becomes possible to identify these interfaces. Below an example of a function fit is demonstrated to give an idea how functions were fitted. Afterwards, interfaces and Functional attributes are introduced that allow the construction of a minimum process flow diagram.

With a minimum PFD it is intended to maintain as many degrees of freedom as possible to evaluate all feasible process flow diagrams, by supplying minimal information. Eventually, additional information may be added to limit the degrees of freedom and thus the number of feasible process flow diagrams that contains the following elements:

1. Aggregation scheme, in which products are unloaded and loaded according to the customer‘s process.
2. Functions are carried out on the corresponding TSUs
3. Functions are carried out in the correct aggregation stage
4. Function are specified (with attributes) such that corresponding Technological/logistical concepts can be selected
5. Functions have a depicted multiplicity (which can be one)

But first, as an example for a function fit on a material flow diagram, a check-in Triplanar project is taken into account that is depicted in Figure 5.2. On the left the original MFD can be seen; while on the right one can see the MFD with fitted functions.

Below, it is explained how these functions are fitted to the MFD. Furthermore, figures are shown in Appendix A that show the introduction of the functions step by step.

The function to be fitted first is the unloading function that represents the lowering in aggregation level. This is done by placing orange “U” blocks at both the check-in desks and the transfer input, where bags are taken from a dolly and are placed on a conveyor.

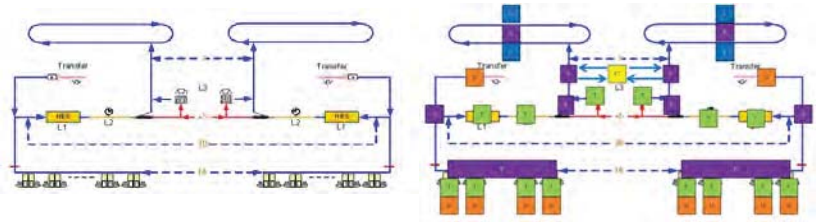

Figure 5.2: An example of fitting functions on a material flow diagram.

Secondly, blue loading blocks are fitted on places were the aggregation level increases. Typically this happens at the make-up area besides the carousels at the top of the MFD. Although, the picture does not depict clearly how many make-up areas are present, it is assumed there are four of them.

Furthermore, purple sort blocks are placed on locations where multiple flows merge and/or divide in more flows.

Then, green transformation blocks are introduced on places where an TSU attribute changes. In the check-in Triplanar system, this occurs at the weighing scale at the check-in desks and at screening locations. In this material flow diagram screening is divided into three levels, which results in three transformation blocks on both sides of the system.

Lastly, a yellow store block is added on the location where early bags are stored. Although, a store is not depicted by the material flow diagram it is assumed bags are stored subsequently to the screening processes but before the final sorting at the carousels. Furthermore it is assumed that the store is a simple manual store and therefore was not depicted in the material flow diagram. Besides the addition of the store block, two sort blocks were added to represent the redirection of bags towards the store and back.

This example shows that it is possible to fit the functions on parts of the system, resulting in a function fitted PFD or MFD. However, for this research it is desired to turn this around, such that technological/logistical concepts can be selected based on the functions.

Therefore, function fits of distinct systems have been compared to investigate the connection between function blocks. Ultimately, the comparison of function fits resulted in to the connection matrix depicted in Figure 5.3, in which a “X” indicates that an connection is allowed from one function towards an other function. Amongst others, it can been seen that the sort block can be accessed from and connected to all other functions. Furthermore it can be seen that the store function can only be accessed by sort blocks.

from\to	U	T	S	ST	L	E
G	X		X		X	
U	X	X	X		X	X
T	X	X	X		X	
S	X	X	X	X	X	X
ST			X			
L	X	X	X		X	X

Figure 5.3: Connection matrix

This is chosen because stores consist of multiple storing locations, that can be selected to store goods. Because of the numerous positions, one performs a sort action when selecting one of these positions. The other way around, the selection which products leave first is also considered a sort action. (As is explained in the previous chapter, where the sort function is introduced.)

Apart from generic functions the matrix also includes a **generator** "G" and **exit** "E" process. These are blocks that, further in this report, are used to depict the system's boundaries. For instance, a generator can be used to depict the arrival of transport modalities or to indicate that goods arrive from another system that are not in the scope of Vanderlande; while exits are used to depict that goods are leaving the systems.

Additionally generators and exits are used to depict the interfaces of empty TSU flows that related to the loading and unloading functions. Both these functions deal with two different aggregation levels, which requires additional thought concerning the number of entries and exits of these function blocks. In the case of unloading one TSU arrives that is unloaded as (multiple) TSU(s) of lower aggregation, remaining with an empty TSU that needs to be discharged.

To describe this phenomenon, there is need for one entry and two exits. One exit for the TSU of lower aggregation and one to discharge the empty TSUs. As the handling of these empty TSU often is not in the scope of Vanderlande systems. There is chosen to dispatch the empty TSUs to an exit block. Thus when an unloading block is placed in a PFD, the corresponding empty flow instantly connected to an exit block. (Additionally, a similar situation holds for loading blocks, but then empty TSUs arrive from a generator.)

For the means of clarification, Figure 5.4.A visualizes the intended functionality of the unloading function that is used further on in this report. In the figure, a bulk flow aggregating items (indicated with B[I]) enters an unloading block, while an empty bulk flow (B[ ]) and a item flow (I) leave. As stated above the empty bulk flow is directed to an exit block, while the item flow forwarded for further processing. Furthermore, the figure depicts the situation with a loading block.

However, in certain cases it is preferred to reuse the empty TSUs. In such cases one should be able to implement this flow into a PFD. To do so, a designer could choose to remove the corresponding generator and exit, and connect the unloading block to the loading block, as is depicted in Figure 5.4.B.

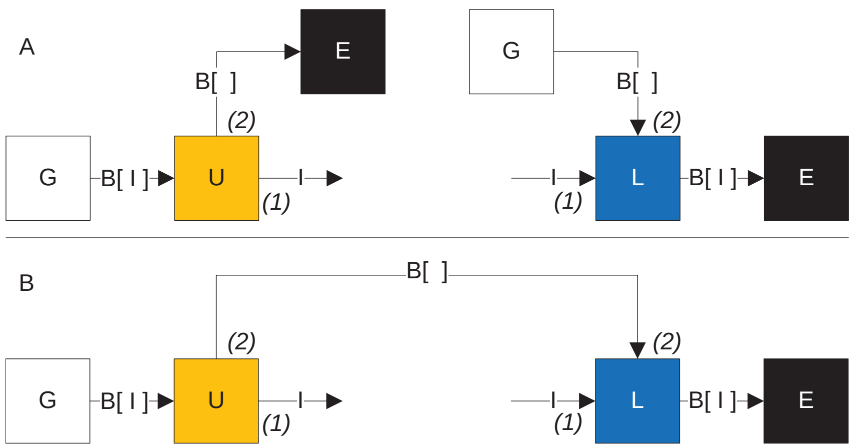

Figure 5.4: Unloading and loading block with generators and exits.

Considering the entries and exits of other functions; no irregularities regarding entries and exits were discovered. Both store and transformation blocks retain just one entry and one exit while the sort block can have any natural number bigger then zero as number of entries and exits.

Altogether, the connection matrix has been established alongside the number of entries and exits of function blocks, which both capture the basics of connecting blocks to one another. However, to construct process flow diagrams more functional attributes are required to be formulated, such as the TSUs on which functions are being applied to. For instance one can store goods as single item or as containerized good(like a pallet), which both lead to different technical concepts.

First considering the functions that do not deal with changes in TSU. Transform, store and sort generally can be applied on every TSU category. However, from the perspective of system design no interest is taken into the handling of bulk TSUs. In a flow diagram, bulk TSUs typically occur only on the interfaces from a generator towards an unloading function or from a loading block towards an exit. So, for both these function the bulk TSU is of importance.

Additionally, both unloading and loading blocks deal with different TSU on entries and exits, as these functions change the level of aggregation. For this, it is required to specify a separate TSU for the entries and for these exits. Since there are multiple entries, there is decided to refer to the non-empty channel as the first, and the empty flow as the second channel, as is depicted in Figure 5.4. Below, it is explained which TSU apply to entries and exits of the unloading and loading function.

Considering the unloading function, there is one entry and two exits. For the entry one can only choose between non-itemized TSUs (as itemized goods cannot be unloaded), and for the exits the "empty channel" (*exit 2*) equals the chosen TSU for the entry. For the other exit (*exit 1*) only "smaller" TSUs than the chosen entry TSU can be selected, since the TSU levels are designed to only aggregate lower TSU levels.

Similarly, considering the loading function, only non-bulk TSUs are allowed to enter from the non-empty flow (*entry 1*), as bulk is the highest TSU level, it cannot be loaded into any other TSU. However, bulk may enter trough the empty channel (*entry 2*) as may all other non itemized TSU, as long as it has a higher level then the non-empty flow. Lastly, the exit of loading equals the empty entry.

Now, with the use of TSUs, functions can be arranged such that an aggregation scheme can be constructed, in which arriving goods are unloaded towards itemized goods and loaded again to TSUs that leave the system. However, due to the fact that TSU levels change throughout a process flow diagram, it might occur that there are two distinct goods flows of the same TSU level. For instance one can store goods as they arrive, but also as consolidation of items(pre-pack).

For such situations it is preferred, besides the specification of the TSUs attribute, to specify the stage in which a function needs to be applied. To introduce the "Stage attribute", first the stages are described followed by an explanation of the attribute domains for the distinct functions.

As previously discussed a basic material handling concept starts with the receiving of goods, ends with the shipping of goods and handles the goods in between. When viewing this next to the change in aggregation, typically the goods first go through a set of unloading processes and later through a couple of loading processes, as can be seen in the example PFD depicted in Figure 5.5. Examining this, it can be considered there first is a stage where the aggregations are "broken down" up to the unit of transshipment, which is followed by a stage where these units are handled and finally are consolidated, "building" new layers of aggregation.

Considering the three stages, breakdown, transshipment and build in combination with the TSUs, it is noticed that the item TSU only occurs in the transshipment stage, which is legitimate with the

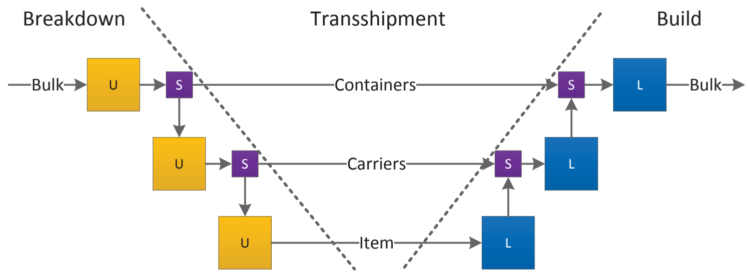

Figure 5.5: The division of material handling stages in an example PFD

fact that items are the lowest TSU. Therefore, there is no need to specify the stage of a function if it considers item flows.

In addition, the stage attribute does not need to be applied to the bulk TSU, as the handling of bulk is irrelevant for the design of material handling system. Thus, not applying to Itemized goods and bulk, the stage attribute only needs to be specified if the selected TSU is either carrier based or containerized goods.

Recalling Figure 5.5, it can be seen that unloading blocks only occur in the breakdown stage and loading blocks only in the building stage, which is common in most material handling systems. However, certain concepts deviate from this typical “unloading-loading” behavior.

To illustrate this, an individual carrier system is discussed as an example of the deviating concept. On large airports, equipped with certain systems, passengers arrive and hand over their bags at a check-in, which is considered as an unloading action. Subsequently, the bag is loaded into a tub and stays in this tub until it is unloaded at a make-up position where it will be loaded in a unit loading device(ULD).

The described individual carrier system, introduces the concept that goods are temporarily loaded in a different TSU before going to the building stage. In Figure 5.6 this is depicted by an item flow entering a loading block in the transshipment stage. This loading block then raises the TSU to a non-bulk unit that will be unloaded to items before the building stage. Because the loading is only temporary there often is a return loop of empty TSUs, which is also depicted in the figure.

With the above description of the stages, a motivation can be given for the attribute domains of the stage attribute for the generic functions. As unloading is used to breakdown aggregation and unload temporary loading devices, it can only occur in the breakdown and transshipment stage, and similarly does loading only occur in the transshipment and build stage. The remaining functions may occur in all three stages.

With the introduction of the Stage attribute, the initial position of functions can be acquired on top of the aggregation scheme. However, more distinction between transformations is necessary to be able to select the correct technological or logistical concept.

For instance, when a weighing transformation is considered, one does not need to consider wrapping stations. To ensure correct concepts are linked to the corresponding transformation an Type attribute is introduced, such that a designer can select the type of transformation that needs to be carried out. Amongst others one can select screening, weigh, and “quality control” to correct failed

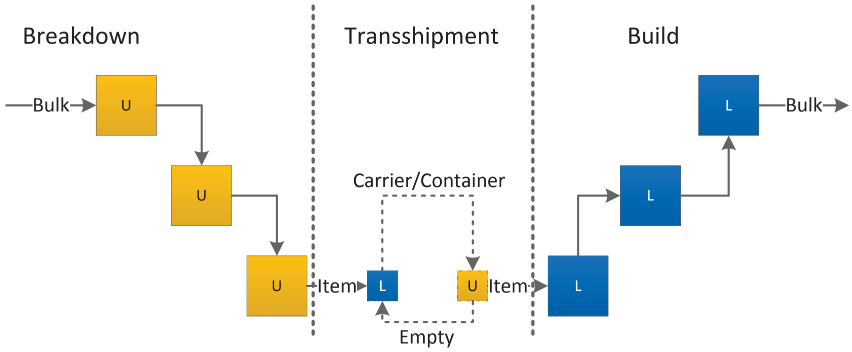

Figure 5.6: An example process flow diagram containing an internal carrier/container loop

transformations. Table B.1 contains all types that came across in this research, but the list is open to changes in the future.

Besides the transformation type attribute that distinguishes distinct transformation; a holding capacity attribute is added to formally distinguish the store from the other function as can be seen in the WA PFD depicted in Appendix D. Using this attribute one depicts the number of positions in the corresponding store; a number that in the selection procedure can be used to evaluate storing concepts. Naturally, the holding capacity of all other functions is equal to zero, as they are not allowed to store goods.

With the introduction of the transformation type and holding capacity technological/logistical concepts can be coupled based on the current functional attributes. However, to obtain a minimum process flow diagram one more attribute is introduced, which is the multiplicity attribute that depicts the minimal number of servers that execute the specific function. For example, when a loading function is given a multiplicity of two; a minimum of two workstations needs to be acquired.

Although, in many cases a function is conducted multiple times due to capacity constraints. In certain cases a customer may require multiplicity because of functional requirements, for which this attribute is introduced.

One of these requirements is the availability of systems. Customers demand high availability such that systems contribute to their processes. One way to increase this availability is with functional redundancy. By carrying out a function by multiple concepts, there is a lower risk a system cannot contribute to the customer‘s process. Due to the multiplicity there mostly is a back-up in the case of a malfunction.

One other reason to have a predefined multiplicity is because of a predefined number of destinations. For instance, a baggage handling customer may desire to be able to load four planes simultaneously independent of capacity. Furthermore, multiple destinations can also be a result of building interfaces. A customer may already posses a building with a specific number of (un)loading docks and desires that all these docks are accessible for the system.

However, multiplicity can only be assigned under certain conditions, since by subdividing functionality into multiple elements one is also required to divide goods amongst these elements. In other words, a sort action is required in case of a multiplication, either preceding and/or succeeding the function.

In Figure 5.7, positions are indicated where a function is allowed to be multiplied. This is between sorting blocks, but also between a sort block and generators and/or exits. Assuming that the sorting action occurs outside of the system interface. In the case a function does hold to these conditions, additional sort blocks should be added such that the particular is solely surrounded by sort functions, and generators and exits.

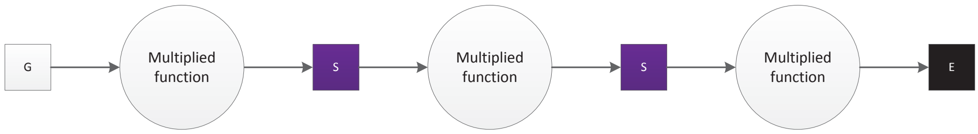

Figure 5.7: A visualization of the multiplication interface

In summary, interfaces and functional attributes are introduced that depict how functions are allowed to be connected and detail functions such that minimum process flow diagrams can be constructed. Before this type of PFD is explained in further detail, one is advised to go to Appendix B for a quick recap on the interfaces and functional attributes.

At the beginning of this section it is mentioned that a minimum PFD is a feasible process flow diagram containing minimal information. Although, the PFD is constructed with minimal information, one can use this PFD as starting point for further design. As an example of a minimum process flow diagram, Figure 5.8 depicts the minimum PFD of the same Check-in Triplanar system that is used to explain the function fit on material flow diagrams.

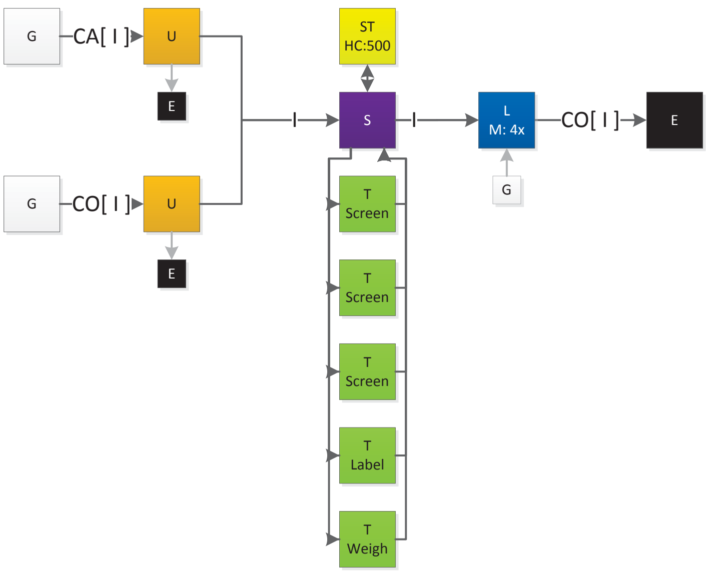

Figure 5.8: Minimal process flow diagram corresponding to

To confirm the depicted PFD is indeed a minimum PFD, the PFD is evaluated on the following four requirements:

1. Aggregation scheme, in which product are unloaded and loaded according to the customer‘s process.
2. Functions are carried out on the corresponding TSUs.
3. Functions are carried out in the correct aggregation stage.
4. Function are specified (with attributes) such that corresponding Technological/logistical concepts can be selected.
5. Functions have a depicted multiplicity (which can be one).

So first, in the PFD two types of goods originate from generators that represent arriving passengers and dollies. Subsequently, goods are merged in a sort block and are then loaded in containers before they are send to an exit. Based on this it is concluded that the PFD fulfills the first requirements.

Secondly, it can be seen that the stores and transformations all take place on the itemized goods as is the case in the material flow diagram. Furthermore, the functions are applied in the transshipment stage, which is the only stage item may occur. From which is concluded the PFD also satisfies requirements two and three.

For the remaining requirement, concepts should possibly be selected for the contained functions that also have a multiplicity. In the PFD all functions have a standard multiplicity of one, except the loading function. As it is assumed that four flights should be build simultaneously, the loading function has a multiplicity of four.

For the selection of concepts, both unloading and loading concepts can be selected that correspond with the transloading behavior of the functions. Based on the type of the transformation type corresponding option can be selected. With a holding capacity of five hundred one is able to evaluate storing concepts. And lastly, sorting concepts are able to be selected based on the number of entries and exits of the sorting block, which all together can, amongst others result into the MFD depicted in Figure 5.2.

That being stated, it is concluded that the PFD in Figure 5.8 is indeed a minimum PFD, which can be used to deploy various system concepts. Nevertheless, in most cases more information is at hand, which can be used to detail the routing in a PFD. By means of TSU attributes, in addition to the functional attributes, one can specify the handled goods and adjust the routing if desired. For instance, one can deploy a separate manual solution for goods that are too big to be conveyed by a standard handling system.

The TSU attributes that are considered in this research are: transshipments, conveyability , time band, fast and slow movers, and transformations are explained and are explained in further detail down below.

The first attribute on which product routing can be adapted is the transshipment attribute, which indicates a TSU will not be broken down any further. As has been discussed introducing the functional stage attribute.

With the transshipment attribute, one can indicate that a shipment contains TSUs that pass up the breakdown phase and directly go to transshipment or build phase. To enforce this flow, an interface is defined that prevents transshipment from being send to an unloading block.

As can be seen in Figure 5.9, a bulk TSU originates form the generator that contains two types of containers. One that has a "(T)" label, which indicates that these containers are meant for transshipment, and the other with a "()", which indicates that these containers are not meant for transshipment. Because the transshipments are not allowed to enter an unloading block, a sorting block is implemented to separate the transshipments of the regular flow.

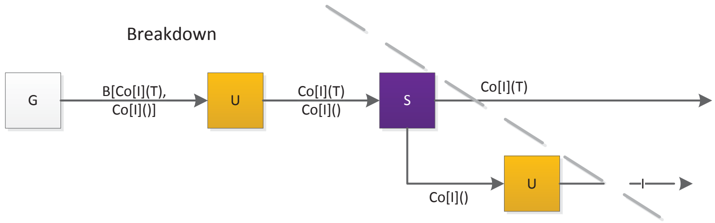

Figure 5.9: An example depicting, the separating transshipments of the regular flow

The second and third TSU attribute cover the ability of a system to convey units from A to B that be categorized in geometry and weight. Generally, systems are designed to convey a standardized TSU with a specified dimension and weight range. However, there are cases wherein products vary from this standard, especially in itemized goods category a high variation in weight and dimensions could be present.

Based on these variations in geometry and weight one can make a distinction between goods of a TSU, as is done in the PFD depicted in Figure 5.10. In the PFD three separate sorting functions are depicted for different formats of "parcels" namely: "Smalls/flyers", "Parcels", and "Irregulars and non-conveyables".

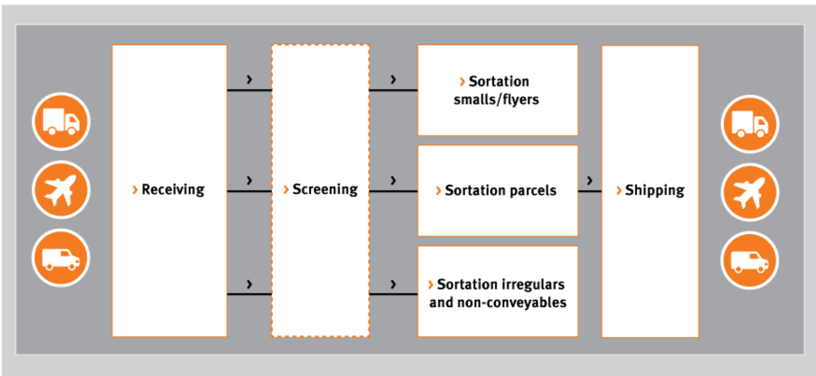

Figure 5.10: Parcel and Postal PFD with separate sorting functions for goods of different geometry.

In this research, a similar division is used to categorize goods with different geometry or weight. Generally, goods that are within the geometry and weight range of Vanderlande equipment are defined as regulars; while products that do not fit are named by the deviating property. For instance products that are too small are referred to as "small" and heavy products as "heavy".

Besides the deviation in dimensions, products can have a particular shape (ball-shaped) such that the product cannot be conveyed by a material handling system. Furthermore, a product can be accoutered with straps or other characteristics that may cause undesired blocking behavior. Both these type of products are considered to be non-conveyable, as they cannot be conveyed by a material handling system. However, non-conveyable can be turned conveyed by placing them in bins.

Apart from the shape the time a product arrives may also influence the handling of goods. Products that arrive early are most likely to be stored, while late products might undergo an accelerated handling path. Especially baggage handling customers make use of time profiles to determine how products are handled.

Figure 5.11 depicts such a time profile, wherein volume of arriving bags plotted against the time till the "scheduled time of departure"(STD). Bags that arrive early are directed to an early bag store, while bags with priority are send directly to make-up.

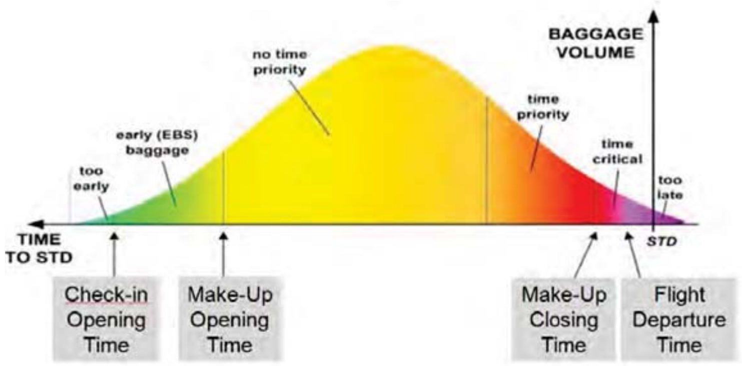

Figure 5.11: An example of a time profile used to determine time based handling

The time profile in the figure contains six time bands to categorize bags. However, in this research, the time band domain just contains the three basic labels "early","In time" and "late" to keep it simple and generic. Nevertheless depending on the customer or business the attribute domain can be adapted.

The next attribute is mostly relevant for systems in the warehouse automation domain. Goods handled by these systems are highly dependent on purchases of consumers, as there are products with a high demand and those with low demand. To accompany this, customers often split stores in two separate concepts, one concept for a select number of SKUs with a high pick frequency and a concept with a high variety of SKUs with a relatively low pick frequency. Therefore, the fast/slow mover attribute is introduced to distinct between the two.

The last two TSU attributes in this research are used to determine a sequence of transformations and specify conditions for which items are allowed to enter a particular function. Furthermore, the origin of goods are taken into account, as some transformation only need to be applied on goods from a certain origin.

To capture both the origin of a product and the order of transformations a table is formulated with transformations depicted horizontally and generators vertically, as demonstrated in Table 5.1. Additionally, the transformations are required to be placed in the desired order of execution. In other words the transformation to be performed first should be in the first column, and the final transformation in the last column. However, sometimes transformations are required, but a fixed order is not. In such cases, one should put a set of transformation in a column, as in the second column of the table. There, both “transformation 2” and “transformation 3” are put together with square brackets.

Table 5.1: An example of an chronological origin table

	T_1	$[T_2, T_3]$	...	T_k
G_1	X	X	...	X
$[G_2, G_3]$		X	...	X

With the transformation in the desired order, they can be coupled to generators that represent the origin of the products. By marking the intersection of the transformation and the generator with an “X” one indicates that the transformation needs to be performed. Similar to the transformation the generators can be grouped together into a single row, if they require the same set of transformations. When this is done for all generators one could eventually translate this input to a process flow diagram.

For Table 5.1 this results into constructions similar to the PFD depicted in Figure 5.12. In the figure three generators are merged into a single sort block as they all require transformations “T2” and “T3”. However, before the merging products originating from “Generator 1” first undergo Transformation one, as is depicted in the table. Furthermore, it can be seen in the figure that both transformations “T2” and “T3” are connected with a double arrow to the same sort block, which indicates that the transformations can be performed in any order.

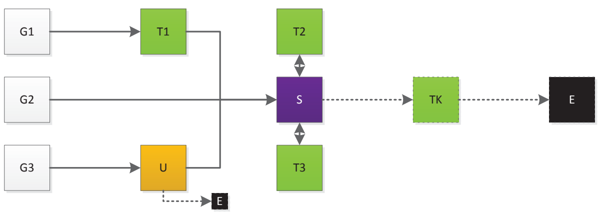

Figure 5.12: A process flow diagram that shows a possible results from the input given in Table 5.1

With the order of transformations in place, one can position the other functions around them by specifying the transformation status of TSUs entering a function or exit. As an example, one can have a store that only accepts good that are successfully transformed by a certain transformation. By setting this condition, the store is supposed to be positioned somewhere “behind” the particular transformation.

However, in certain cases a transformation may fail, like in the screening process of baggage handling systems that may consist of up to 5 different screening levels, which subsequent one another. In case the previous cannot give conclusive screening results. To clarify, Figure 5.13 depicts a process flow diagram with a transformation block that “repairs” failed products of a previous transformation.

The TSU transformation attribute of “T2” in this case is set to T1==Failed, so only Failed transformation are allowed to enter. Goods that completed transformation one successfully, by-pass the second transformation and are merged with successfully transformed goods of transformation number two.

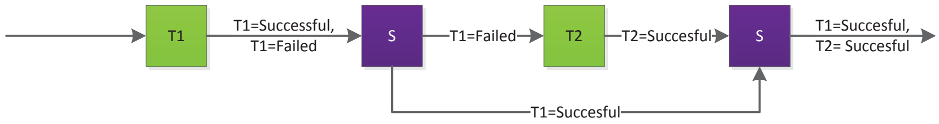

Figure 5.13: A process flow diagram of a transformation(T2) that repairs failed products of a previous transformation (T1)

Since there is a mixed flow leaving the last sort block, it is required for successive blocks to have {T1==Successful $\vee$[1] T2== Successful} Transformation, if that is required for the order that process occur.

In the scenario depicted above, products are send to a subsequent transformation process that handles the failed products. However, in certain situations a product revisits the initial transformation, as is the case for rework. Figure 5.14 depicts such situation in which products are reworked in case of a fail.

To be send back towards “T1”, the TSU transformation attribute of transformation number one should at least contain that T1 failed. However, to avoid conflicts with products that never have been at T1 an “or” statement is required just like before. In this particular case the TSU transformation should depict: {T1==Not started $\vee$ T1==Failed}.

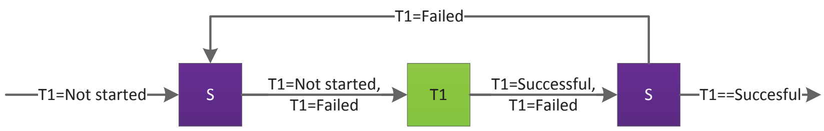

Figure 5.14: A process flow diagram of a rework process

So, in addition to interfaces and functional attributes; TSU attributes have been introduced which can be used to determine routing in a process flow diagram. To demonstrate how these can be used to construct process flow diagram both a parcel and postal and baggage handling case are treated in the next two sections.

[1] The $\vee$ sign is used in logic to depict the word “or”

5.3 Case: Design of a parcel and postal PFD

In this Section, a process flow diagram of a parcel and postal system is constructed to demonstrate how the interfaces and attributes are to be used. First, a minimum process flow diagram is constructed that subsequently is extended using TSU attributes.

The goods that arrive in this parcel and postal case are delivered in trucks that are loaded with loose parcels, and trucks that contain roll cages with parcels. The arriving parcels are all destined to be shipped in trucks with roll cages. Furthermore the parcels have to undergo up to four transformations, which are Identification, weigh, volume scan and quality control. Lastly the system includes transshipment of roll-cages.

To build a minimum PFD the information is translated to the functional attributes that are depicted in Table 5.2, In which the trucks are depicted as Bulk, the roll-cages as container and parcels as items.

Table 5.2: The required functional attributes to construct a minimum PFD for the P&P case.

Block	TSU	Transformation type
Generator(s)	Bulk[Item] Bulk[Container[Item]]	- -
Exit(s)	Bulk[Container[Item]]	-
Transformations	Item Item Item Item	1: Identification 2: Weigh 3: Volume scan 4: Quality control

Using the information from the table the minimum PFD in Figure 5.15 is obtained. The arriving bulk flows are broken down to items using unloading blocks and build up afterwards by means of loading blocks. Additionally, the transformations are carried out on the itemized goods. There is chosen to compound the four transformations in one single block, indicated by the “{1,2,3,4}”, to maintain a more compact PFD.

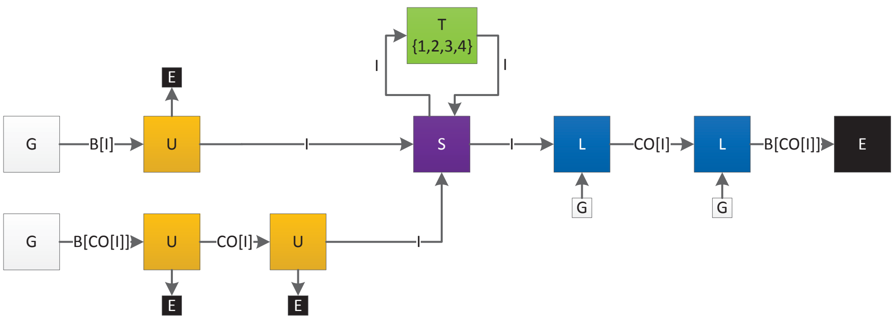

Figure 5.15: Minimum PFD of a parcel and postal system

Table 5.3: Presumed transformations for the considered parcel and postal system.

ID	Transformation type	TSU	Conditions
T1	Weigh	Itemized goods	T4 == Not started ∨ T4 == Successful
T2	Volume determination	Itemized goods	T4 == Not started ∨ T4 == Successful
T3	Identification	Itemized goods	T4 == Not started ∨ T4 == Successful
T4	Quality control	Itemized goods	T1 == Failed ∨ T2 == Failed ∨ T3 == Failed

To include the transshipments of containers, the TSU transshipment attribute is enabled on the containerized goods. Which results in two types of containers, namely: "CO[I]() " and "CO[I](T)" that are required to be separated by a sort block and merged again before the loading function, which results in the red outlined sorting blocks depicted in Figure 5.16.

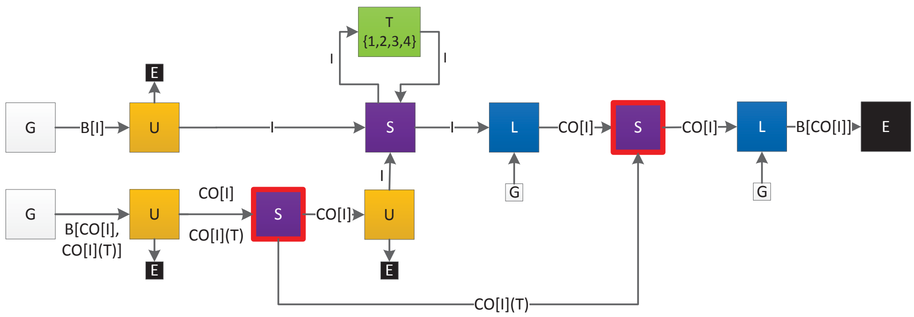

Figure 5.16: Transshipment within a parcel and postal system, indicated by the red inclined sort blocks.

With aggregation flows and transshipments in place, transformations can now be added to the PFD. For the considered parcel and postal system, the presumed transformations are depicted in Table 5.3. Typically parcels are all weighted, volume scanned, and identified, which are transformations known to occasionally fail on items that are damaged. This frequently results in a "hospital" area where the quality of items is inspected, repaired in case of a defect, and sent back to undergo the other three transformations again.

Holding the conditions in mind, a process flow diagram like the one in Figure 5.17 is obtained. In this particular Process flow diagram, items first go through a transformation block that embodies the weigh, volume and identification transformations. Subsequently, items go to a sort block from which items either go to transformation four or, to loading, based on the item‘s status. Items that failed are sorted to the Quality control and "successful" items proceed to loading, which can be specified in the TSU attributes of the particular loading block.

All in all, Figure 5.17 depicts the final PFD, that with further design decisions can be converted towards a material flow diagram.

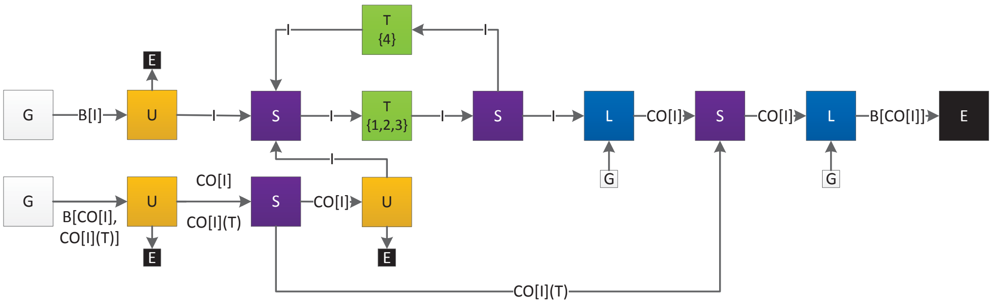

Figure 5.17: Parcel and postal system including transformations.

5.4 Case: PFD of a Baggage handling system

To demonstrate how the attributes and interfaces cooperate in the construction of process flow diagrams a case is treated that shows the construction of a process flow diagram of a Vanderlande system.

In this case a process flow diagram of a large airport, which is depicted in Figure 5.18, is constructed using the attributes and interfaces that are defined in the previous section. In Appendix C one can find an upscaled version of the depicted PFD and is described how the functions are fitted on the original process flow diagram.

First a minimum PFD is designed by determination of functional attributes, that is extended with design decisions towards the process flow diagram designed by Vanderlande.

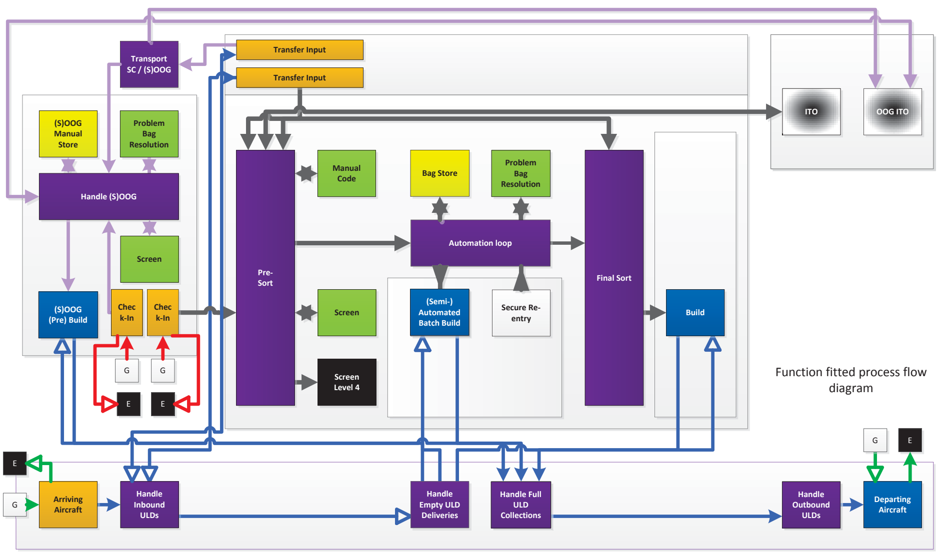

Figure 5.18: Minimal PFD resulting form input of Table 5.4

To build a minimum PFD, it is required to know how goods arrive and how they need to be send away to determine the generators and exits of a system, along with the corresponding unloading and loading blocks. Furthermore, it is required to know what type of transformations are necessary to be performed, on what TSUs. Lastly, it is mandatory to identify the need for a store.

For this airport bags are delivered by passengers and by planes that provide bags loaded in unit loading devices. Furthermore, it is desired to connect the new system to an already implemented system, preferably as a single bag flow. This means both bags enter and leave without being unloaded or loaded. Lastly, the planes that leave the airport are loaded with unit loading devices that contain the bags.

The receiving and shipping of bags as described resulted in the need for generators and exits with the TSU‘s as indicated in Table 5.4. Furthermore due to the uncontrolled arrival of bags there was chosen to implement a store, to have a process simpler to control.

Although, in the original PFD, an “ULD buffer” and “ULD store” are depicted, these functions are assumed to have an accumulation function, and are mainly portrait for better communication with the customer. Additional research is advised on this topic, how the use of the function blocks is communicated with the customer.

Besides the potential of bags being stored; the bags can undergo six distinct transformations on item level, which are Label, Weigh, Identification, Screen and Quality control 1 & 2. In the original PFD, however, only the screening and quality control processes are depicted. The remaining transformations are assumed to be compounded by the “Check-in” and the “Transfer input”.

To not over complicate the process flow diagram constructed in this case, it is assumed that the units that leave the unloading already underwent a Label, Weigh and Identification transformation, either successful or failed. Leaving only a screening and two quality control transformations, as is also done in the original PFD.

Table 5.4: Functional Attributes/Information required to construct a minimal PFD for the BHS case.

Block	TSU	Transformation type
Generator(s)	Item	-
	Item	-
	Carrier[Item]	-
	Bulk[Container[Item]]	-
Exit(s)	Item	-
	Item	-
	Bulk[Container[Item]]	-
Store	Item	-
Transformations	Item	1: Label
	Item	2: Weigh
	Item	3: Identification
	Item	4: Screen
	Item	5: Quality Control 1
	Item	6: Quality Control 2

Based on the information demonstrated in the table one can construct the process flow diagram depicted in Figure 5.19. The unloading and loading blocks are introduced to breakdown and build the level of aggregation. Due to multiple generators and/or exits, also a sort block is introduced to connect all item flows. Additionally, the store block is connected to this sort block as well as the transformations.

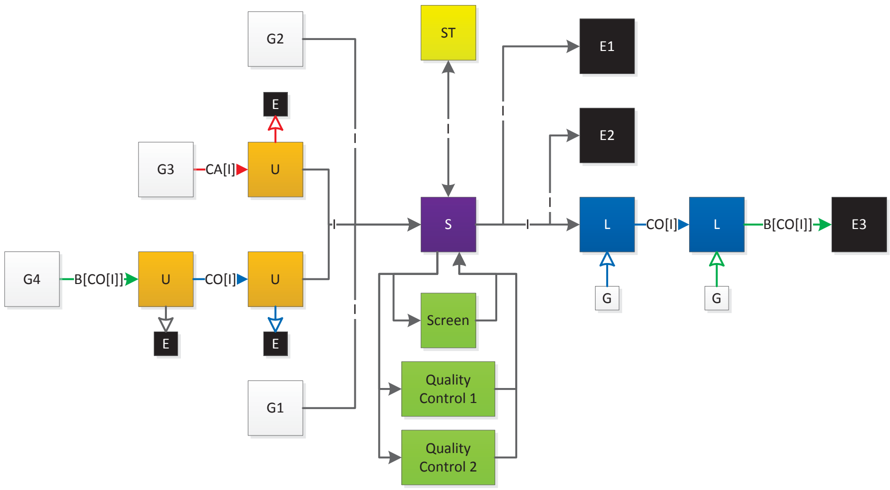

Figure 5.19: Minimal PFD resulting form input of Table 5.4

As mentioned above, a store was implemented due the uncontrolled arrival of bags, which means bags arrive early, in-time or late. For this system, it was desired to have a distinct loading process for early bags into unit load devices. Such that less effort is required closer to the departure time of the plane.

Therefore it is necessary to split the original loading block that handled all time bands into two separate blocks, as is depicted in Figure 5.20. In the figure, each function is marked with abbreviations of the time bands it handles; "E" for early, "IT" for in time and "L" for late. One can see the store only holds early and in time bags and the two loading blocks; of which one handles early bags and the other in time and late bags. Additionally, to support the split, an additional sort block was inserted to satisfy the multiplication interface.

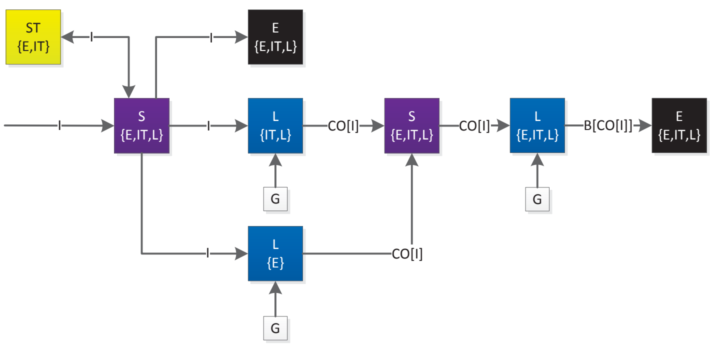

Figure 5.20: Store and Loading processes including the time band TSU.

The next step in the design process is the sequence of functions on the item TSU level. Therefore both the TSU attributes considering transformations, order and conditions, need to be determined. For this PFD only the screening transformation needs to be sequenced, as the other two transformations are conditional based and are not obligatory.

Knowing that only one process needs to be sequenced it is only required to determine the origins it needs to be applied to, which, in this case, needs to applied on product originating from generators two, three and four. Generator one is excluded as these are bags that re-enter the system after successful "level 4" screening processes.

Furthermore, the conditions of transformations are required to be filled in. Table 5.5 depicts the conditions for the relevant functions and exits. And based on these one can construct alternatives, of which two are depicted in Figure 5.21. Both concept "A" and "B", satisfy the Transformation conditions, but both have a different number in sorting blocks and the way they are connected to those blocks.

Table 5.5: Transformation conditions

Function	**Transformation conditions**
Quality control 1	Identification = failed
Quality control 2	Quality control 1 = failed ∧ Screening = Successful
Store	Screen = successful ∧ (Identification = successful ∨ Quality control 1 = successful ∨ Quality control 2 = successful)
Loading[item]	Screen = successful ∧ (Identification = successful ∨ Quality control 1 = successful ∨ Quality control 2 = successful)
Exit 1	Screen = failed
Exit 2	Identification = successful ∨ Quality control 1 = successful

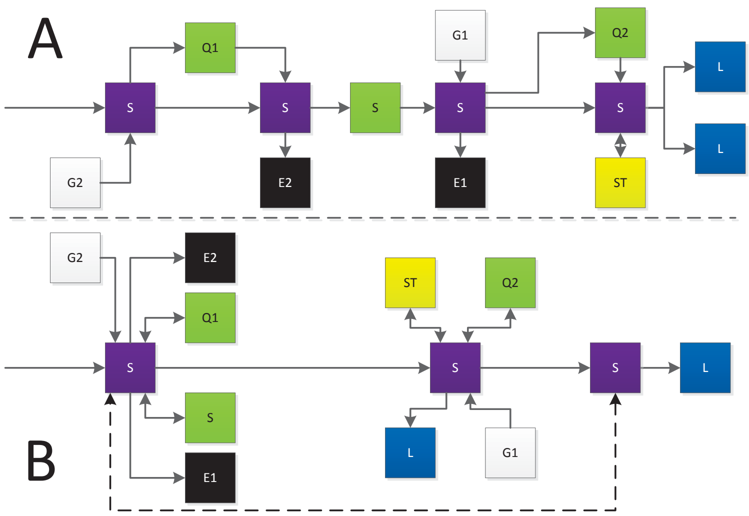

Figure 5.21: Two alternatives (A & B) based on the conditions depicted in table 5.5

Which of the alternatives is the best is hard to say, but for the considered baggage handling system alternative B was chosen. A reason it looked like this is because of building aspects, where all function connected to a sort block are allocated in a particular section of the building. This, however, has more to do with the abstraction level of material flow diagrams.

The last part of the PFD construction is the handling of empty containers, which is added to the PFD by removing the empty generators and exits and connect them to one and other via a new sort block, as is depicted in Figure 5.22. Furthermore, this figure depicts the full reconstruction of the function fitted PFD.

Thereby it is demonstrated that the PFD of the baggage handling system, can be reconstructed with the use of Generic function blocks, that are tight together by means of attributes and interfaces. The next phase in the design process would be the selection of concepts and the conversion to a material flow diagram. Because these topics are not in the scope of the research, recommendations are suggested in Section 6.2.

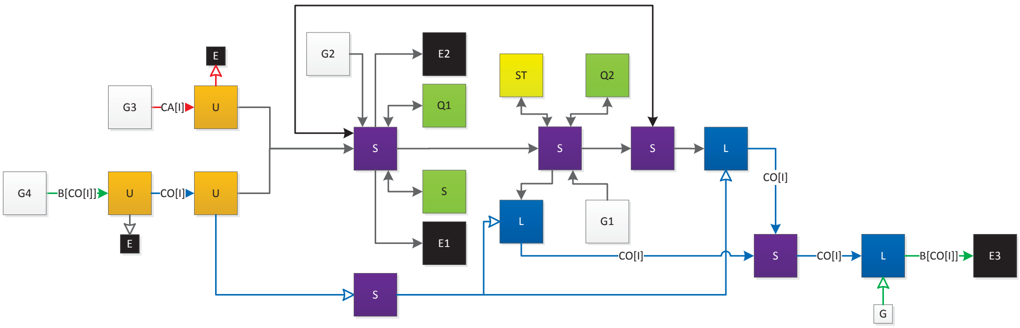

Figure 5.22: The re-constructed process flow diagram of a baggage handling system

Chapter 6

Conclusions & Recommendations

6.1 Conclusions

The initial goal of this research was to define and implement a multi-domain model that allows Vanderlande to explore and experiment with different parameter settings, new technologies and logistical concepts. However, due to limited time and bigger extent than priorly expected, the research only elaborated a partial definition of the multi-domain model.

From the literature discussed in Chapter 3, it was established that the design of an industrial systems could be subdivided into attributes, design abstraction and sub-systems. And based on the underlying relations it was decided the design of material handling systems should be designed from a abstracted function level, on which a designer selects equipment based on requirements. Because of the desired abstraction level, there was chosen to model the material handling systems in process flow diagrams.

However, to avoid three separate models a generic description of material handling systems was required. In Chapter 4 the handled material was generalized into four categories of "Transport and storage units"(TSU), which amongst others were used to describe goods flows and the aggregation levels. Aside from the TSUs, generic functions were introduced that describe the functionalities of a material handling systems, independent of any domain. Research on both process and material flow diagrams resulted in the functions **unloading** and **loading** that change the level of aggregation, **sort** to merge and split goods flows, **store** to store goods and **transform** to change a status of a product.

Furthermore, to be able to construct process flow diagram, the resulting functions were more formalized using functional attributes that specify functions, and distinct the functions from one another. Amongst others, the functional attributes determine the number of entries and exits of a function block, and the TSU categories on which functions can be applied.

In addition to the functional attributes, TSU attributes were introduced to enable handling based on the properties of a TSU. As a customer may desire to have separate handling for products that, for example, are bigger than defined dimensions. Furthermore, interfaces were introduced to ensure blocks are properly connected to one another. Finally, by means of cases it was demonstrated that process flow diagrams can be constructed using the generic functions with attributes and interfaces.

With this research, a preparative step is made towards the multi-domain model that can be extended, with additional research, to the conversion of process flow diagrams to material flow diagrams. The recommendations and suggestions for future work are discussed in the next section.

6.2 Recommendations

This chapter represents the recommendations for future research. Ideas are sketched that came across the research but where not part of the scope or where not carried out due to limited time.

The suggestions that are demonstrated are divided into two sections. The first section is about the TSU categories; and the other section illustrates suggestions for the conversion of a process flow diagram to a material flow diagram.

6.2.1 TSU categories

In section 4.1 four TSU categories are introduces that are used to investigate generic properties in material handling systems. However, the number of categories and names of categories might change in the future. Therefore a generic categorization is recommended and is described below.

One way to describe the TSU categories is with a directed acyclic graph, wherein vertices represent the TSU categories and are connected with arrows that indicate the order of aggregation. This means that an arrow going from “A” to “B” indicates that TSU B can be aggregated by TSU A. It is recommended for the graph to be acyclic to avoid an “aggregation paradox”, as it should not be possible to load B in A while A can be loaded in B.

When the directed acyclic graph description is applied on the current categories, it results in the graph in Figure 6.1. The figure demonstrates that Bulk can aggregate containers, carriers and items, but also it shows that items cannot aggregate other categories. Furthermore it can be seen, one cannot return to a TSU following any set of arrows.

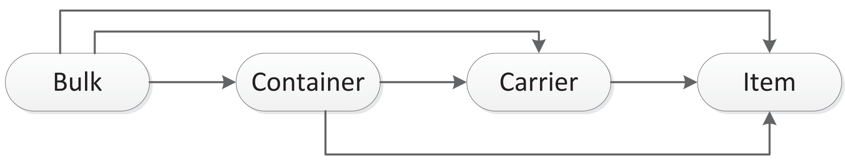

Figure 6.1: TSU categorization in directed acyclic graph format

This rather simple example can easily be checked by hand. However, as the number of categories increase the manual effort to determine a graph is acyclic increases as well. To check for the acyclic property one could use algorithms treated in graph theory literature, like Topological sorting, that eventually can be automated.

6.2.2 PFD to MFD

To be able to convert a process flow diagram to a material flow diagram, one should select technical or logistical concepts for the functions in the PFD. Additionally, more requirements have to be taken into account. Some functions might need adaptation due to the conversion, building interfaces need to be taken into account, and one should be able to choose a method of transport.

Each of these topics is explained in more detail in upcoming subsections.

Concept selection

The research concluded with functional attributes, TSU attributes, and interfaces that can be implemented to construct process flow diagrams. The next step in the design process would be the selection of concepts. To able to select a concept, one must weigh several attributes to make a decision. This section suggests an selection procedure that could be applied choosing concepts.

For better visualization, Figure 6.2 depicts an example decision sheet, wherein a concept needs to be chosen to load items into containers. (For simplicity reasons only BHS concepts are demonstrated) The remaining concepts are a manual, mechanic and automated solution.

Technology: [Loading]	Manual	Mechanic	Automated
Picture:			
Design Capacity [Bags per hour]	300	250	150
Multiplicity	2400/300 -> 8	2400/250 -> 10	2400/150-> 16
Capital expenditure	+	-	--
Operational expenditure	+	+	++
Footprint	+	+/-	-
Ergonomics	--	+	++
Requirements	None	None	Automated Store

Figure 6.2: An example decision weighing sheet

The first step in the selection procedure most likely is the determination of the capacity, such that multiplicity of concepts can be determined, which is necessary to determine a cost estimation and an indication for the footprint. To calculate the multiplicity one should also take the capacity related availability to determine if extra redundancy is required.

With a cost and footprint estimate, one is already able to make decisions. However, other parameters, like quality parameters, or requirements can be decisive as well. In case one has to choose between manual handling and mechanic concept, one could for instance take ergonomics into account. And if an automated loading robot should be selected one is also required to have an automated store.

Note, that the multiplicity changes the number of entries and exits of implemented sort blocks and may even require for additional sort blocks to be added. So one is advised to save sorting concepts for last. Additionally, there are sorter concepts that are used for transport of goods, so one might select sorter concept simultaneously with a transport concept.

To conclude, the recommendation considering the selection of concepts are summed below.

- Determine selection criteria to select concepts.
- Determine decision rules to weigh the distinct criteria.
- Save the selection of sorter concepts for last.

Functions

In this research, five functions were formulated along with functional attributes. However, in the conversion towards an MFD more attributes might be required to make distinctions in a design concept. The number of Attributes may increase as the level of abstraction decreases.

Below two examples are handed, which suggest this might be the case. The first example covers the change of a sort block and the second example sketches a situation in which functionality of unloading and loading might need an adaptation.

In the research it was briefly mentioned that a single sort block eventually may be performed by multiple blocks. Figure 6.3 portrays an example to support this idea.

Left in the figure a "regular" sort block can be seen with one entry and four exits and on the right a possible MFD representation is depicted, which consist of three sort blocks. First goods are sorted towards two distinct sort blocks that divides the incoming goods over two exits, creating the same effect as the 1:4 block. In the selection of sorter principle one should take this segregation behavior into account.

One other concept considering sorting blocks should be taken into consideration. As one of the introduced interfaces was: "Blocks may only be connected from an exit to an entry of another block." Which excluded the implementation of self loops in a process flow diagram. However in a material flow diagrams self loops may occur, hence the loop sorter concept.

In the middle of Figure 6.3, one can see a sorting concept implemented with self loop that allows recirculation of goods. It is believed that recirculation might be an functional attribute on the abstraction level of a material flow diagram.

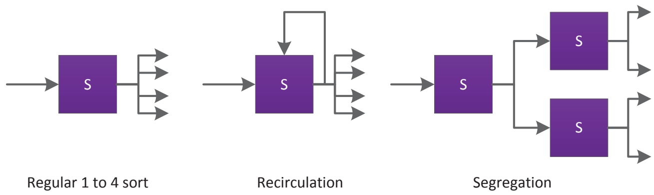

Figure 6.3: Conversion of a PFD 1:4 sort function to possible MFD configurations

The other example considered both the unloading and loading function, and shall be explained on the basis of a Warehouse automation example. In Figure 2.13, page 11, a schematic layout of a zone picking system is depicted. A concept where operators independently pick items for an order and load these items into the same carrier, which suggest both unloading and loading action can done partially. In other words, the empty channel does not necessarily have to be empty in an MFD, which may lead to a shared (un)loading configuration as depicted in Figure 6.4, in which (un)loading blocks are connected to the same sort block, returning the "half-empty" TSU once it is used.

To conclude this subsection the research questions considering functions are summed below.

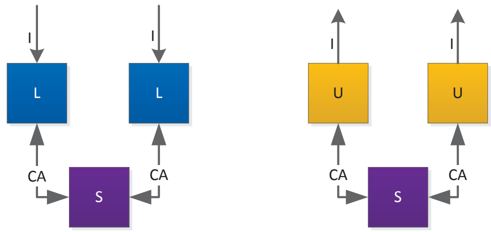

Figure 6.4: Shared loading and unloading

- Are additional functional attributes necessary to transform a process flow diagram to a material flow diagram?
- How should recirculation and segregation be implemented in a sort block when converting to a material flow diagram?
- How do process flow diagram convert to shared (un)loading principle?

Building Interfaces

The concept of a building, brings new design parameters into the picture. As a building may exist of multiple rooms and floors, there are multiple configurations to layout the system. Furthermore, it may occur that the distance between two point is relatively large that a specific method of transport might be preferred.

To be able to fit systems into a specific area, generally volume envelopes are used as a measure of space a concept requires. These envelopes are connected to one and other like in a process flow diagram. Then with the use of heuristics [11, 15] a configuration is determined that satisfies the constraints.

Apart from industrial system design one should also look into the packing of integrated circuit boards, which shows similar cases as the described problem.

To conclude this subsection the research questions considering building interfaces are summed below.

- Which building interfaces are important for the design for a material flow diagram?
- Is it necessary to perform a building fit in order to design a "useful" material flow diagram, and if so what method should be used?

Transport

Apart from equipment that performs one of the five functions, also the method of transport is required to be chosen.

The most important attribute considering transport, is the goods that are being transported. Additionally, to be able to select a method of transport, one is amongst others dependent on, distance and speed to fulfill in-system times. Furthermore, it might be required to have transport between floors, leading to vertical or spatial transport concepts.

In both [13] and [15] more inspiration can be obtained for transport related attributes.

When selecting a method of transport one should not forget it is possible that goods can temporary be loaded/consolidated into a carrier or container, as is described in section 5.2. Which in some case may be more beneficial then, for example, a single item flow.

To conclude this subsection the research questions considering Transport are summed below.

- Are more TSU attributes required in order to limit design options considering transport?
- Which are relevant transport attributes to be able to select a transport system?
- In what cases is it beneficial to temporary load units in a carrier or container?

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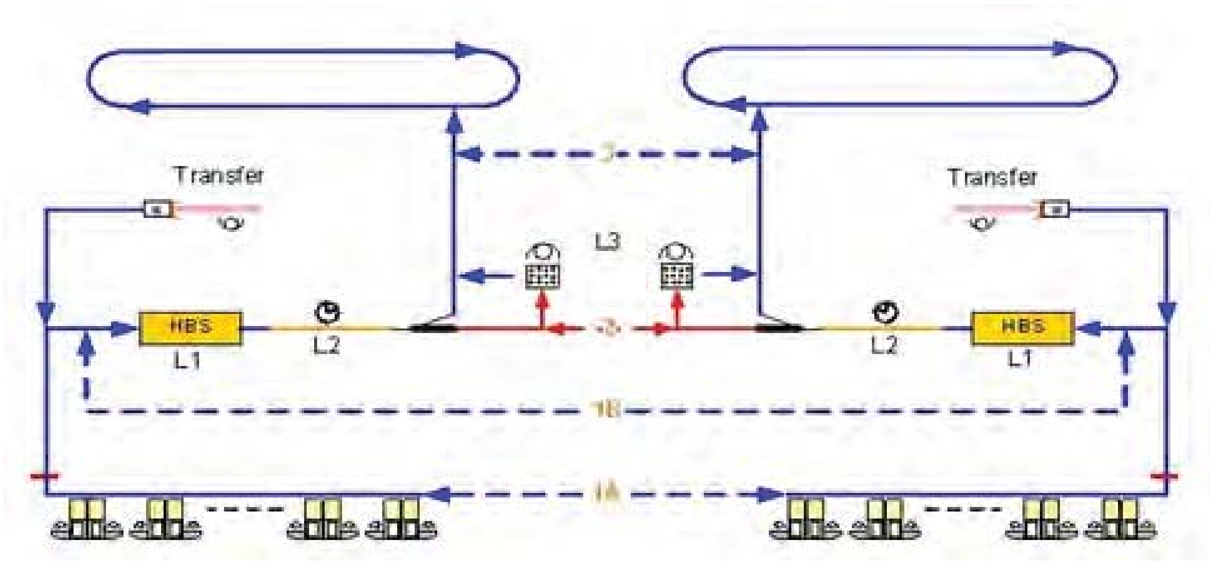
Appendices

Appendix A

Function mapping on a material flow diagram

On the next two pages one can see how the functions fit in Figure 5.2 are fitted step by step. Below the steps are stated briefly.

1. Orange unloading blocks are placed on locations where the aggregation level decreases, which is at the check-ins and transfer inputs.
2. Blue loading blocks are positioned there where the aggregation level increases. This is besides the carousels at the top of the MFD.
3. Purple sort blocks are added on places where flows are merged and/or split.
4. Green transformation blocks are allocated to places where the status af a TSU changes, which is at the check-in where bags are weighed and labeled and at the three screening locations.
5. A yellow store block is added, with additional sort blocks, at the position where bags are stored.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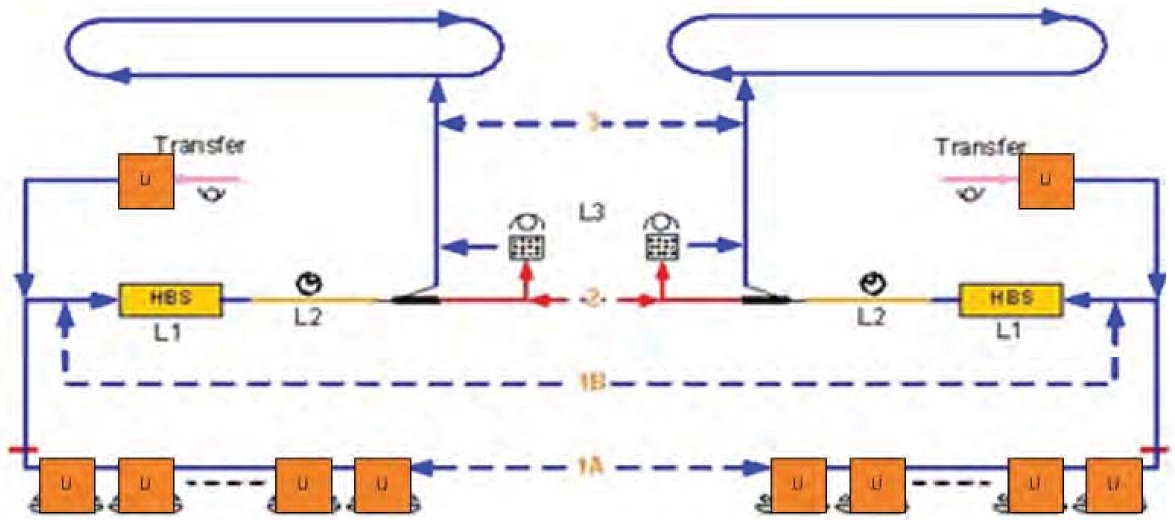
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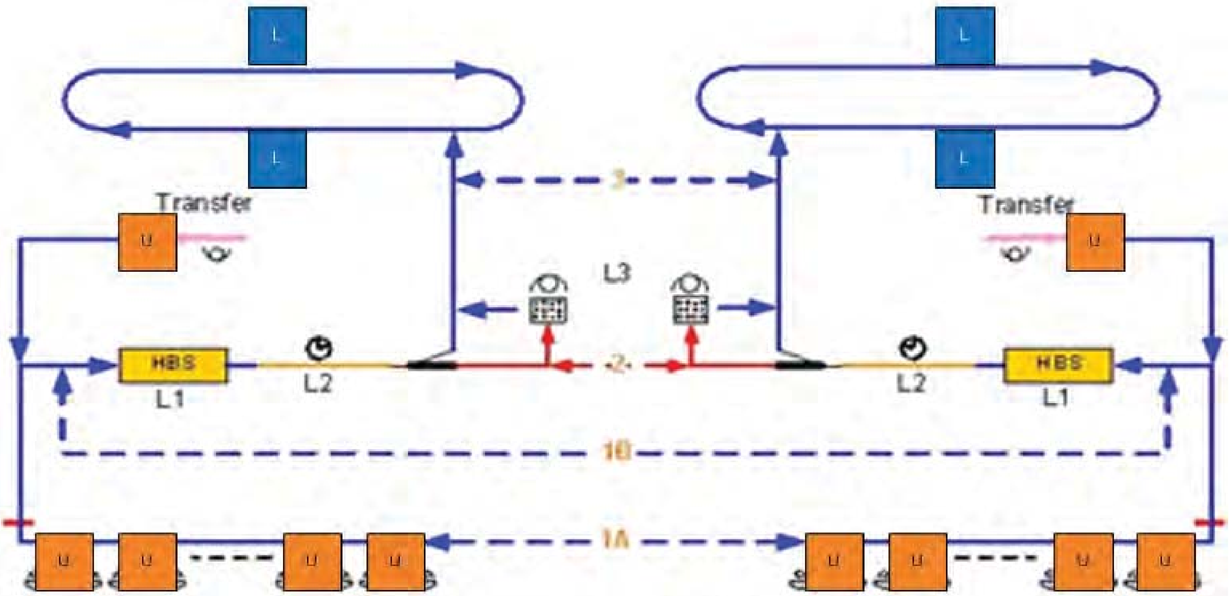
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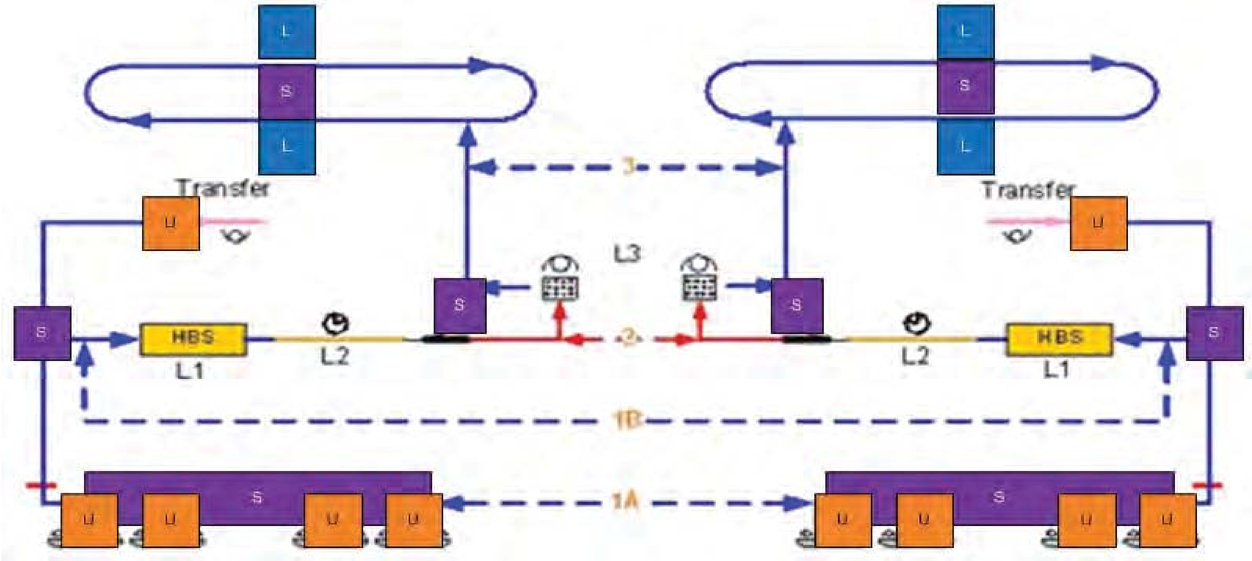
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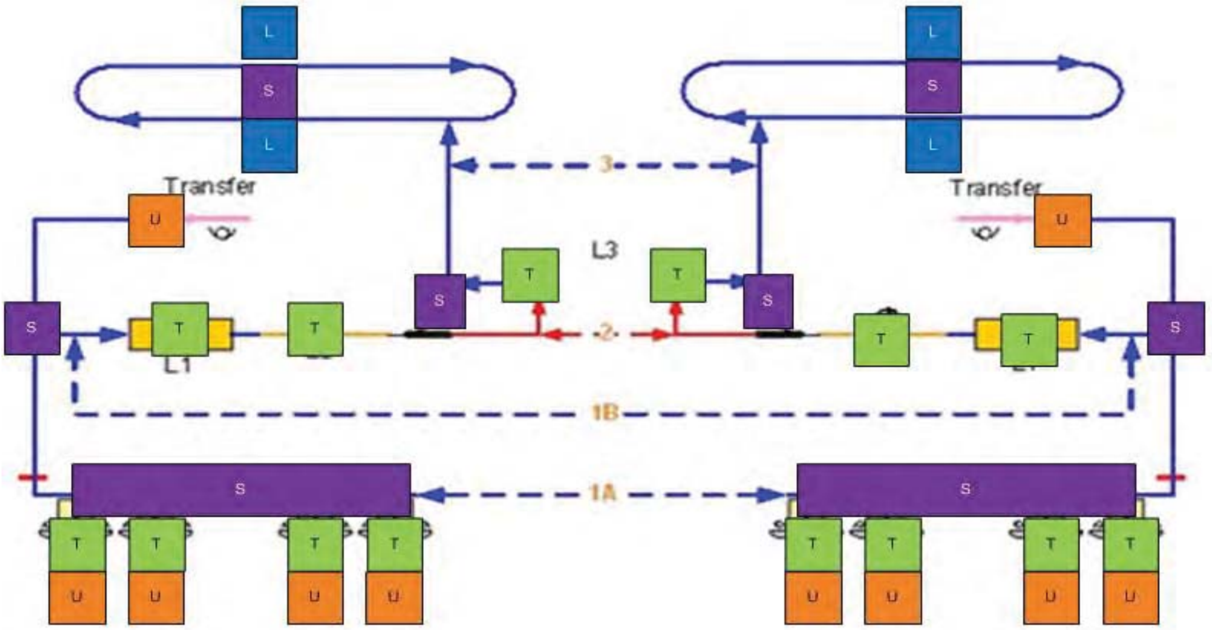
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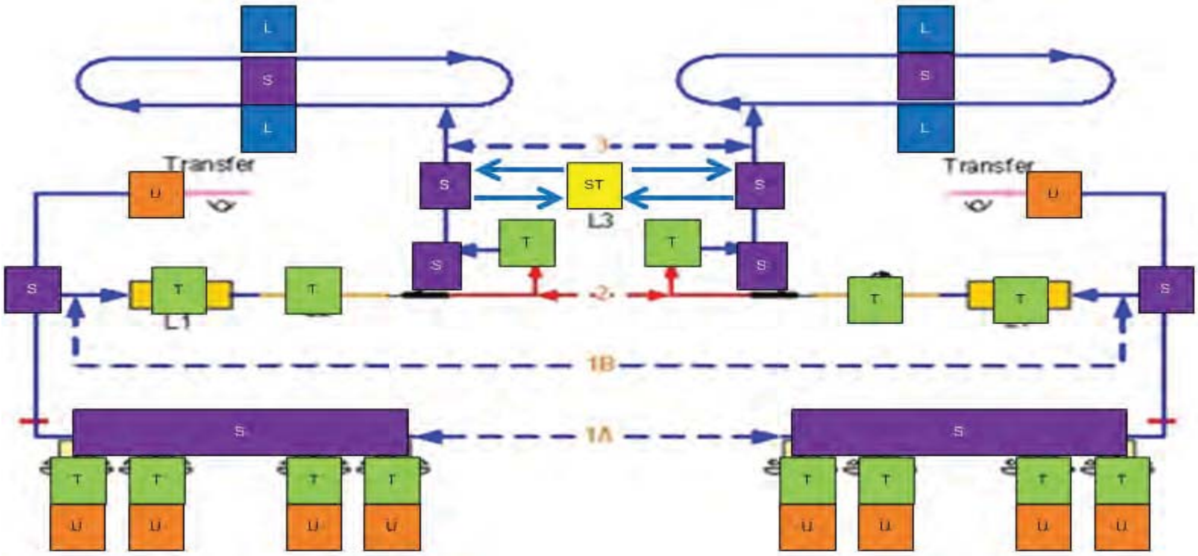
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Appendix B

Overview of attributes and interfaces

This appendix shows an overview of the attributes and interfaces described in Chapter 5.

B.1 Interfaces

This section summarizes the interfaces that are explained in Section 5.2. Figure B.1 depicts how blocks are allowed to be connected to one another.

1. Blocks may only be connected from an exit to an entry of another block.
2. Blocks are only allowed to be connected according to Figure B.1
3. Blocks that are connected must be of the same TSU level.
4. Empty channels from unloading functions are instantly connected to an exit.
5. Empty channels to loading functions are instantly connected from a generator.
6. TSU Transshipments may not be connected towards an unloading block.
7. Multiplication may only be applied on functions that are enclosed by sort functions, generators and/or exits.
8. Function blocks must be connected such that TSU attribute constrains are not violated.

B.2 Attributes

This section summarizes the attributes that are explained in Section 5.2. Table B.1 depicts the functional attributes that are used to construct minimal PFDs. Furthermore, Table B.2 depicts TSU attributes that are used to specify the handled TSU and Routing in a PFD.

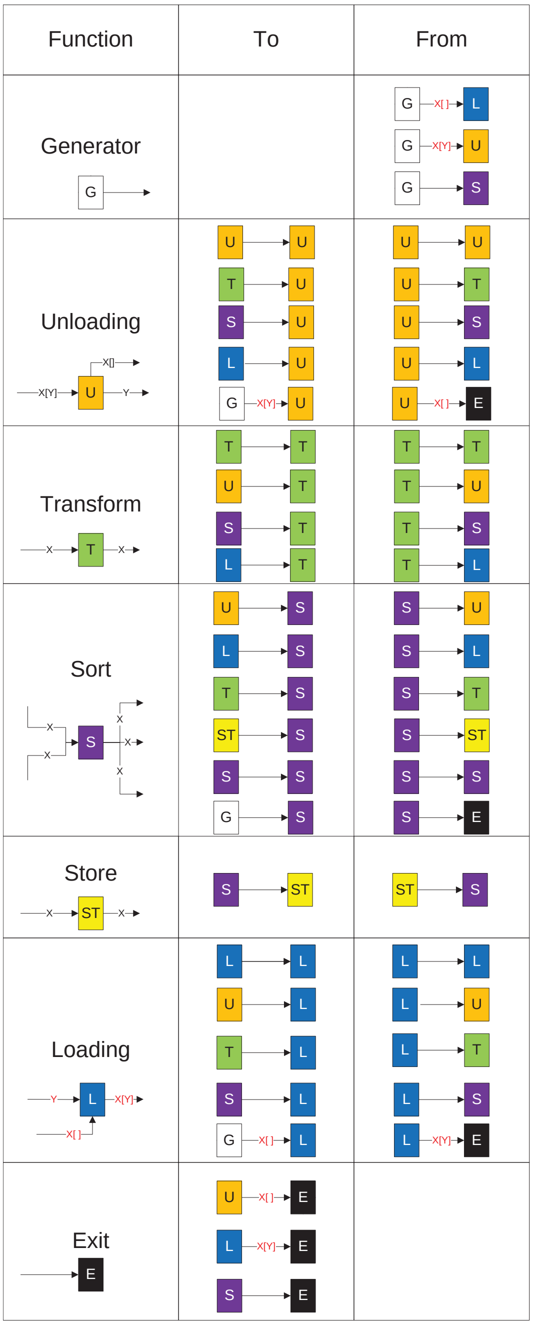


Figure B.1: Visualization of the connection matrix that is depicted in Figure 5.3

Table B.1: Functional attributes for the five generic functions

Function	**Unloading**	**Loading**	**Sort**	**Transform**	**Store**
Number of entries	1	2	$\mathbb{N}^+$	1	1
Number of exits	2	1	$\mathbb{N}^+$	1	1
TSU entry (entries)	{Bulk, Containers, Carriers }	*Entry 1:* {Containers Carriers, Items} *Entry 2:* {Higher then, TSU entry 1}	{Containers, Carriers, Items}	{Container, Carriers, Items}	{Containers, Carriers, Items}
TSU exit(s)	*Exit 1:* {Lower then TSU entry} *Exit 2:* Equal to TSU entry	Equal to TSU entry 2	Equal to TSU entry	Equal to TSU entry	Equal to TSU entry
Stage (*only on containers and carriers*)	{Breakdown, Transshipment}	{Transshipment, Build}	{Breakdown, Transshipment, Build}	{Breakdown, Transshipment, Build}	{Breakdown, Transshipment, Build}
Holding capacity	0	0	0	0	$\mathbb{N}^+$
Type	-	-	-	{Screening, Label, Weigh, Volume Scan, Contour check, Sealing/Wrapping, Identification, Quality control, Alignment Stack Rotation tripper VAS}	-
Multiplicity	$\mathbb{N}^+$	$\mathbb{N}^+$	$\mathbb{N}^+$	$\mathbb{N}^+$	$\mathbb{N}^+$

Table B.2: TSU attributes that can be used to specify TSUs and routings in PFDs

TSU Attribute	**Attribute domain**
Transshipment	{Yes, No}
Conveyability (Geometry)	{Small, Regular, Irregular, Non-conveyable}
Conveyability (Weight)	{Light, Regular, Heavy}
Time band	{Early, In time, Late}
Fast/slow mover	{Fast,Slow}
Transformation (Order)	Generator$_i$ {Set of Transformations in chronological order} For i = 1 to 'number of non- empty Generators'
Transformations (Conditions)	T_k=={Succesfull, Failed, Not started} For k = 1 to 'number of transformations'

Appendix C

Case: Function fit on a BHS process flow diagram

For the case in section 5.4, a process flow diagram is recreated to match with the process flow diagram designed by Vanderlande. The original process flow diagram and a function fitted PFD are depicted on the next two pages. (As the focus in the case lies on the departure only the function encircled in red are taken into account.) Below, it is described how the function are fitted to the PFD.

The first step is the identification of aggregation changes, which, in this process flow diagram, happens on places were arrows change color. Table C.1 demonstrates the meaning of the colors used in the PFDs, which determine if a function is a loading or unloading action; additionally, empty arrow heads represent empty transport.To fit the unloading and loading functions, generators and exits are added to the check-in and aircraft functions.

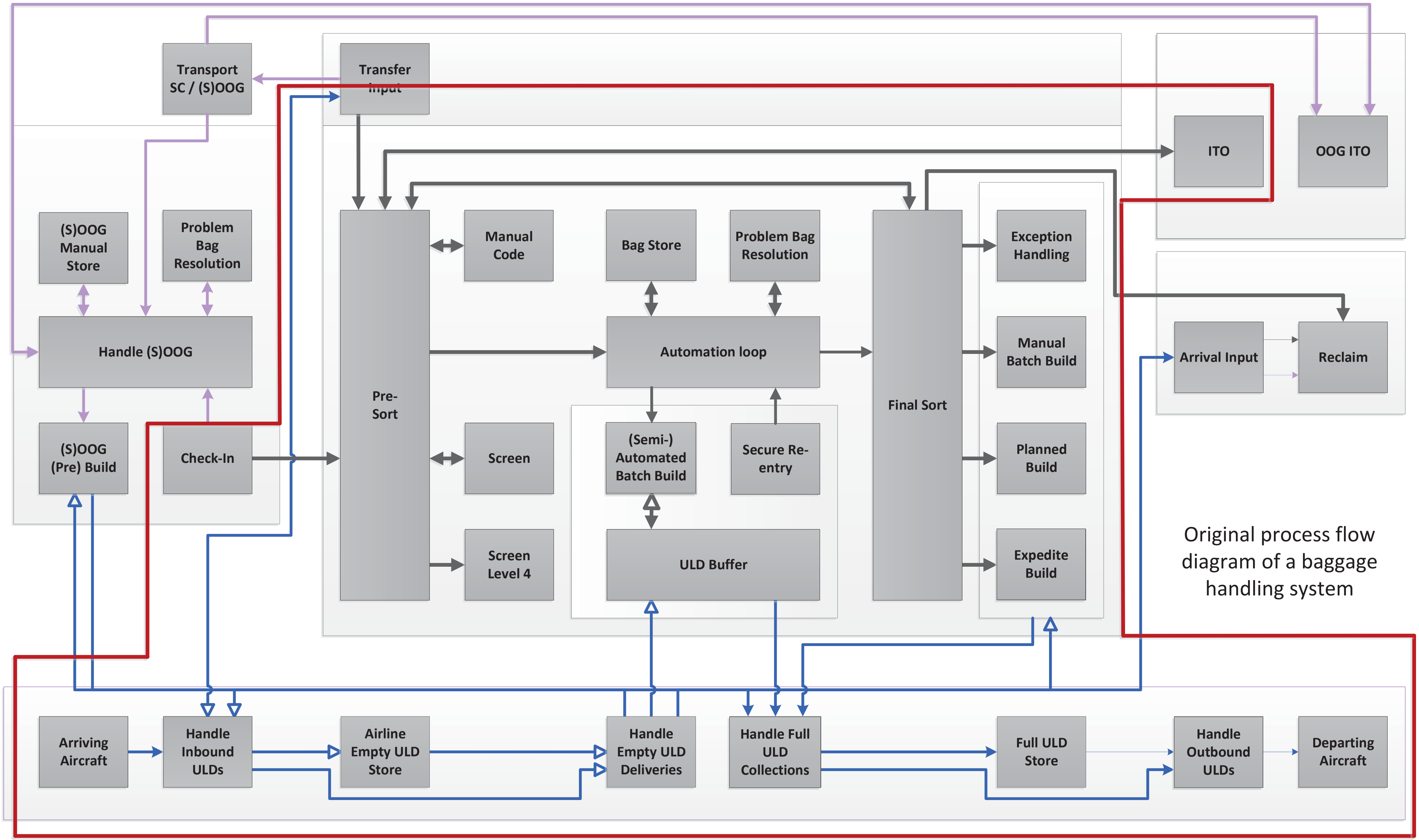
Table C.1: Arrow color legend

Arrow color	Represents	Generic TSU
Black	Regular Bags	Item
Pink	Irregular Bags	Item
Red	Passenger	Carrier
Blue	ULD	Container
Green	Plane	Bulk

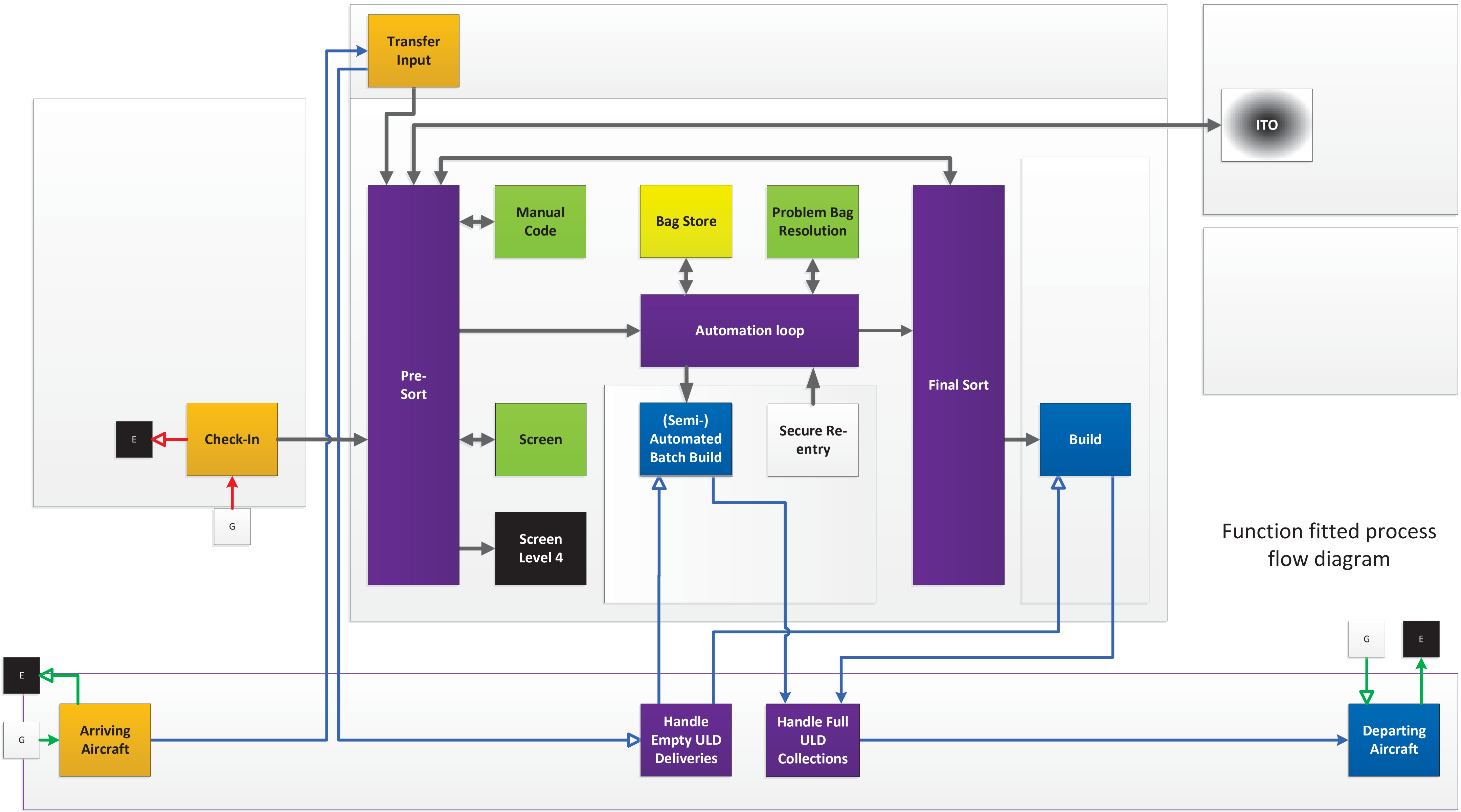
Besides the added generators and exits for aggregation purposes, functions that represent system interfaces are colored either white or black. Amongst others this applies to the "ITO" blocks that represent a connection to other already existing systems. Additionally, this applies to the "Screen level 4" and the "secure re-entry" as level 4 screening is performed externally.

Subsequently, blocks are colored green when it represents a transformation, and yellow if it considers a store. Although the functions "ULD Buffer","Airline Empty ULD Store", and "Full ULD Store" suggest being stores, they are assumed to represent accumulation and are depicted because the customer demanded the specific process to be depicted as they wanted to reserve space for them. In this research, however, accumulation is part off transport. Therefore the functions were removed in the function fit.

With the transformation and stores in place only the sort function is left to be fitted, which is done on the remaining functions with multiple entries and/or exits.



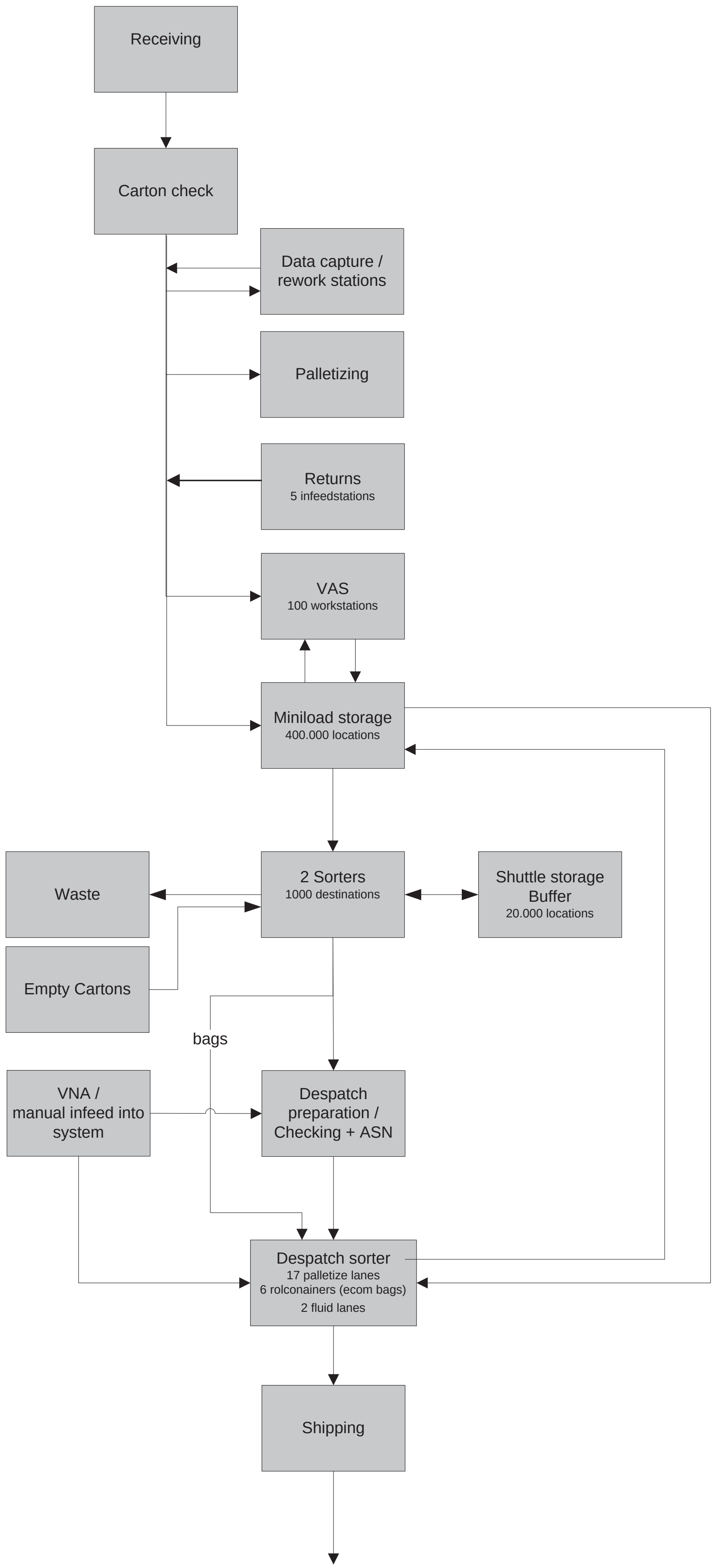
Original process flow diagram of a baggage handling system


Transfer Input
Check-In
E
G
Pre-Sort
Manual Code
Screen
Screen Level 4
Bag Store
Problem Bag Resolution
Automation loop
(Semi-) Automated Batch Build
Secure Re-entry
Final Sort
Build
ITO
Arriving Aircraft
E
G
Handle Empty ULD Deliveries
Handle Full ULD Collections
Departing Aircraft
G
E
Function fitted process flow diagram

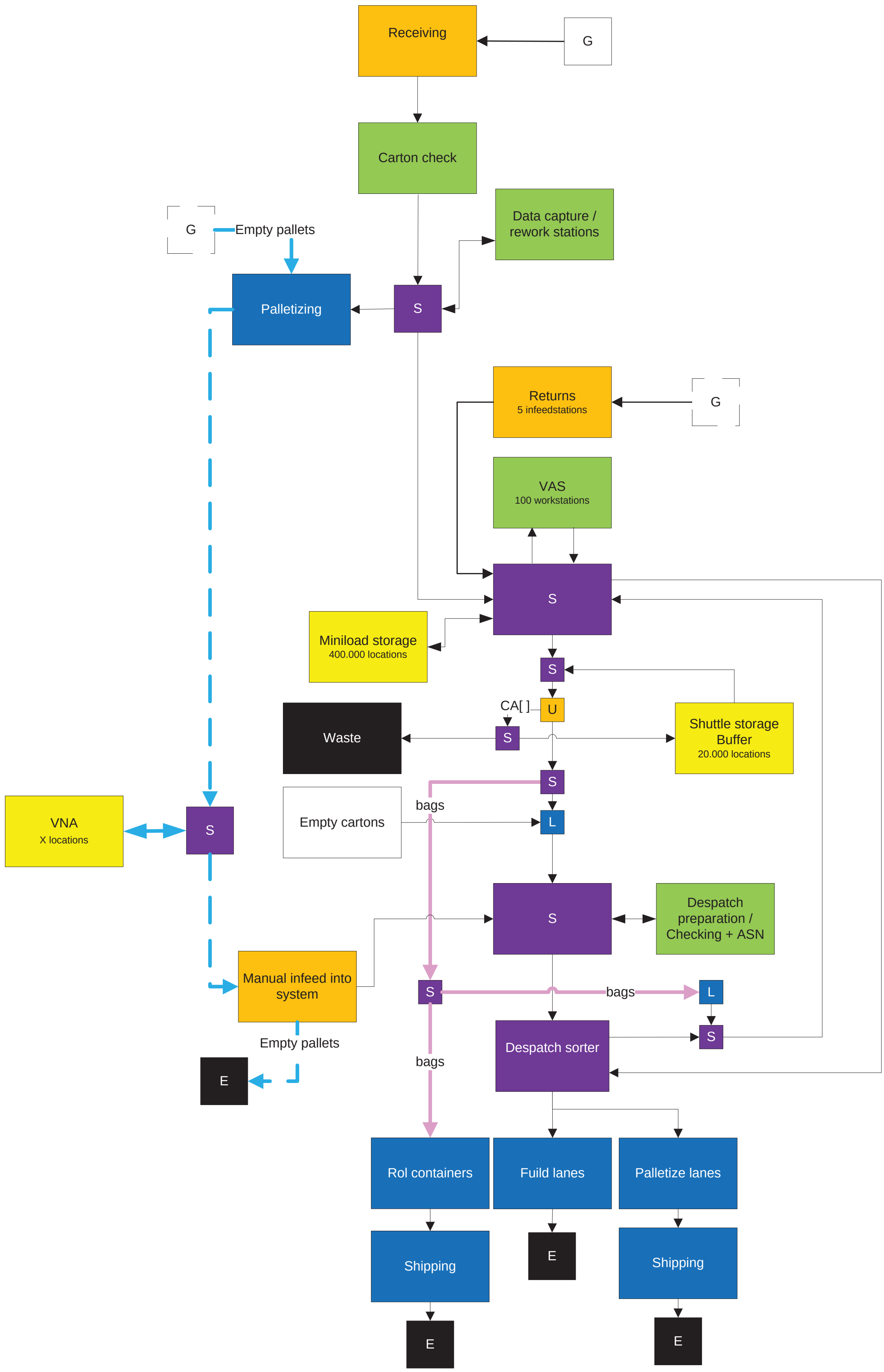
Appendix D

Function fit on a WA process flow diagram

In this Appendix a function fit on a warehouse automation system‘s PFD is depicted to demonstrate that the generic functions also can be used to construct warehouse automation. With the use of the quotation document underlying functionality of the process were discovered, which resulted into the function fit.



Receiving
Carton check
Data capture / rework stations
Palletizing
Returns
5 infeedstations
VAS
100 workstations
Miniload storage
400.000 locations
Waste
2 Sorters
1000 destinations
Shuttle storage Buffer
20.000 locations
Empty Cartons
bags
VNA / manual infeed into system
Despatch preparation / Checking + ASN
Despatch sorter
17 palletize lanes
6 rolconainers (ecom bags)
2 fluid lanes
Shipping


Receiving
G
Carton check
Data capture / rework stations
G
Empty pallets
Palletizing
S
Returns
5 infeedstations
G
VAS
100 workstations
S
Miniload storage
400.000 locations
S
CA[ ]
U
Waste
S
Shuttle storage Buffer
20.000 locations
S
bags
Empty cartons
L
VNA
X locations
S
S
Despatch preparation / Checking + ASN
Manual infeed into system
S
bags
L
S
Despatch sorter
Empty pallets
E
bags
Rol containers
Fuild lanes
Palletize lanes
Shipping
E
Shipping
E
E