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A Simulation Approach to Warehousing Policies: The GrandVision Case

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Aknowledgment

This master thesis project started more than 2 years ago and represented several hours passed in GrandVision’s Warehouse and behind a desk.

I would like to acknowledge my friend Jorge Afonso, in those times Logistics Manager of GrandVision’s Portugal, for the invitation for making part of this project. I also would like to acknowledge all the persons who helped in the company: Andreia, Bruno, João, Joana, Luís, Mário, Marta, Paulo and Pedro who always gave me all the support and information I needed.

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Resumo

Esta tese de mestrado é um projecto desenvolvido na empresa GrandVision na área da Gestão da Cadeia de Abastecimento, mais concrectamente em Armazenagem, que apesar de muitas vezes desprezada, representa em média entre um quarto a um quinto dos custos logísticos.

Apesar dos grandes avanços na tecnologia os armazéns tradicionais, de picking manual, continuam a representar 80% do universo.

Aproveitando a vontade da Gestão da empresa em desenvolver projectos de melhoria para o Armazém, foi proposto o estudo ,através de simulação, de novas políticas de Armazenamento e de Picking para a operação de aprovisionamento das lojas MultiOpticas e GrandOptical.

Os modelos testados em simulação partiram dos estudos previamente desenvolvidos nesta área e os resultados obtidos estão alinhados com os que foram anteriormente reportados.

Com a conclusão desta tese, a Gestão da GrandVision fica no seu dispor de um procedimento de Arrumação baseado em Classes que quando combiando com uma política de Agrupamento de orderns podem trazer **poupanças de tempo de ciclo a rondar os 32%,** segundo o modelo de simulação.

Palavras-chave:

Modelos de simulação, cadeia de abastecimento, politicas de gestão do armazém, tempo de ciclo.

Abstract

This master thesis is a project which took place in the company GrandVision. It is under the Supply Chain field of study, more precisely Warehousing; which despite having its importance underrated for many times, represents on average from one quarter to one fifth of the overall logistic costs.

Regardless of the great technology break-troughs, traditional manual picker-to-part warehousing systems still represent 80% of the universe.

Taking advantage of GrandVision's management will in develop improvement projects to its warehouse; it was proposed the study, through simulation, of new Storage and Picking policies for the weekly Replenishment operation of MultiOpticas and GrandOptical Shops.

The simulation models were created based on previous findings in this area of study, and results obtained are according with the ones previously reported in literature.

With the conclusion of this master thesis, GrandVision's management has in its possess a procedure of Class-Based Storage, which combined with a Batching Policy can bring, according with the simulation model, **improvements around 32% of the Total Fulfillment Time.**

Keywords:

Simulation models, supply chain, storage policies, fulfillment time.

Contents

1. Problem Context Definition

1.1 Introduction to GrandVision

In the 6th of July 2010 a press release of HAL, an international investment company, informs its two biggest major optical subsidiaries and two strong players in the market, Pearle Europe B.V. and GrandVision S.A., would merge and combine their activities creating GrandVision B.V.[1]

GrandVision B.V. borned the 1st of January 2011 and has more than 4000 stores in 40 countries worldwide and sales of more than 2,5 billion €. The company has its headquarters in Schiphol, the Netherlands.

In Portugal GrandVision B.V. owns the companies MultiOpticas and GrandOptical and its core products are: frames and sunglasses (regular branded, exclusive branded and private label), regular lenses and contact lenses (both not studied here as its flow does not pass in the warehouse) and contact lenses solutions (branded and white label).

1.2 MultiOpticas

MultiOpticas counts presently with 82 own shops and 60 franchising shops and it is a brand which deliveries value for money products through a mass market orientation; its customers find in its shops products of good quality but not too expensive. In 2010 the average ticket price was 238€ and the best offer was 59€. The company has a central lab in Oporto where it is done the assembly operation of all own shops.

1.3 GrandOptical

GrandOptical has four own shops in Portugal, the one of Centro Comercial Colombo deserves a special mention has it was the biggest Pearle shop in Europe with incomes of 6,2 million €. GrandOptical is a company directed to a target which searches mainly branded products and

[1] http://www.halholding.com/pdf/2010-07-06%20Pearle%20GV%20HAL%20ENG.pdf
http://www.grandvision.com/

presents a best service and wide assortment. The average ticket price was 202€ in 2010. GrandOptical assembles the lenses of its costumers on each shop.

1.4 Main Suppliers

Frames and sunglasses sold in the shops can be either private label or branded. Private label suppliers are located mostly in the Far East (in China mostly), the delivery times are never shorter than three months being the average time four months, which brings high stock; the unit price cost goes from 2€ to 15€. The more recent data indicates that Luxottica and Safilo represent about 80% of branded purchases; the delivery time is between two to eight weeks and its unit price cost is in the range of 25€ to 100€. GrandVision strategy for the time to come is to reduce the dependence of Luxottica and substitute it by Safilo (a company also part of HAL) mainly by progressively leaving Luxottica Stars, a vendor management inventory program designed for thirteen shops and embracing one with Safilo.

Contact lenses solutions can be white label and branded. White label suppliers are Sauflon from the UK, with a delivery time of two to three weeks, and Alcon from the US, with a delivery time of three to four months. Liquilentes, Novartis and Primalba all have distribution centers in Portugal and its delivery time is in average of one or two weeks.

"Warehouses are a key aspect of modern supply chains and play a vital role in the success, or failure, of business today". (Baker and Canessa, 2009: 425)

2. Literature Review

This chapter presents a literature review of the state-of-the-art in research on Warehousing. The object of study of this master thesis is a bin-shelving picker-to-part system therefore that tends to be the focus of this chapter.

2.1 The Role of the Warehouse

Warehouses are strategic infrastructures built with "*the prime objective of facilitate the movement of goods through the supply chain to the end consumer*" (Baker *et al.*, 2010: 226). Despite many times its importance is underrated, studies show that its operating costs represent about 22% of the overall logistic costs in the USA (Establish, 2005), while in Europe the percentage is around 25% (ELA/AT Kearney, 2004).

Although throughout the years many initiatives as just-in-time (JIT), efficient consumer response (ECR) or collaborative planning, forecasting and replenishment (CPFR) have showed up with the objective of connecting the manufacturer to the end consumer, it is likely that supply chains "*will never be so well coordinated that warehousing will be completely eliminated*" (Frazelle, 2002: 1).

Modern warehouses assume one or more of the following roles (Baker et al., 2010):

- ***Inventory holding point***. In a context of increasing market volatility, supply chains might often need decoupling points; distribution centers which work as buffers and help to smooth variations between supply and demand, allowing agile response times to customers. Inventories might also have cost justifications as enabling manufacturing economies of scale, to obtain purchasing discounts for large quantity orders, to build seasonal stock in advance, and to cover for production shut-downs.
- ***Consolidation center***. Warehouses usually perform the function of consolidate different orders lines of the same customer and make sure they are sent together.
- ***Cross-dock center***. Sometimes customers are served with goods coming from other warehouses or directly from the manufacturer; in that cases goods might pass in the

warehouse without being placed into storage, going directly from an incoming to an outgoing vehicle.

- ***Sortation center***. In an operation similar do cross-dock, warehouses can work as places where goods pass to be sorted and assigned to different customers or regions.
- ***Assembly Facility***. Given the increasing product range proliferation it is often useful to postpone the final assembly of products down the supply chain as much as it is possible, reducing the inventories along the way.
- ***Trans-shipment point***. Whenever remote zones of a country need to be supplied, sometimes there is no need to hold inventories in local warehouses; therefore they work just as depots where the goods are sorted to smaller vehicle loads for immediate delivery to customers.
- ***Returned goods center***. Returning of goods is becoming an important feature of modern warehouses, either by performing customer services or for environmental legislation issues.

2.2 Warehouse Design

Despite warehouses are crucial nodes in modern supply chains; several authors have pointed a lack of systematic approaches for its design (Baker and Canessa, 2009; Goetschalckx *et al.*, 2002; Rouwenhorst *et al.*, 2000). In fact, most of the existing literature on warehousing addresses specific topics regarding planning and control and do not present a holistic perspective of warehouse design; perhaps because of the complexity of the subject itself.

Warehouse decisions are regarded as highly complex as often deal with conflictive performance objectives (costs, throughput, storage capacity, response times etc.) and trade-offs have to made (Rouwenhorst *et al.*, 2000). Moreover, more than one design can be feasible for running an operation, which reinforces the importance of taking well-grounded decisions.

Indeed, most of the authors agree that this process involves clusters of interrelated problems, which should not be separated, but optimized simultaneously in order to reach a global optimum (Rouwenhorst *et al,* .2000).

Gu et al. (2007) and *Gu et al.* (2010) developed a framework which combines warehouse design and warehouse operation, through performance evaluation. The model consists in bringing up the various design alternatives by taking five interrelated group of decisions: determining the overall warehouse structure; sizing and dimensioning the warehouse and its departments; determining the detailed layout within each department; selecting warehouse equipment; and selecting operational strategy.

A figure with detailed description of these decisions is presented below:

Description of warehouse design and operation problems

Design and operation problems			Decisions
Warehouse design	Overall structure		• Material flow • Department identification • Relative location of departments
	Sizing and dimensioning		• Size of the warehouse • Size and dimension of departments
	Department layout		• Pallet block-stacking pattern (for pallet storage) • Aisle orientation • Number, length, and width of aisles • Door locations
	Equipment selection		• Level of automation • Storage equipment selection • Material handling equipment selection (order picking, sorting)
	Operation strategy		• Storage strategy selection (e.g., random vs. dedicated) • Order picking method selection
Warehouse operation	Receiving and shipping		• Truck-dock assignment • Order-truck assignment • Truck dispatch schedule
	Storage	SKU-department assignment	• Assignment of items to different warehouse departments • Space allocation
		Zoning	• Assignment of SKUs to zones • Assignment of pickers to zones
		Storage location assignment	• Storage location assignment • Specification of storage classes (for class-based storage)
	Order picking	Batching	• Batch size • Order-batch assignment
		Routing and sequencing	• Routing and sequencing of order picking tours • Dwell point selection (for AS/RS)
		Sorting	• Order-lane assignment

Figure 1 – Warehouse design and operation problems (Gu, 2007)

Performance evaluation methods considered are benchmarking, analytical models and simulation models. They should be the link connecting warehouse design and warehouse operation. Thus, in the early design stage, performance evaluation helps in the decision making process by narrowing down the alternatives. Further in time, when the operation is already running, performance evaluation is a way of constantly access what can be improved or redesigned, in a sort of iterative process.

Warehouse operation is divided in four main problems: receiving and shipping, storage and order picking. The division between operation strategy problems and warehouse operation problems is not always quite clear; apart the first relates to long term decisions and the last to decisions which can easily be changed.

The generic framework is presented next:

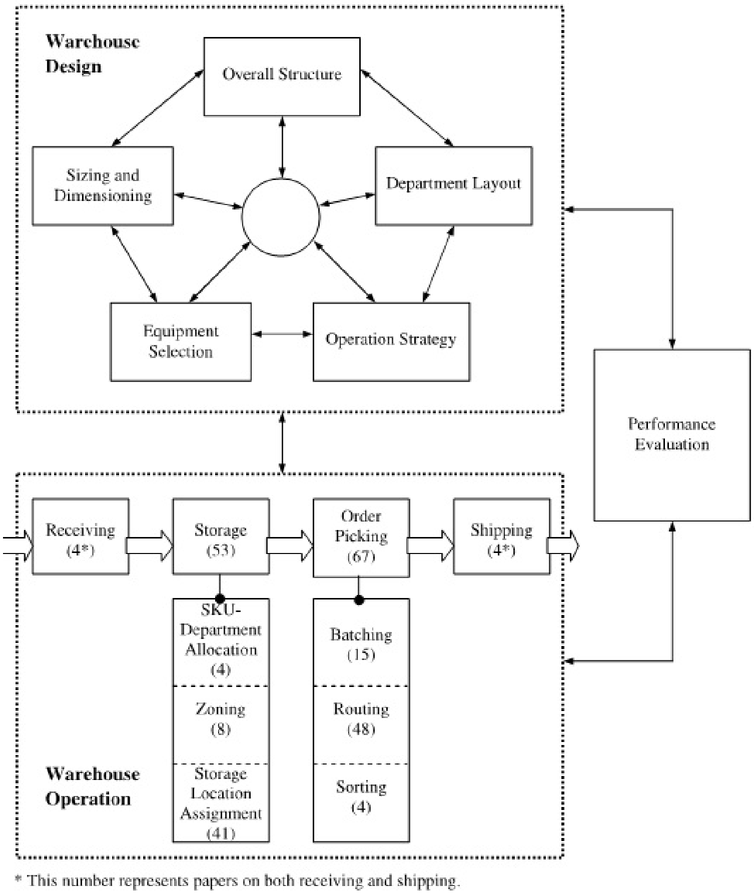

Figure 2 – Warehouse generic operation framework (*Gu et al.,* 2010).

2.3 Warehousing Systems

A storage system (Rouwenhorst *et al.*, 2000), order picking system (De Koster, 2007), or just warehousing system (Van den Berg and Zijm, 1999; Van den Berg, 1999); refers to specific combinations of human resources and technology which allow material handling activities to be accomplished in an effective way.

Warehousing systems can be divided in the ones which need human intervention and the ones which run in a completely autonomous way. It is not uncommon a warehouse to function with multiple systems; either because the storage unit (e.g. pallets, carton boxes or plastic boxes) changes during the process flow or simply because products handled have different specifications.

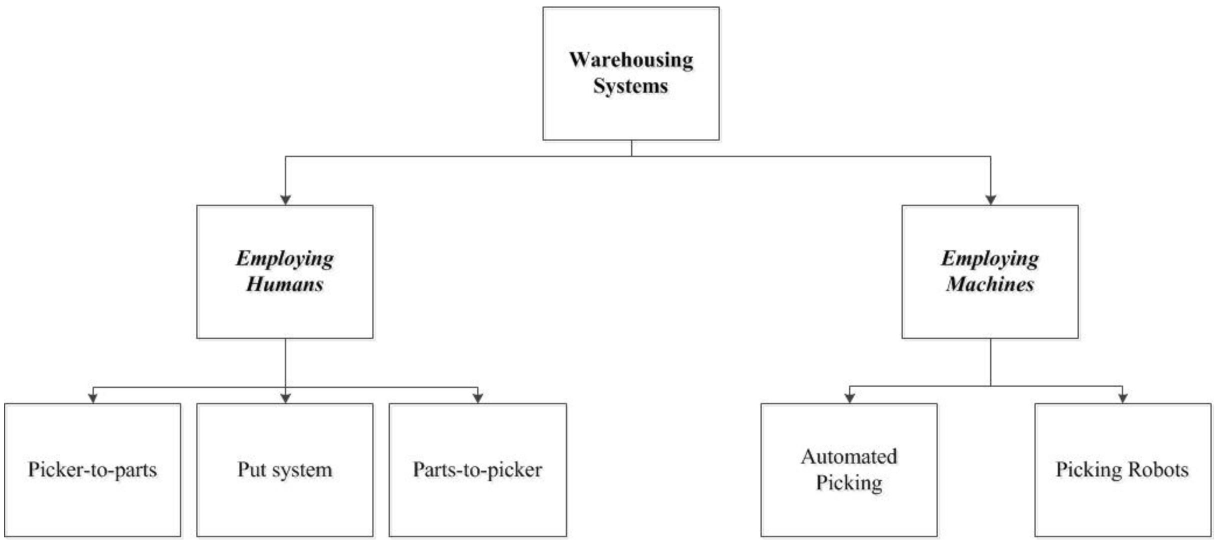

Figure 3 – Warehouse systems (based on De Koster *et al.*, 2007).

The big majority of warehouses employ humans in its activities, and three different systems can be identified: picker-to-part systems, put systems and. parts-to-picker systems.

Picker-to-parts or manual warehousing systems represent about 80% of all order picking systems in Western Europe (De Koster, 2007). As the name suggests, orderpickers travel along aisles collecting items either from bins at low-level storage racks (bin-shelving); or from high-level storage racks. Petersen *et al.* (2005) found in their bin-shelving environment simulation, that placing higher demand SKU's in the "golden zone" (the area between a picker's waist and shoulders) would significantly reduce total fulfillment time, although it might increase travel distance; an idea also suggested by Saccomano (1996) and Jones and Battieste (2004). Pick carts and container carts are vehicles widely used for low-level picking, whereas high-level picking operations are done by the help of man-aboard lifting trucks or cranes (Van den Berg and Zijm, 1999).

Parts-to-picker or automated systems are developed so orderpickers do not have to traverse the warehouse during the picking operation, diminishing travel time (Frazelle, 2002). Generally they consist of mechanized systems which pick up and drop off items in a certain depot where orderpickers are waiting to collect them. The two major types of parts-to-picker systems are carousels and automated storage/retrieval systems (AS/RS). Carousels consist in a set of bins or drawers which rotate around a close loop all together or independently (rotary rack); the biggest advantage of this system is that orderpickers can use rotation time to do other activities such as sorting, packaging or labeling (Van den Berg and Zijm, 1999). AS/RS, unit-load or end-of-aisle systems are the ones *"that use fixed-path storage and retrieval (S/R) machines running on one or more rails between fixed arrays of storage racks"* (Frazelle, 2002:105). Automated cranes retrieve one or more unit loads and leave them in a depot where orderpickers collect the items they need, after which the remaining load is stored again (De Koster, 2007). Automated cranes can work in different operating modes: in single command only one retrieval or storage operation is performed in one cycle; the dual command cycle includes one storage operation and one retrieval operation; and finally S/R machines working in multiple command have more than one shuttle and can pick up and drop off several loads in one cycle.

Put systems or order distribution systems are an optimized work environment in which various techniques are combined, such as batch picking, radio frequency scanning and sort to light. The system consists in a retrieval process, either picker-to-parts or parts-to-picker, followed by a distribution process. Usually picking is done by article and brought inside a bin to an orderpicker who sorts the items to different orders, most commonly using barcode scanning technology. This kind of system is especially suitable when limited number of customers order many articles.

Some warehouses employ machines instead of humans in its activities, these systems *"perform high-speed picking of small-or medium-sized non-fragile items of uniform size and* *shape"* (Van den Berg and Zijm, 1999: 523). Among them are A-Frames, which consist of conveyor belts surrounded on both sides by magazines in A-Frame style (a system similar to vending machines). Each conveyor is divided in cells which are destined to different orders. When a cell passes a magazine which contains an item required for that specific order, the item is automatically dispensed. Picking Robots are other example of warehousing systems employing machines but only in rare instances are justifiable.

2.4 Warehouse Processes and Organization

Items flow within a warehouse in different configurations: pallets, cases and broken cases (units) (De Koster, 2007). On one hand storing items in pallets minimizes space utilization, but on other hand, broken and full-case picking productivity is unacceptably low when done from pallets. Hence, a great number of warehouses are designed to have a reserve or bulk storage area, where products are stored in the most economical way, and a forward or fast pick area where products are stored in a way which increases picking productivity in ten to twenty times (Frazelle, 2002). In this kind of layout configuration inventory must flow cyclically from the reserve area to the fast pick area, a concept defined as replenishment.

Furthermore, the flow of items through the warehouse can be divided in distinct phases, which are called processes; the design of the process flow is considered a strategic level decision (Rouwenhorst *et al.*, 2000). Most literature refer four basic processes: receiving, storage, order picking and shipping; although some authors go more in detail and include other steps as pre-advice, checking, put-away, replenishment, packing and cross dock (Richards, 2011). Each process runs according established rules or policies which *"have important effects on the overall system and are not likely to be changed frequently"* (Gu *et al.*, 2010: 543). Figure 4 depicts these flows.

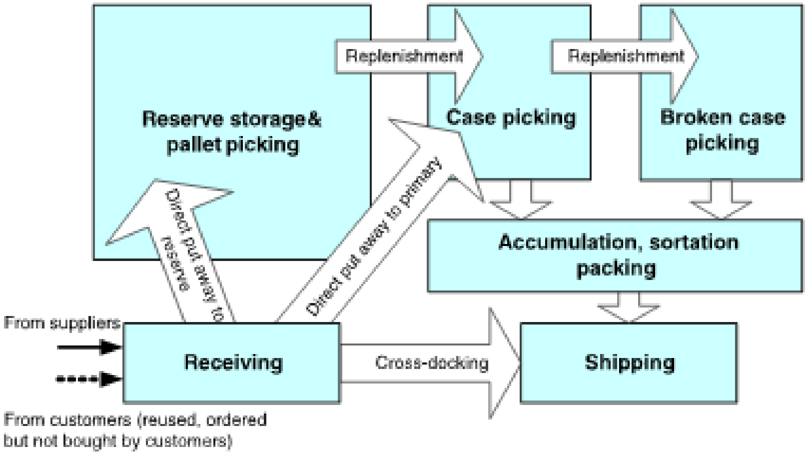

Figure 4 – Items Flow (De Koster *et al.*, 2007).

A study conducted in the United Kingdom showed that the order picking process represents around 60% of the overall operating costs in a traditional warehouse, being the most labor-intensive process and the one which is more difficult to manage (Frazelle, 2002; Petersen *et al.*, 2004; Van den Berg, 1999). Figure 5 depicts the distribution of cost category by warehouse process type.

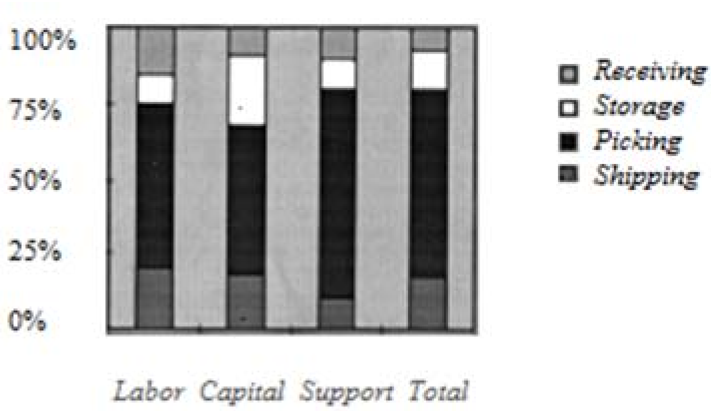

Figure 5 – Warehouse Cost Category (Van den Berg and Zijm, 1999).

2.4.1 Receiving and Shipping

The receiving and shipping processes are the ones which define the boundaries of warehouse operation in the supply chain.

Gu *et al.*(2007) group these two activities as similar problems where the outcome is to determine: (1) The assignment of inbound and outbound carriers to docks, (2) The schedule of the service of carriers at each dock, (3) The allocation and dispatching of material handling resources, such as labor and material handling equipment; Given: (1) Information about incoming shipments, such as arrival time and contents, (2) Information about customers demands, such as orders and their expected shipping time, (3) Information about warehouse dock layout and available material handling resources; Subject to performance criteria and constraints such as: (1) Resources required to complete all shipping/receiving operations, (2) Levels of service, such as the total cycle time and the load/unload time for the carriers, (3) Layout, or the relative location and arrangement of docks and storage departments, (4) Management policies, e.g., one customer per shipping dock, (5) Throughput requirements for all docks.

Receiving and shipping processes seem to lack relative importance in the case of small warehouses, as the one here studied, which don't have any docks and where material is shipped in small packages with no great need of human resources or complex material handling equipment. The most important problems to be solved in these cases are to schedule material deliveries in a way workload peaks are not generated and to assure bottlenecks do not exist and do not affect levels of service and throughput requirements.

2.4.2 Storage

Storage is a major warehouse function and the way material is destined to storage locations is the most important factor affecting the performance of the order picking process (Chan and Chan, 2011; Rouwenhorst *et al.*, 2000). Hence, storage and order picking should be considered a cluster of problems, and decisions regarding its policies should not be taken isolated.

The storage location assignment problem or product slotting, consists in decide where to store SKU's within a warehouse department in a way that storage and access efficiency are considered optimal. Regarding this issue: *"Frazelle (2002) estimates that warehouses are spending 10-30 percent more per year than they should because it is estimated less than 15 percent of the SKU's are properly slotted"*.(Petersen *et al.*, 2005:997)

Five frequently used types of storage assignment policies can be identified (De Koster *et al.*, 2007):

- ***Random Storage***. An incoming product has equal probability of being stored in the eligible storage locations, and no special criterion defines the storage assignment. This storage policy brings high space utilization while increases travel distance as a trade-off (Choe and Sharp, 1991).
- ***Closest Open Location Storage***. An incoming product is stored in the first empty location encountered by the employee. It is similar to the random policy and has the same pros and cons.
- ***Dedicated Storage***. Every incoming product has assigned a fixed location in the warehouse and it is always stored in the same place. An advantage of this storage policy is the higher familiarity that orderpickers gain with products locations and a disadvantage is that a location is reserved even for products that are out of stock, thus, space utilizations is low.
- ***Full-turnover Storage***. Incoming products have assigned locations according with its turnover and products with the highest sales rates are located near the P/D point while the slow moving products are located further from the depot. This kind of policy outperforms all others in picker travel criteria (Petersen and Aase, 2004), but requires a cyclic re-organization of the products in the warehouse, as demand rates vary constantly. Loss of efficiency might be a serious risk associated with this policy.
- ***Class-based Storage.*** It is a compromise between some of the policies presented so far. Incoming products are assigned to different classes depending specific criteria, in turn classes are associated to dedicated areas in the warehouse. Storage within an area is random, and that is the main difference between classed-based and full-turnover policies.

Gu *et al.*(2007: 8) suggest that:. *"If the number of classes is equal to the number of products, then this policy is called* ***Dedicated Storage.*** *If the number of classes is equal to one, it is called* ***Random Storage****. Otherwise it is called* ***Classed-Based Storage***".

Moreover, when deciding to rank or order SKU's in classes, different criteria (also referred as slotting measures) can be used (Frazelle, 2002):

- ***Popularity.*** Defined as the number of retrieval operations of a given SKU. In practice is the number of times a picker travels to a storage location. It is considered the most common slotting measure in practice.
- ***Turnover.*** The total quantity of a SKU shipped during a given period of time, also known as the demand of a SKU.
- ***Volume.*** The demand for an SKU multiplied by the volume of the SKU.
- ***Pick Density.*** The ratio of popularity of a SKU to the cube (volume) of the SKU.
- ***COI (cube-per-order-index).*** The ratio of the volume of a SKU to the turnover of the SKU.

Having decided which criteria (i.e. slotting measure) will be followed, a storage implementation strategy, which will define the location of each class in the warehouse, has to be chosen. Among them can be referred: ***within-aisle strategy*** which locates the most frequently picked SKU's in the aisle nearest to the Pick-up/Drop-off point (Jarvis and McDowell, 1991); ***diagonal strategy***, which defines imaginary diagonal lines along the warehouse layout; and ***across-aisle strategy*** which assigns classes transversely to the warehouse layout. An explicative figure is shown below:

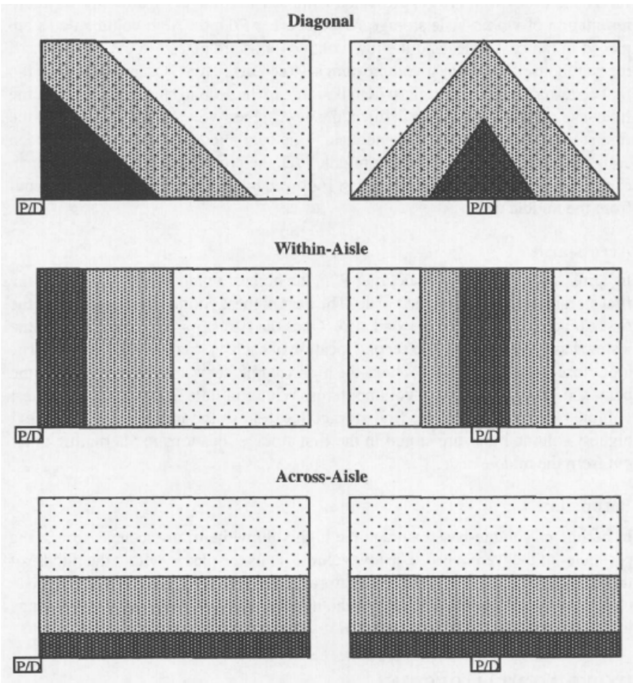

Figure 6 – Storage Implementation Strategy (Petersen and Schmenner, 1999).

2.4.3 Order Picking

Order picking can be defined as *"the process by which products are retrieved from storage to satisfy customer demand"* (Vis and Roodbergen, 2005: 799); and is typically the most important process in a traditional picker-to-part warehousing system (Van den Berg, 1999).

According with Petersen *et al* (2004), order picking performance depends on three main aspects: picking policies, routing policies and storage policies (which have already been referred). Different combinations of these three policies will result in considerably different operations; therefore it is worth taking a closer look to each one of them.

2.4.3.1 Picking Policies

Picking policies concern the number of orders (and therefore items) picked by an orderpicker during a picking tour (Frazelle, 2002). Three basic picking alternatives can be identified: single order or strict order picking, batch picking and zone picking (Ackerman, 1990; Bozer, 1985).

Under ***strict order picking***, each orderpicker collects one, and only one, order at a time and "*different orders are never combined in the same trip*" (Cormier, 2005: 103). Although this policy never jeopardizes order integrity and avoids rehandling, it can be very time consuming as *"it is likely to require a worker to traverse a large portion of the warehouse to pick an order"* (Petersen, 2000: 321).

The essence of ***batch picking*** is precisely to reduce travel distances by assigning more than one order to an orderpicker during a picking tour. Orders are not split among orderpickers. Selecting this policy implies the need of a sorting process, which can be done while picking the items, or downstream by a separate workforce (sequentially). Considerable amount of literature can be found regarding proximity batching algorithms, which identify orders to be picked together. Hong *et al.* (2011) classify them in: seed heuristics; saving heuristics; metaheuristics and optimal approaches.

Zone picking consists in assigning an orderpicker to a specific picking zone, from where he will exclusively collect the items. Different variations of this policy exist. When performing under ***sequential zone picking*** *or progressive zoning*, items of an order are passed from zone to zone until the order is completely assembled, thus order integrity is maintained.

Transportation between zones may be manually performed, may use a conveyor or use automated guided vehicles (Frazelle, 2002). The main disadvantage of this policy *"is that delays can result from imbalances in the workload of the picking zones and from the sequencing orders"* (Petersen, 2000:322).

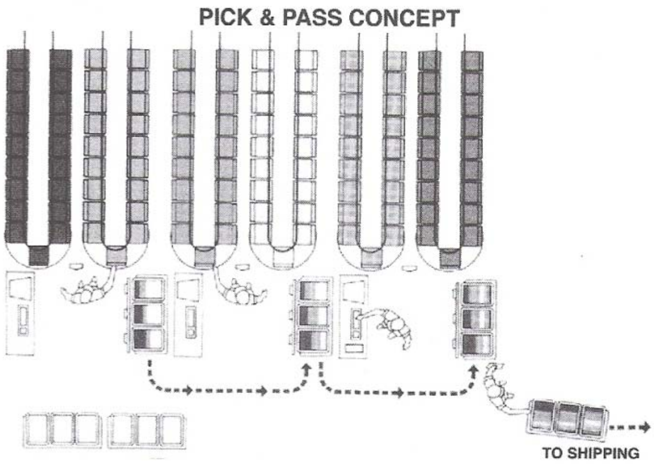

Figure 7 – Pick & Pass Concept. (Frazelle, 2002)

In ***synchronized zoning*** (Jane and Laih, 2005), all zones are processing the same order at the same time, orderpickers work in parallel and partial orders are merged downstream. If orders are batched together, the policy has the name of ***batch zone picking***; under this policy orderpickers are responsible for picking all the items in its zone and place them in a conveyor, the next batch of orders only starts when all pickers have unloaded the previous batch; a sortation process is also needed downstream. If batches are based on a length of time and not in the number of items then the policy is called ***wave picking***; this is most commonly used when picking large batches.

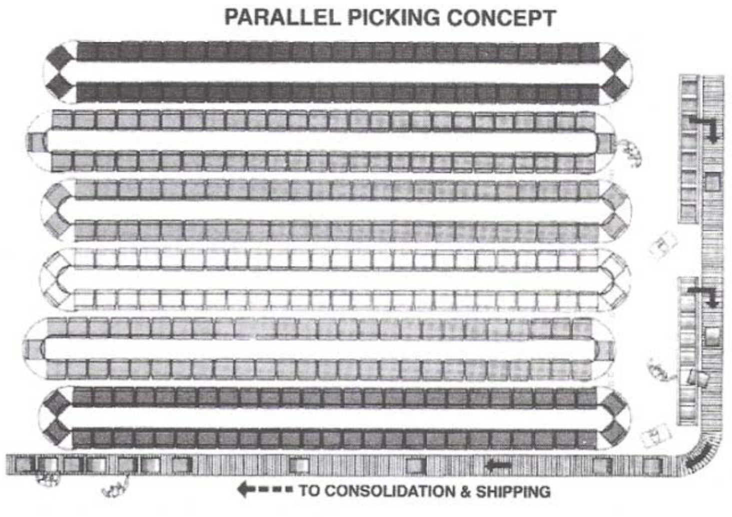

Figure 8 – Parallel Picking Concept. (Frazelle, 2002)

2.4.3.2 Routing Policies

After having decided the number of orders an orderpicker shall pick in a picking tour, one faces the problem of picking routes, which *"consists of finding a sequence in which products have to be retrieved from storage such that the travel distances are as short as possible."* (Roodbergen and De Koster, 2001:1866). This is a simplified variant of the well-know and difficult to solve travelling salesman problem (Caron *et al.*, 1998).

Several routing heuristics and optimal procedures have been developed, from which are highlighted: traversal, combined (Roodbergen and De Koster, 2001) and optimal (Ratliff and Rosenthal, 1983). Although optimal procedures offer the best solutions, they are often confusing and difficult to explain; while heuristics yield near-optimal solutions and are easier to implement (Petersen and Aase, 2004).

Traversal routing policy (also known as s-shape), states that any aisle which contains a pick location should be traversed in its entire length (Roodbergen and De Koster, 2001). Aisles where no item has to be picked are skipped. Orderpickers enter in the leftmost pick aisle and describe s-shape trajectories during the picking tour, finishing in the front aisle. This is considered to be the simplest and most commonly used routing procedure (De Koster *et al.*, 2007).

Under ***combined*** routing every time all items of an aisle are picked successfully a decision is made whether to go to the rear end of an aisle or to return to the front end, depending of the shortest route. Items are picked aisle by aisle.

Optimal procedures compute the shortest possible route by using mathematical models. Ratliff and Rosenthal (1983) presented an algorithm based on dynamic programming, which solves the problem of the shortest route to rectangular warehouses without cross aisles (also known as single-block warehouses). Calculations become increasingly more complex when dealing with multiple cross aisles warehouses; Roodbergen and De Koster (2001) developed a set of heuristics regarding this matter.

The figure presented below shows examples of ***s-shape***, ***combined*** and ***optimal*** routing procedures applied in warehouses with no cross aisles and warehouses with two cross aisles.

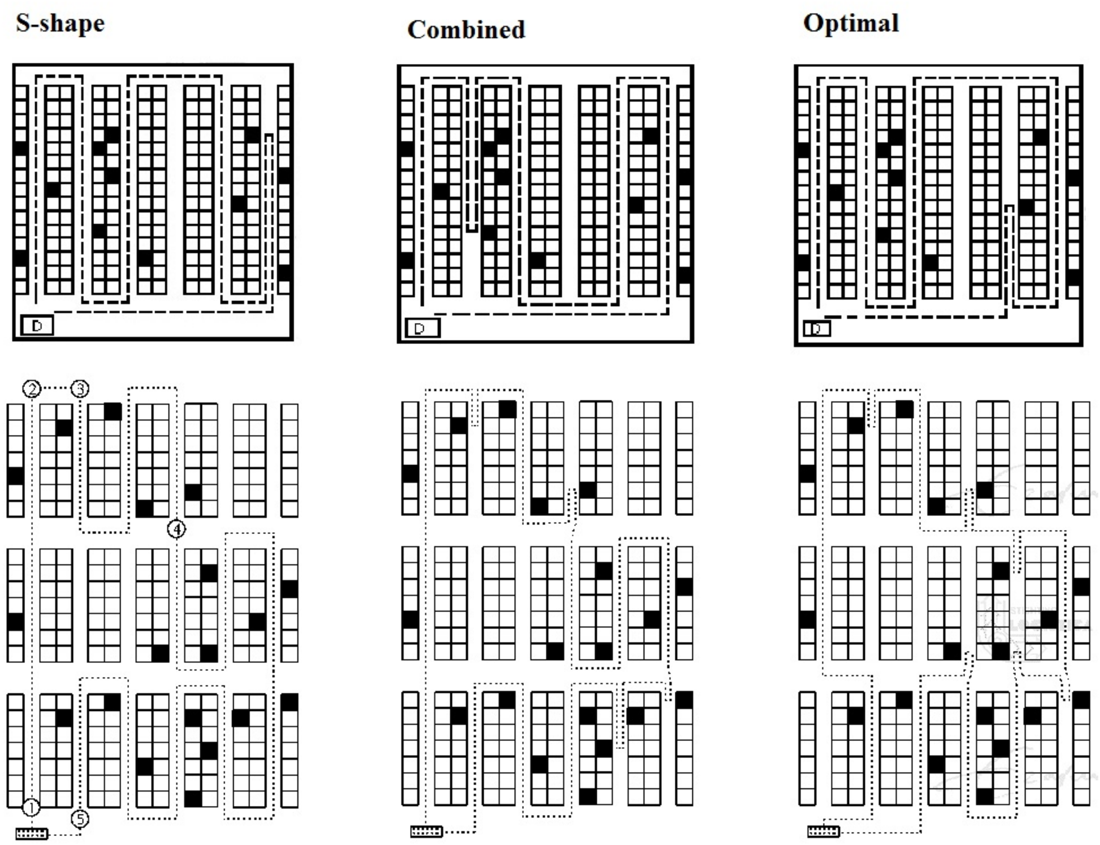

Figure 9 – Routing Policies. Erasmus University Rotterdam available at URL http://www.fbk.eur.nl/OZ/LOGISTICA/rout.html

2.5 Performance Evaluation

"Performance evaluation provides feedback on the quality of a proposed design and/or operational policy, and more importantly, on how to improve it" (Gu *et al.,* 2010). Therefore is essential for every warehouse operation to have its performance constantly accessed according with well-defined criteria. Among them are commonly stated: Investment and Operational Costs, Volume and Mix Flexibility, Throughput, Storage Capacity and Order Fulfillment Quality (Accuracy) (Rouwenhorst *et al.*, 2000); though Travel Distance and Total Fulfillment Time (total travel and picking time) are the most commonly used when referring to traditional warehouses.

As presented before, order picking is not only the most costly and labor intensive process of a traditional (bin-shelving) warehouse but also the most complex; hence its optimization for cost-efficiency is usually a major design goal, being the objective maximizing throughput at minimum investment and operational costs.

Gu *et al.*, (2010) refer three different approaches for performance evaluation:

- ***Benchmarking.*** Consists in gathering quantitative performance data, analyze it and propose an improvement plan of action. Benchmarking is classified as ***internal*** if the objects of study are the operations of the company itself; as ***competitive*** if the objects of study are the companies conducting business in the same industry or as ***external*** if it is focused outside the company's industry. (Frazelle, 2002).
- ***Analytical Models*** usually provide estimates of travel or service time, although some of them address multiple criteria. To a large extend the literature regarding analytical models concern Automated Storage and Retrieval warehousing systems, nonetheless some authors have developed models for conventional picker-to-parts systems (Hwang *et al.*, 2004; Caron *et al.*. 2000; Chew and Tang, 1999).
- ***Simulation*** modeling technique allows the evaluation of an operating system prior to its implementation and it's becoming widely used in the warehousing context, as it is shown more in deep in the next section (2.5.1).

2.5.1 Simulation in the Warehouse Design Context

Wild (2002) defines an operating system as a configuration of resources combined for the provision of goods or services. Manufacturing plants, Supply Chains and Transport systems can all be given as examples of operating systems; as they are the result of human design and they are meant for some sort of human activity. The purpose of simulation is that of obtain a better understanding of an operating system, identifying opportunities for its improvement.

Moreover, is also a way of simplifying the reality and experiment with it, predicting the performance of an operating system under a specific set of inputs, being a powerful "what-if" analysis tool. Robinson (2004:4) defines simulation as the "experimentation with a simplified imitation (on a computer) of an operations system as it progresses though time, for the purposes of better understanding and/or improving that system.".

It is the nature of operations systems to be subject to variability, to have its components interconnected and to be complex on a combinatorial dimension (number of combinations of system components that are possible) and in a dynamic dimension (interaction of the components in a system over time). Simulation has advantages over other modeling approaches (e.g. mathematical programming and heuristic methods) as it suits better the characteristics of operations systems, allowing to model variability and requiring few assumptions. Furthermore, some systems just can't be modeled analytically. Simulation has also advantages against real experimentations as it is less costly and time consuming, it allows designers to control the experimental conditions, and to test systems that do not yet exist (Robinson, 2004).

Discrete-event simulation is one of the possible approaches to model the progress of time, and is the base of most commercial simulation software. The system is modeled as a series of events, that is, instants in time when a state-change occurs.

Robinson (2004) classifies two kinds of events:

- ***B (Bounded or Booked) events:*** are the ones that can be scheduled to occur at a point in time. In general B-events relate to arrivals or the completion of an activity. For instance, the arrival of a customer order to the warehouse or the time needed to complete the order picking.

- ***C (Conditional) events:*** are the ones that depend on the conditions in the model. In general C-events relate to the start of an activity. For instance, a worker can only start picking the products if there is a customer order and if the worker is not busy.

Having identified all the events and the way they are connected, one can actually run a simulation. Discrete-event simulation follows a three-phase method: at A-phase the simulation clock is advanced to the time of the next event, according with the event list; at B-Phase all bounded or booked events scheduled to the clock time are executed, and at the C-phase all conditional events whose conditions are met are executed. Moreover, the execution of C-events can lead to the execution of other C-events.

The simulation then returns to A-phase in a cyclical process, till it is concluded. The figure next shown describes this process.

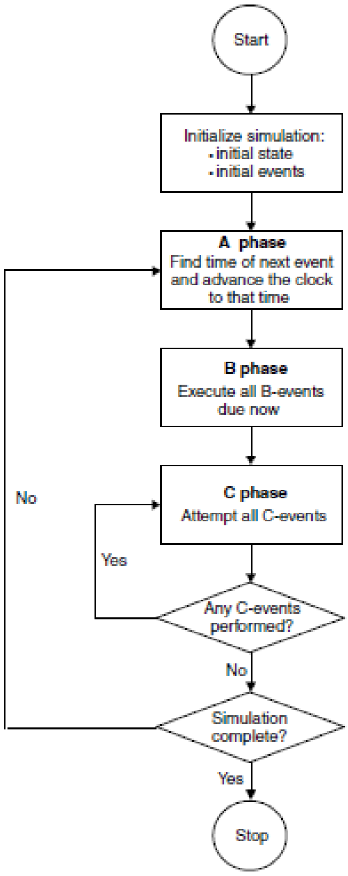

Figure 10 – Discrete-event Simulation Process Robinson(2004:19)

A great number of researchers (e.g. Chan and Chan, 2011; Hwang and Cho, 2006; Petersen and Aase, 2004) have found good use in discrete-event simulation technique when studying warehousing problems. In fact, a warehousing system is an operating system, and reflects all its characteristics: processes are subjected to variability, are strongly interconnected, and its design is highly complex (see section 2.2).

Geraldes and Pereira (2011:279) concluded in their survey regarding simulation in the warehouse design and management context; that *"in such a complex context a decision support system (DSS) which combine simulation and analytical techniques can be of great help"*.

2.5.2 Picker-to-Parts Performance: Previous Findings

Previous research has been conducted concerning the performance of traditional warehousing systems (picker-to-parts), resulting on interesting findings which highlight some directions when applying theoretical knowledge into case studies.

Travel distance per day and total fulfillment time are considered the most important performance measures when dealing with manual bin-shelving warehousing systems. Previous finding show that a picker travels across the warehouse at a constant rate of 45, 72 m/min (Petersen, 1997; Gray *et al.*, 1992), and takes 0, 30 minutes to pick a single unit of a SKU from a golden zone storage location (i.e. SKU's in the bins located between picker's waist and shoulders) and 0, 40 minutes from other storage location.

By the means of a Monte Carlo simulation, Petersen and Aase (2004) compared twenty-seven different combinations of picking, routing and storage policies, regarding total fulfillment time of orders. All possible combinations are compared against a baseline scenario of strict order picking, random storage and traversal routing policies combination; *"results indicate that a warehouse manager could reduce total fulfillment time between 17% and 22% by batching orders or by using either volume-based or class-based storage."*(Petersen and Aase, 2004:15). This study concluded that the implementation of a full-turnover storage policy results in less than 1% of savings when compared with class-based storage policy. Authors are also peremptory with complex routing heuristics or optimal routing when compared with traversal routing procedure: *"discussions with several firms also revealed that simple routing* *heuristics, such as traversal policy, were considered much more acceptable because they tend to form more consistent routes when compared to routes generated by optimal procedures. This should not be overlooked."* (Petersen and Aase, 2004:19).

Petersen *et al.* (2004) studied the effect of the implementation of class-based storage on order picking performance. The research reinforces the idea that through class-based storage one can obtain similar benefits as full-turnover storage, with less management time and effort. The importance of storage implementation strategy when implementing class-based storage is also highlighted: *"the within-aisle strategy outperformed the other storage implementation strategies regardless of the number of storage classes or pick list sizes"* (Petersen *et al.*, 2004:543). Regarding the partition strategy (number of storage classes and given percentages to each one of them), the authors refer that *"a large portion of the potential savings may be attained with a very simple two-class class-based storage policy and that additional classes yield decreasing marginal improvements (…) The results show that a 30-70 or 40-60 partition strategy performs best, regardless of the pick size."* (Petersen *et al.*, 2004:538).

Regarding the performance of the order picking process, Petersen *et al.* (2005) evaluate different slotting measures and storage assignment strategies through a Monte Carlo Simulation. More specifically the paper is focused on the impact of using golden zone storage. The research shows that Turnover, COI, and Popularity are the best slotting measures in reducing total fulfillment time; Popularity particularly performs well also in total travel distance. Furthermore the research concludes *"that these new storage assignment strategies significantly reduced the total fulfillment time by placing highly slotted SKU's in the golden zone reducing picking time, but resulted in higher travel distances."* Petersen *et al.* (2005:1009), nonetheless the time savings from picking SKU's in the golden zone compensate additional travel distance. Strategies which combine Golden zone within-aisle and across-aisle were considered the best, although the results are dependent of order size, demand distribution, and the difference between the picking time for golden zone and non-golden zone SKU's.

"In such a complex context (referring to warehouse design and planning) a decision support system (DSS), which combine simulation and analytical techniques can be of great help".

Geraldes and Pereira (2011:279)

3. Conceptual Framework

This master thesis is a company project; therefore its main objective is not the one of finding a gap in the current research, but to use the previous findings to propose improvements to the current operation.

This chapter presents the conceptual framework of this master thesis, a simplified description of its structure, namely: the Problem Statement, the Previous Findings and the proposed Problem-Solving Methodology.

3.1 Problem Statement

The responsible for GrandVision's Logistics at Portugal, wants to gain insight of the warehouse operation with the objective of improving organization and consequently performance. Among the projects he wants to carry out, is the one of finding the Storage, Picking and Routing policies which optimize Shop Replenishment Operation.

The problem statement can be resumed as shown below:

Given:

- Information on the Warehouse Layout
- A certain set of Human-Resources
- Information of SKU's stored in the Warehouse and its Turnover.
- The average number of daily Replenishment Orders.
- The average number of daily Replenishment Order Lines.

Determine:

- ***A combination of Storage, Picking and Routing policies which will bring an improvement to the performance of the Shop Replenishment Operation.***

3.2 Previous Findings and Hypotheses

Chapter **2.5.2** made reference to the previous findings regarding Picker-to-Parts Warehousing System Performance, among them can be highlighted:

- Batching orders and using a Class-Based storage policy can improve total fulfillment time from 17% to 22% Petersen and Aase (2004).
- Simple Routing Heuristics, such as traversal, were considered by firms the more consistent Petersen and Aase (2004).
- Class-Based storage policy can bring similar improvements as Full-Turnover, being the within-aisle strategy the best implementation strategy Petersen *et al.*(2004).
- Turnover, COI, and Popularity are the best slotting measures in reducing total fulfillment time. Golden Zone Storage can reduce significantly total fulfillment time even when increasing travel distance. Within-aisle and across aisle were the storage implementation strategies which best combine with Golden Zone Petersen *et al.* (2005).

Hence, the previous research clearly points a way to the problem solving process, narrowing policy combinations to be tested.

A decision was made of focusing the study in the effect of batching, class-based and golden zone policies, under the following **hypotheses**:

1. A Class-Based Storage Policy will improve GrandVision's Warehouse Replenishment Operation.

2. A Batching Picking Policy will improve GrandVision's Warehouse Replenishment Operation.
3. A Golden Zone Storage Assignment Strategy will improve GrandVision's Warehouse Replenishment Operation.

3.3 Problem-Solving Methodology

The methodology selected to test different combination of policies was discrete-event simulation as is widely considered the best modelling approach of operating systems Robinson (2004). Specifically the software used was SIMUL8.

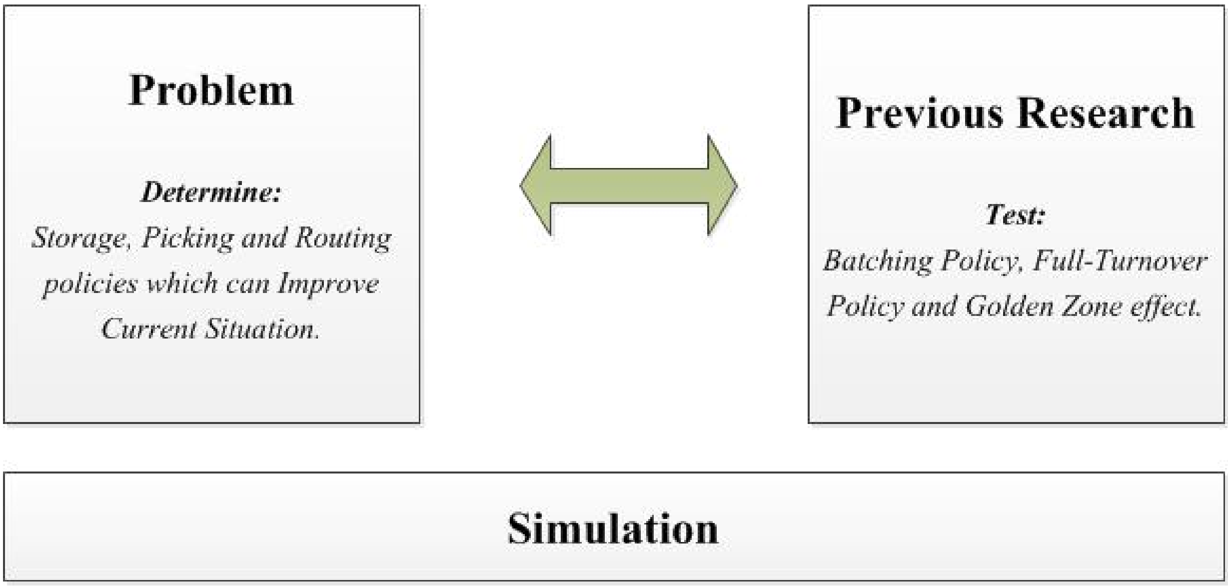

Figure 11 – Conceptual Framework

4. Data Analysis

4.1 Current Situation

In this chapter it will be described the Current Situation of Grand Vision's warehouse operation and its Major Logistic Flows. Those flows will be characterized according with the four main warehouse processes: Receiving, Storage, Order Picking and Shipping. A decision was taken of focusing in the flows itself and not just in the general description of the processes, hoping not to lose valuable information in this way.

4.1.1 Layout

Warehouse Layout measurement was made on the field and although it was not done with modern technology, it presents a fairly good and sufficient representation of the reality.

The Warehouse entrance door is around 2, 84m, its length about 26, 76m and its width around 21, 92m.

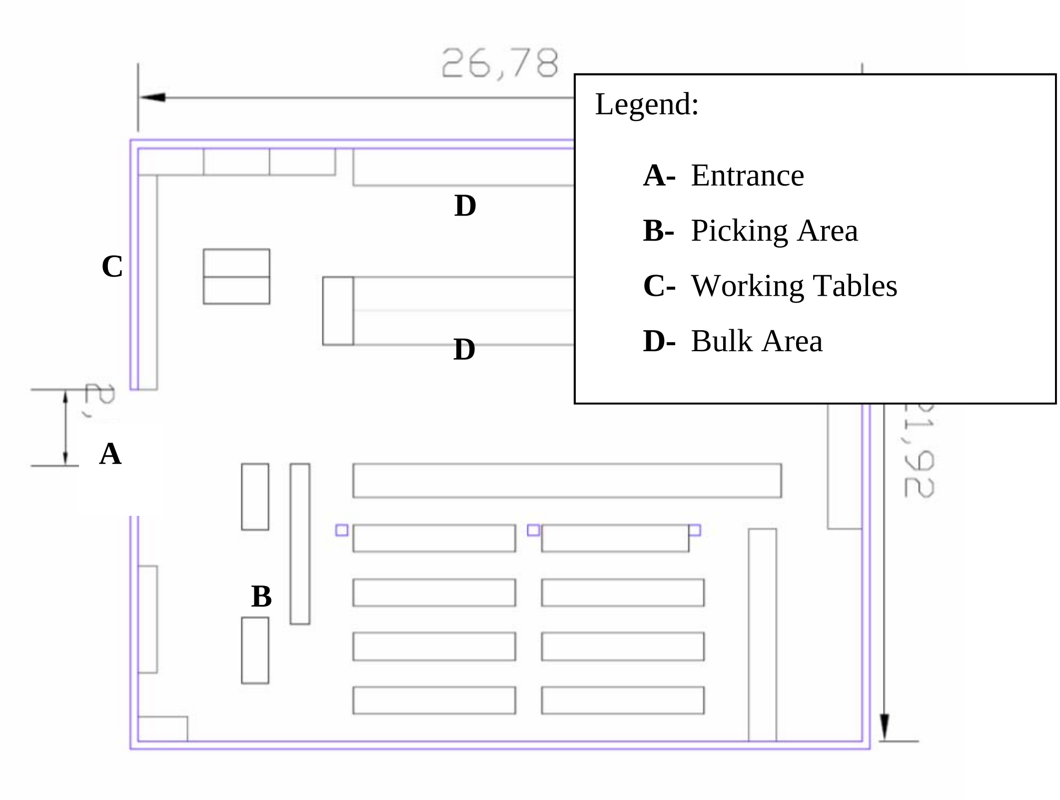

Figure 12 – Warehouse layout

4.1.2 Warehouse Resources

Warehouse Human Resources totalize 5 persons: a General Manager, which accounts for the entire operation; a person responsible for Shop Assistance, who deals with Costumer/Warranty Service issues; and 3 Orderpickers, who work in all warehouse processes, especially in Shop Replenishment. All this Human Resources are under Logistics Manager supervision.

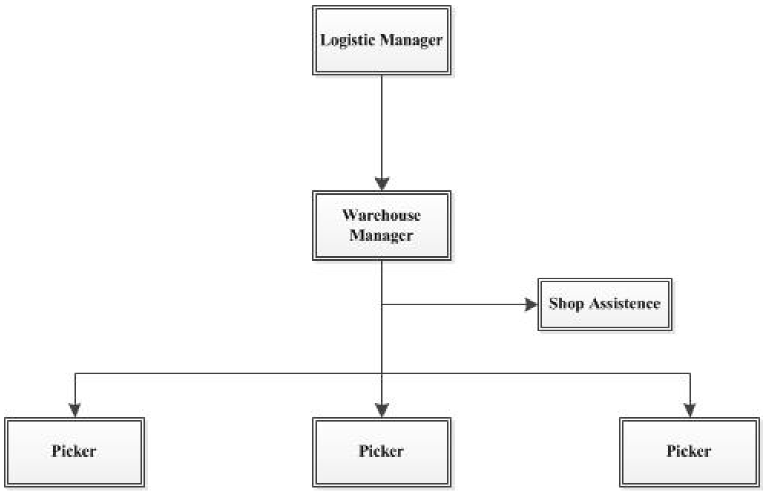

Figure – 13 Warehouse Resources

4.1.3 Processes and Organization of the Major Logistic Flows

It is considered a Major Logistic Flow of the warehouse one important flow of goods and/or information since the receiving till its shipping.

It were catalogued five important Logistic Flows: Frames and Sunglasses shop replenishment, Cases replenishment, Contact Lenses Solutions and Office Supplies shop replenishment, Shop Assistance and Marketing Supplies.

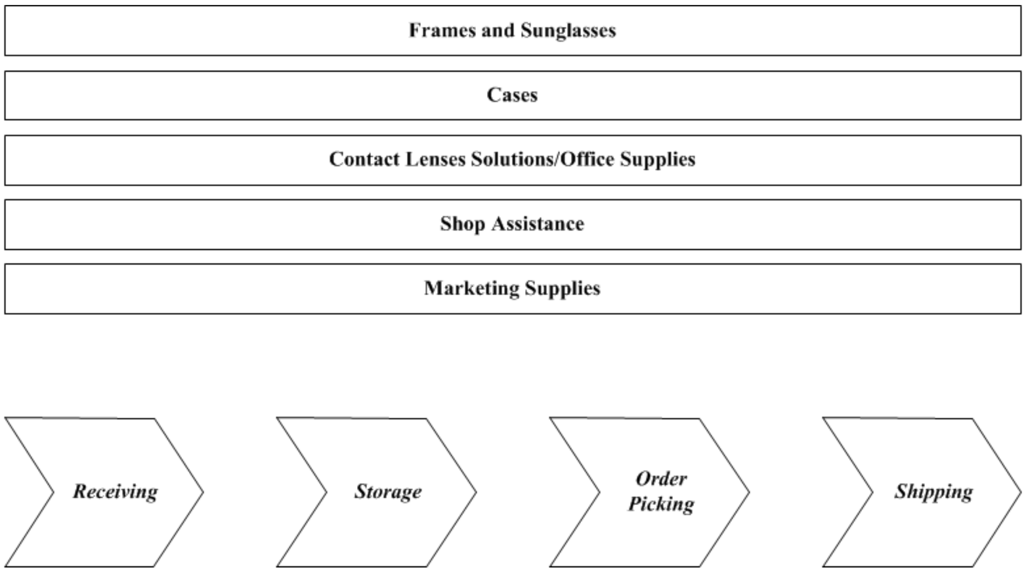

Figure 14 – Warehouse Processes

A) Frames and Sunglasses

The warehouse replenishes the stock of frames and sunglasses in MultiOpticas own shops twice a week and GrandOptical shops once a week. Cases of Branded Frames and Sunglasses are also sent together along with some special Private Label brands. This can be considered a core logistic flow as it relates with the core business.

Two main tools are used to allocate the SKU's and its quantities to each shop: the Brand Distribution Map (which states which brand can be sold in each shop) and the Assortment Map (which classify the shops according with its sales, allocates quantities, gives stock information and presents cost and selling prices).

The Inventory Policy on frames is based on keeping the minimum inventory in shops, being the usual SKU quantity one. The warehouse only replenishes one SKU when the inventory reaches zero, and usually with only one unit. The Policy on sunglasses can be different in the high season, as the shops with higher inventory turnover keep a safety stock of one or two units, being the replenishment done according with weekly sales. The ERP system (Navision) is parameterized in its section of Inventory Management so each time a Transfer Order is created the system check the inventory in the shops and establishes the quantities to send, following the inventory policies. One of the warehouse's main functions in this model is to receive back SKU's that are not being sold in some shops and redistribute them to others Points of Sale.

The Shop Replenishment Process starts usually at Monday at the end of the day and it's concluded Tuesday. The Product Manager runs the ERP system, the transfers are created and the transfer documents/delivery notes accompanied with the price tags printed. The documents go to the warehouse where its workers do the order picking and prepare the boxes to be shipped.

A1) Receiving

Frames and sunglasses arrive to the warehouse in small rectangular boxes (between ten and twelve units) placed in cardboard boxes (each box brings in average about twenty rectangular boxes). Sometimes, especially in private label orders coming from China and in special branded orders, the cardboard boxes can arrive in pallets but usually they arrive one by one.

The receiving process consists in opening the cardboard boxes, putting the rectangular boxes in the working tables, grouping the glasses by its supplier reference, counting them one by one, checking the quantities according with the delivery note, registering the arrival in the system and finally creating picking carton boxes where GrandVision SKUs are written down with the help of the purchase history document.

A2) Storage

Frames and sunglasses are stored in the fast pick area. The fast pick area follows a mix of Random Storage Policy and Family Grouping Policy. The items to be picked are stored in different places depending on being frames or sunglasses and branded or private label; nevertheless the replenishment is stored in the fast pick area, in the top rackets or down the corridor with no special criteria. Branded cases are stored in the fast pick area and Private Label Cases near Contact Lenses Solutions.

A3) Order Picking

The Product Manager runs the ERP system for initiating the Order Picking and the transfer documents are brought to the warehouse where its workers start to do it. Orderpickers assemble a cardboard box and start picking the transfers by shop. After having picked all the items the cardboard is tapped and left in the shipping zone in the top of a pallet, waiting for Chronopost to come picking it.

There is no Zoning Policy established and despite of the picking area is divided into zones they are not served by different orderpickers. A Single Order Picking policy is used as orders are picked one by one, following what is written in the transfer documents. There is no Routing Policy defined as the orderpickers do its own path to the retrieval locations. A Dwell Point Policy is also inexistent as there is not order pick equipment.

A4) Shipping

Shipping is not a really important process in this chain; the cardboard boxes are left in top of a pallet near the exit where Chronopost comes to pick them. When they are more than two, workers start to put the ones full near the main corridor.

A Dock Assignment Policy does not exist as simply there aren’t any docks and small vans come to pick the orders, not trucks.

Shipping Process is exactly the same in all the Major Logistic Flow, so it will be omitted from now on.

B) Cases

Cases of Private Label Frames and Sunglasses are currently replenished on a monthly basis on MultiOpticas own shops. Product Manager controls shop’s inventory via Navision and makes a Stock Transfer Order when he feels it is needed. GrandOptical shops do their orders randomly along the month via Excel file.

B1) Receiving

Cases are delivered by trucks and arrive in pallets of sixty six cardboard boxes, having those boxes from twenty to fifty units. Some boxes are taken from the pallets so they can fit in the rack.

Cardboard boxes are counted and compared with the delivery note information, but not opened neither the quantities received are conferred. The arrival is then registered in the ERP system.

B2) Storage

Cases are stored in the same corridors of contact lenses solutions following a Family Grouping Policy.

B3) Order Picking

Transfer documents are brought to the warehouse and its workers start to do the picking following a Single Order Picking policy as orders are picked one by one accordingly with what is written in the documents.

C) Solutions and Office Supplies

Contact Lenses Solutions and Office Supplies are replenished once a week in MultiOpticas own shops and GrandOptical shops. Office Supplies includes pens, markers, clips, tapes, staples, post-its, glue sticks, ATM rolls and printing cartridges. Along with those items are also sent paper bags, cleaning cloths, cleaning sprays, candies and contact lenses cases. Shops make the order via mail in an Excel sheet and while MultiOpticas own shops send their files usually at the end of the week to be processed Monday, GrandOptical send theirs randomly along the week.

C1) Receiving

Contact Lenses Solutions are brought in trucks and arrive in pallets which can carry from twenty four to thirty cardboard boxes, being in each box from twenty five to forty eight units, depending of the product. Cardboard boxes per pallet are counted, the information compared with the delivery note and the arrival registered in Navision.

Office Supplies are received and counted but there is no arrival registered in the ERP as those items are not in the system. The invoices go directly to the headquarters where the accounting department takes knowledge of the cost.

C2) Storage

Contact Lenses Solutions are stored in the corridor near the working tables following a Family Grouping Policy.

Office Supplies are stored in a locker in the beginning of the main corridor.

C3) Order Picking

Office Supplies are the first to be picked; orders processed one by one with the help of the Excel files and put in plastic document boxes located in the racks near the exit; there is one plastic document box for each MultiOpticas own shop. Transfer Orders are not created as this flow is not recorded in Navision.

Contact Lenses Solutions come next, Stock Transfers are created and the documents brought to the warehouse. It is a common practice to send an entire cardboard box if the quantity ordered is a bit less than the quantity per box, which makes the picking process faster. With the help of tray service carts, orders are picked by destination, brought to the working tables and combined together with Office Supplies items in cardboard boxes.

There is no Zoning Policy, Routing Policy or Dwell Point Policy established.

D) Shop Assistance

Customer/Warranty Service and Extraordinary Sales Requests Fulfillment are included either in MultiOpticas own shops or GrandOptical shops normal activity. These two processes are called informally in the organization by Shop Assistance.

By law, warranty service has to be given for frames and sunglasses for a period of two years, and in this process shops are intermediaries between costumers and the warehouse or between customers and the suppliers, whether the product is private label or branded.

GrandVision policy for warranty claiming of branded products states that MultiOpticas own shops can only contact suppliers directly for claiming warranties of spare parts, while complete pieces claims have to pass by the warehouse; this system was created to force shops managers to respect assortment maps and avoid them to order products by their own. If spare parts are claimed by shops, suppliers endorse them directly to shops. Complete pieces claimed by the warehouse are received there and then sent to shops.

GrandVision policy for warranty claiming of branded products in GrandOptical is different, as all claims either of spare parts or complete pieces pass through the warehouse with the help of a shared data base called SAV (which stands for "service après vente"). The warehouse claims the warranties, receives the replacement parts and sent them to shops.

The warehouse responds for warranty claims of private label products, therefore, according with GrandVision policy, all replacement parts should come from its stock; in case a certain SKU is out of stock it is possible to transfer stock between MultiOpticas own shops, or between GrandOptical shops. MultiOpticas own shops warranty claims of private label products are done via mail, phone or fax, GrandOptical claims are done via SAV. Franchisees also claim warranties of private label product to the warehouse via phone or fax; replacement parts are sent and damaged parts received in the opposite way.

Extraordinary Sales Requests refer to the process where a customer wants to buy a frame or sunglass that a certain shop does not possess and is not supposed to possess (according with the brand distribution and assortment maps); in this case shops need to contact the warehouse to order either private label products or branded products. Whether in MultiOpticas own shops or GrandOptical shops, GrandVision's policy states that product should be sent first from the warehouse; in case of stock out in the warehouse the product can be transferred between shops of the same company. If there is not any stock in the warehouse or in other shops, product can be ordered from the supplier, if branded, but the customer have to advance some money; if private label, product is not ordered as logistic costs per unit are big. Sales between companies are also possible, but as last option as they represent a cost for the company which purchases. Last but not least, a word should be said to state that in practical terms this policy is not completely followed, as MultiOpticas own shops use more stock transfer between them to fulfill extraordinary sales request than are replenished from the warehouse.

All the flow charts representing physical and informational flows between shops, the warehouse and suppliers can be seen in appendix.

D1) Receiving

Shop Assistance can generate a Receiving Process in the warehouse when Branded Suppliers are involved, whether related to a warranty or to an extraordinary sale request. Usually Shop Assistance coming from Branded Suppliers arrives in the warehouse in small boxes. The process consists in open the boxes in the working tables, store the replacement parts in the plastic document boxes (also used for Office Supplies) and create a purchase and an arrival in Navision. For minimizing logistic costs, replacement parts are only transferred when Contact Lenses Solutions are replenished.

D2) Storage

Shop Assistance replacement pieces are stored in the plastic document boxes, in the racks near the entrance

E) Marketing Supplies

Marketing Supplies refer in one hand to material that supports the commercial activity of MultiOpticas own shops and GrandOptical shops and in other hand to material that gives support to marketing campaigns. The first type of material previously stated is ordered by shops to the Marketing Department at least once a month, which in its turn sends a compiled Excel file to the warehouse once a week in no specific day. Marketing Campaigns material might include flyers, backlights and some displays and it is ordered directly from Marketing Department to suppliers, going from there to the shops; usually a stock is kept in the warehouse. Marketing Supplies are not registered in Navision, thus the responsible for shipping them from the warehouse controls de inventory and warns Marketing Department when the inventory is arriving to a critical level.

E1) Receiving

Marketing Supplies can arrive either in pallets or cardboard boxes, its quantities are confirmed according with the delivery notes, which go after to the Marketing Department in the headquarters.

E2) Storage

Material for Marketing Campaigns is stored down the main corridor and it’s mainly MultiOpticas related as it is not kept stock of GrandOptical material.

Material for Commercial Activity Support is stored near the working tables or in the main corridor, near the shipping area, whether it is MultiOpticas own shops or GrandOptical, respectively.

4.2 Data Collection

Simulation modelling requires an information input in order to emulate the performance of an operating system as close to the reality as possible.

In order to input that information in the simulation software, data was collected not only from Management maps and Grand Vision’s ERP, but also by taking part in the Replenishment Operation in the field; namely:

- Warehouse Layout Measures.
- Data regarding Replenishment Orders (RO) size and its content.

- Data regarding Turnover of each SKU.
- Data regarding Picking times.

4.2.1 Replenishment Orders

Warehouse Replenishment Orders data collection was a key process to establish patterns:

- On the average number of Replenishment Orders sent to the warehouse in a regular weekday;
- On the average Order Lines number and average shipped quantities.
- On the SKU's distribution within the Replenishment Order.
- On the travelling times.
- On the picking times.

Data collection was made from Grand Vision's ERP, and considered the universe of orders in the entire year of 2011; a set of 7065 Replenishment Orders and a total amount of 230404 products prepared and sent to the shops, as it is shown in the table 1 below:

Table 1– Replenishment Orders

	Nº of Replenishment Orders	Quantites Shipped
January	628	23 395
February	484	26 591
March	379	16 690
April	761	22 302
May	1 027	22 534
June	794	24 694
July	753	22 313
August	536	21 787
September	676	18 757
Octuber	312	11 863
November	186	7 843
December	529	11 635
Total	7 065	230 404

From Table 2, one can characterize the daily Replenishment Orders number and its distribution, being the minimum 1 and the maximum 160 orders in a single day. Average number is 54 and standard deviation 39.

Table 2 - RO/Day

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
RO por dia	131	0	131	1,000	160,000	53,931	39,205

Tuesday is, on average, the weekday with more replenishment orders being sent to the warehouse, being Friday the less busy day.

Table 3 – Weekday Distribution

	Average number of Replenishment Orders by Weekday
Monday	59,60
Tuesday	77,21
Wednsday	50,88
Thrusday	45,44
Friday	29,08
Total Average	53,93

Replenishment Orders have on average 32 Order Lines, being the Minimum 1 and the Maximum 184.

Table 4 – RO Order Lines

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
Nº of Order Lines	7065	1,000	184,000	32,612	28,222

Below the distribution histogram:

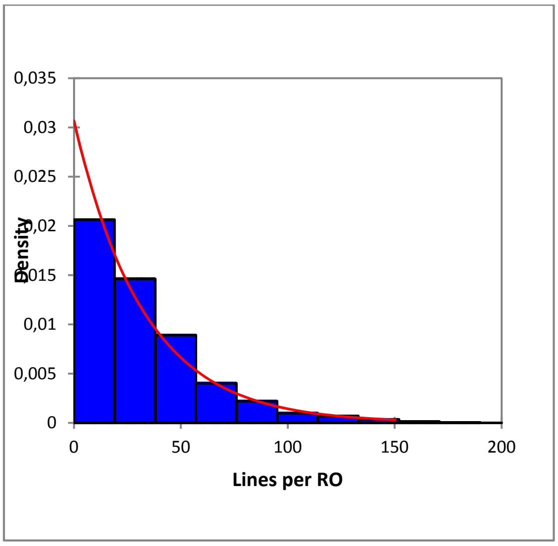

Figure 15 – Lines per Order

Although Order Lines distribution by RO's seems like the exponential type, the Kolmogorov-Smirnov test: rejects the null hypothesis (Table -5), so a decision was made to incorporate in the simulation the empirical distribution presented in the above histogram.

Table 5 - Kolmogorov-Smirnov test:

D	0,097
p-value	< 0,0001
alpha	0,05

4.2.2 SKU Turnover

Having identified Order Lines average number, and its variability, it is then required to know which SKU's in concrete form the RO. Since RO's contents are not available in the files extracted from the ERP, it is assumed that they follow the same pattern as SKU's Turnover, from which there is information available (see attachment).

As previously stated, Grand Vision commercializes two kinds of products: Frames and Sunglasses, which can be either of Private Label or Branded.

In a total of 2031 SKU's, Branded products represent 73,4% of Total, being the remain 26,6% Private Label.

Table 6 – Coomercialized SKU's

	Nº de Modelos'11	%
Branded	**1 491**	**73,4%**
Frames	870	42,8%
Sun Glasses	621	30,6%
Private label	**540**	**26,6%**
Sun Glasses	362	17,8%
Frames	178	8,8%
Total	**2 031**	100,0%

Even though these are important facts, Warehouse work is affected by the turnover of each SKU, which is the criterion used here to extrapolate the probability of a product being part of a Replenishment Order.

In fact, from the 142696 SKU's sold, only 41,9% are Branded against 58,1% Private Label, as it is shown in the Table below:

Table 7 – Sold Quantities

	Sales '11	%
Private label	**82 841**	**58,1%**
Sun Glasses	70 604	49,5%
Frames	12 237	8,6%
Branded	**59 855**	**41,9%**
Sun Glasses	31 175	21,8%
Frames	28 680	20,1%
Total	**142 696**	100,0%

The empirical distribution of Quantities Sold by SKU was incorporated in the Simulation software, generating RO's content according with it.

4.2.3 Travel and Picking Times

A small sample of travelling and picking times was taken on the field, and it shows an average travelling velocity of 28 meters/minute:

Table 8 – Average Travel Times

Meters per Rack	Asverage Travel Time (seconds)	Average Travel Time (minutes)	Average Velocity (m/S)
7	15	0,25	28,00

An average picking time is also retrieved from the sample.

Table 9 - Picking times

Piking Time	Average picking time (Minutes)	Standart deviation
Normal Zone	0,18	0,05
Golden Zone	0,16	0,05

4.3 Simul8 Model

As explained before in the Conceptual Framework chapter the main objective of simulating the Replenishment Operation is to determine a combination of Storage, Picking and Routing policies which can bring an improvement to the current situation. Therefore it is logic that Replenishment Orders are the Work Items of this model.

4.3.1 Replenishment Order Generation

The modelling started by defining a *spreadsheet* type variable, designated *store glasses*, where it was inserted all the information regarding: the identification of each SKU; its storage place (aisle and rack) and a binary variable which identifies if the SKU is stored or not in a Golden Zone.

Table 10 – SKU's Data

NO	Type Product	Brand	Model	Stock	Sales' 11	Rack Nr	Aisle Nr	Rack_Zn
1	Frames	Ray Ban	ARM RB 5121 2012 50	36	19	6	4	1
2	Frames	Ray Ban	ARM RB 5168 2388 52	6	13	6	4	1
...	...	...	...	...	...	...	...	...

It was created a Replenishment Orders *Work Entry Point* which is triggered every morning at a specific hour. *Batching* option was configured according with a normal distribution of average 54 and standard deviation 39. This procedure makes sure RO's are available for picking all at the same time, instead of arriving at the warehouse within a time period.

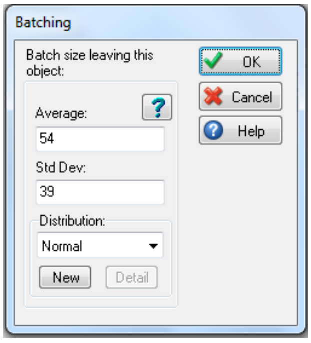

Figure 16 – Batch size RO per Day

RO’s were generated with a unique and sequential number attached, in order to control its execution.

At the same time were equally created labels which allowed product location control within the warehouse.

Having created Replenishment Orders, its contents were generated following two steps:

- First, using the *Batching* option creating the order lines, based on the empiric distribution aforementioned.

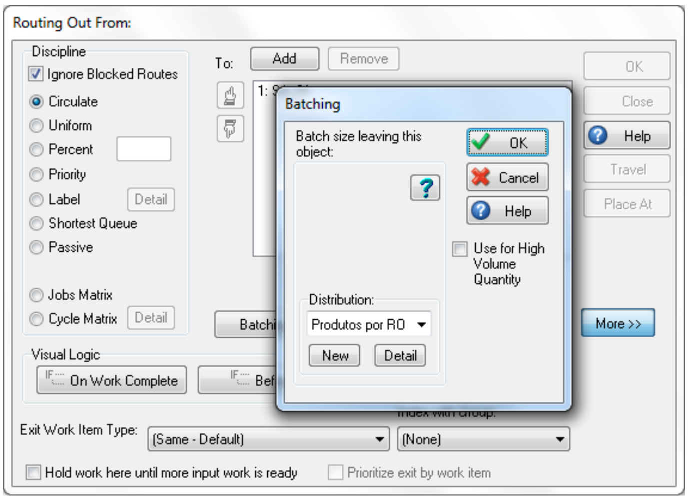

Figure 17 – Batch size Lines Per Order

- Second, creating a Product ID *label* through the command *set value*, based on the empiric distribution of the Turnover by SKU.

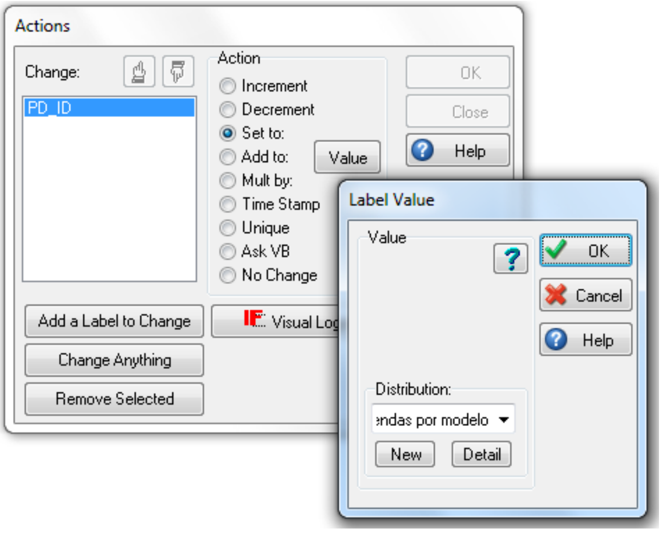

Figure 18 – Link Products to Order Lines

In this way all Order Lines of Replenishment Orders were generated, and then stored in a *spreadsheet type* variable, designated *RO_Orders_lines;* as it is shown in the table 11 presented below:

Table 11 – RO_Orders_lines's contents

RO_ID	P_ID	P_Type	Brand	Model	Rack Nr	Aisle Nr	Zn_Nr
1	1907	Sun Glasses	SEEN	SEEN 2081 B BROWN	3	1	1
1	1088	Sun Glasses	Ray Ban	SOL RB 3293 004/71 63*13	2	2	1
...	...	...	...	...	...	...	...

At the same time it was created another variable, *RO_Orders*, which identified the location and quantities of SKU's making part of the Picking List. See table below:

Table 12 – Quantities to be Picked and its Locations by RO

RO_ID	Rack_01	Rack_02	Rack_03	Rack_04	Rack_05	Rack_06	Rack_07	Rack_08	Rack_09	Rack_10	Rack_11	Rack_12	Rack_13	Rack_14
1	12	5	5	4	4	2	2	1			2	1		
2	8	4	5				1	1						
3	4	3	4	3	1	1		1	1	1				
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

RO_Orders spreadsheet variable was also created for products stored in *Golden Zone.* This information made possible to compute the different picking times inside or outside the *Golden Zone*.

Simulation model was now generating Replenishment Orders.

4.3.2 Routing

Traversal Routing Heurist was the one chose to be modelled. According with this procedure, the picker travels to the first aisle encountered in the furthest aisle block from the depot with a pick location. Then the entire furthest aisle block is traversed doing an S-trajectory. If there is any pick location the aisle is traversed in its entire length, if not is skipped. The procedure is then repeated for the closest aisle block from the depot, in the opposite way.

The implementation of this algorithm in the Simul8 was done by the introduction of *Routing Work Centers*, and work according with a *label route*, whose actions were programmed.

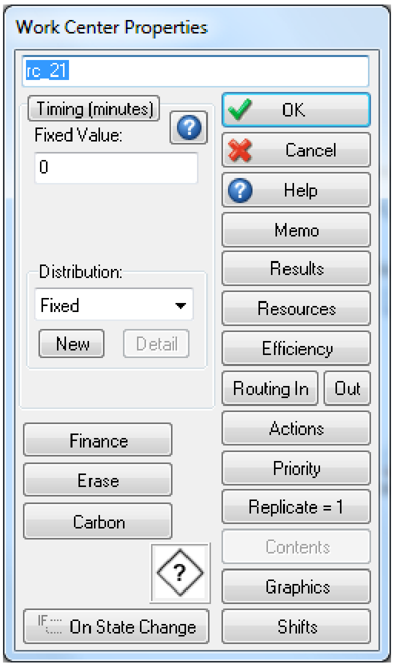

Figure 19 – Routing Work Centers

These *Routing Work Centers* have null timing value inserted as it main objective is to route the *Work Items.* At each *Routing Work Center* a label value is controlled in order to define the path the picker should take. Eight routing labels were created, from *Aisle 1* to *Aisle 8*, and its value is defined by the sum of pick locations in the respective aisle, retrieved from *spreasheet RO_Orders.* Aisle is then traversed only if its label is activated in the *Work Item*. The path the *Work Item* takes depends on label *lbl_route*, as defined in *routing out* options.

Take the example showed below of the *Routing Work Centers* (*rc_14*, located in the first aisle).

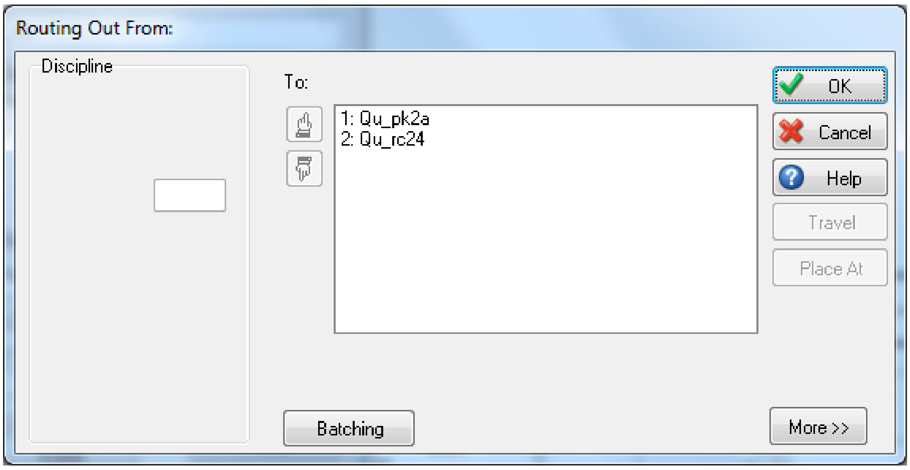

Figure 20 - Routing out options

VL SECTION: rc_14 Action Logic

IF [[Aisle2+Aisle4]+Aisle6]+Aisle8 >= 1

SET lbl_route = 1

ELSE

SET lbl_route = 2

Since Total Fulfillment Times are not only dependent of picking times but also depend on travelling times, and since order pickers should traverse the warehouse along with the *Work Item*, in the first *Routing Work Center* the *resource* is associated to the *Work Item*.

The parameterization of the picker resource in the *routing work center rc_01*, was defined as:

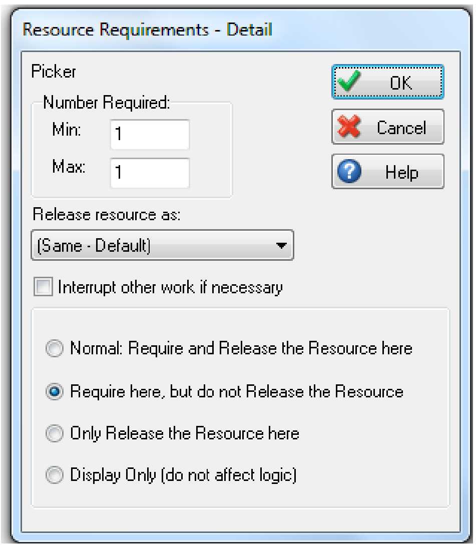

Figure 21 – Resource requirement

Being the resource released only in the end of the route, in *rounting work center rc_21:*

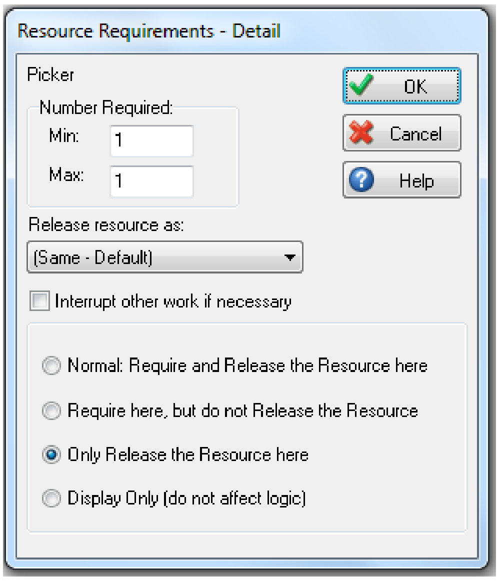

Figure 22 – Resource release

Travel times are defined in *routing out* options of *picking work centers*:

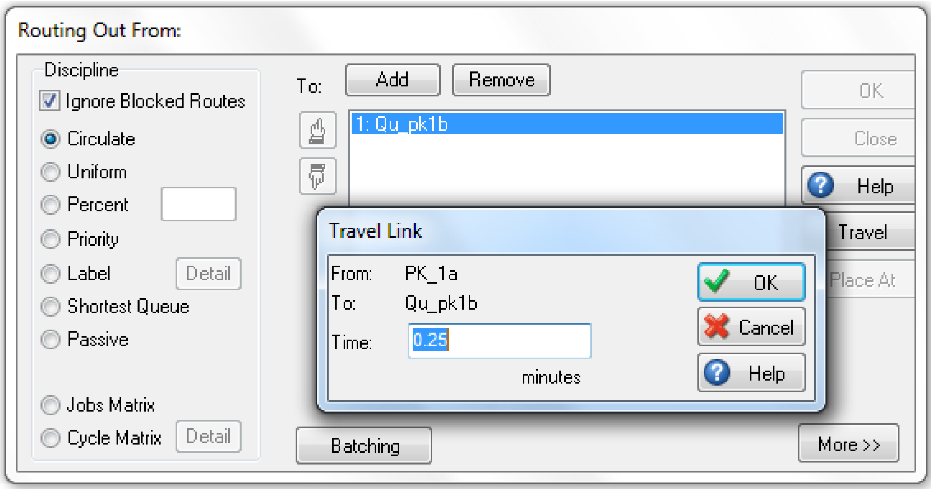

Figure 23 – Travel time

Two minute time was defined for opening and closing one RO. Travelling time within an aisle was defined as 15 seconds, according with sample aforementioned.

In order to compute picking times, *picking work centers* were created, one in each aisle.

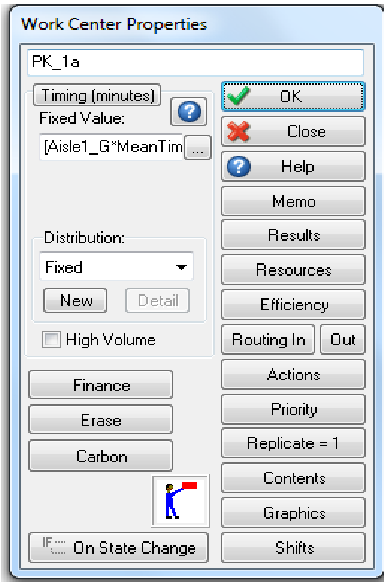

Figure 24 – Picking Time

The time the *work items* take in one of those *picking works centers* depend on the total number of items to collect at each rack, which will be controlled by *Aisle labels* already referred.

An average picking time distribution was created with an average of 0, 16 minutes per item stored in a golden zone and 0, 18 minutes per item outside that zone, standard deviation considered was 0, 05.

For the example of *Picking work center Pk_1a*, there is the following average time parameterization:

[Aisle1_G*MeanTime_Piking_G]+[Aisle1_N*MeanTime_Piking_N]

As it can be verified, the *working time* in this *work center* will depend on the product between number of items in each zone and its average picking time.

4.3.3 Batching

Batching policies relate with the number of orders assigned to an orderpicker during a picking tour. They were parameterized in the model through the option *collect* in the first *routing work center* routing in options. There it can be inserted the number of orders to be assigned together by each picking tour.

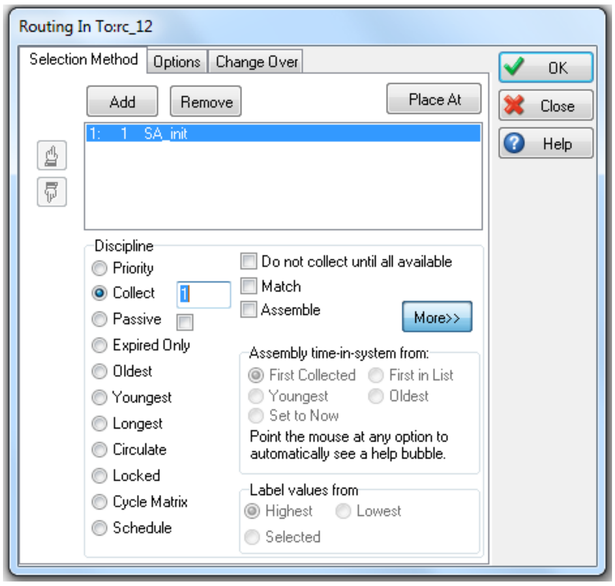

Figure 25 – Collect option

With this parameterizations the final model had the following configuration:

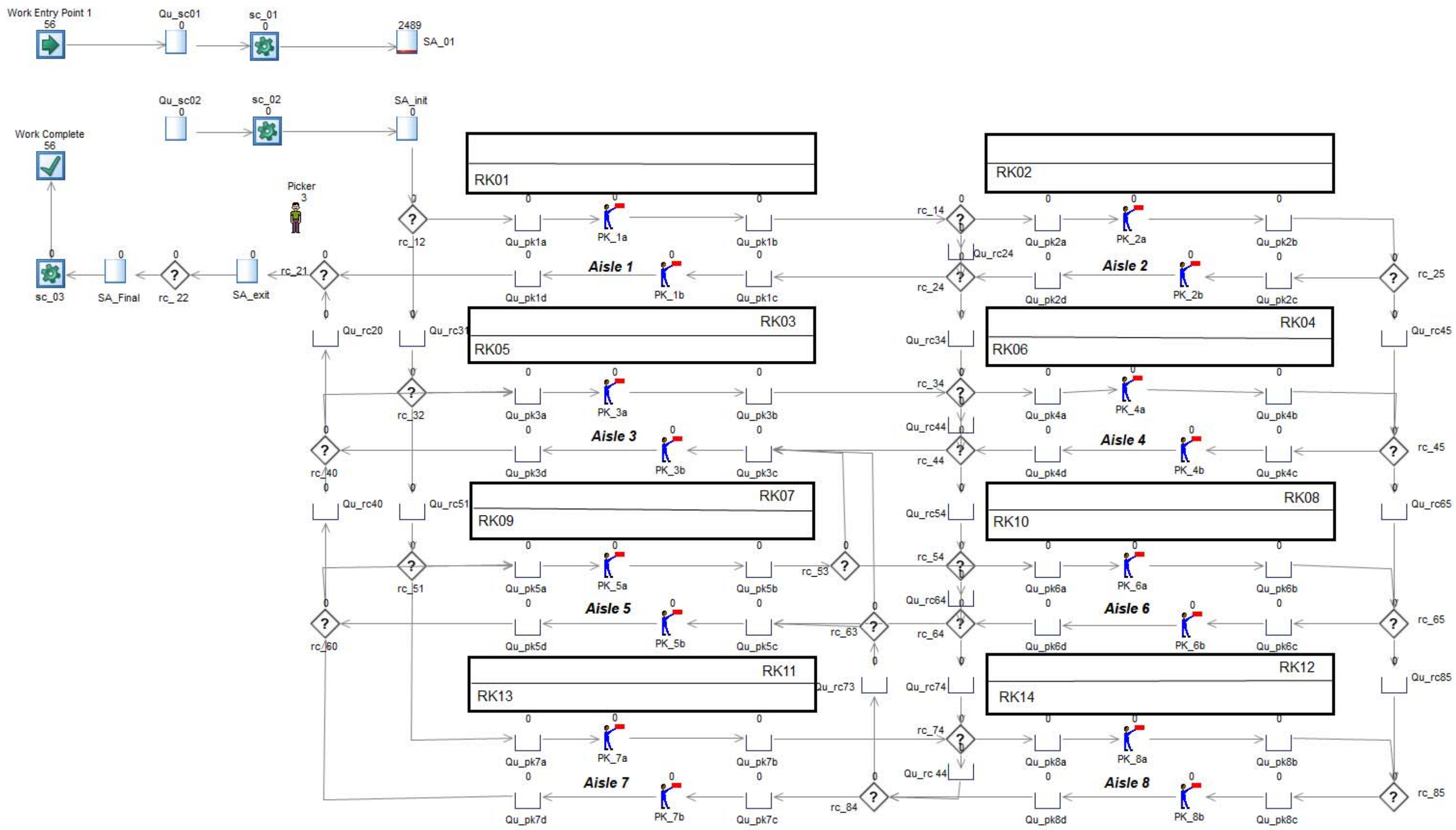

Figure 26 – Simulation Model

4.4 Simulations

This master thesis comprehends the elaboration of 3 different simulation models. For every each of them are analyzed the Total Fulfillment Time of the Replenishment Operation; the amount of Replenishment Orders processed at the end of the day and the Percentage of Utilization of the Resources (order pickers).

4.4.1 Current Situation

The first model to be created simulates the as-is situation, and its storage and picking policies are re-created. Storage policy follows a Class-Based policy based on Type of Product: Frames and Sunglasses, either Private Label either Branded. Strict order picking is the picking policy implemented. Routing Policy is random, but for a matter of simplification is used the traversal policy in the simulation.

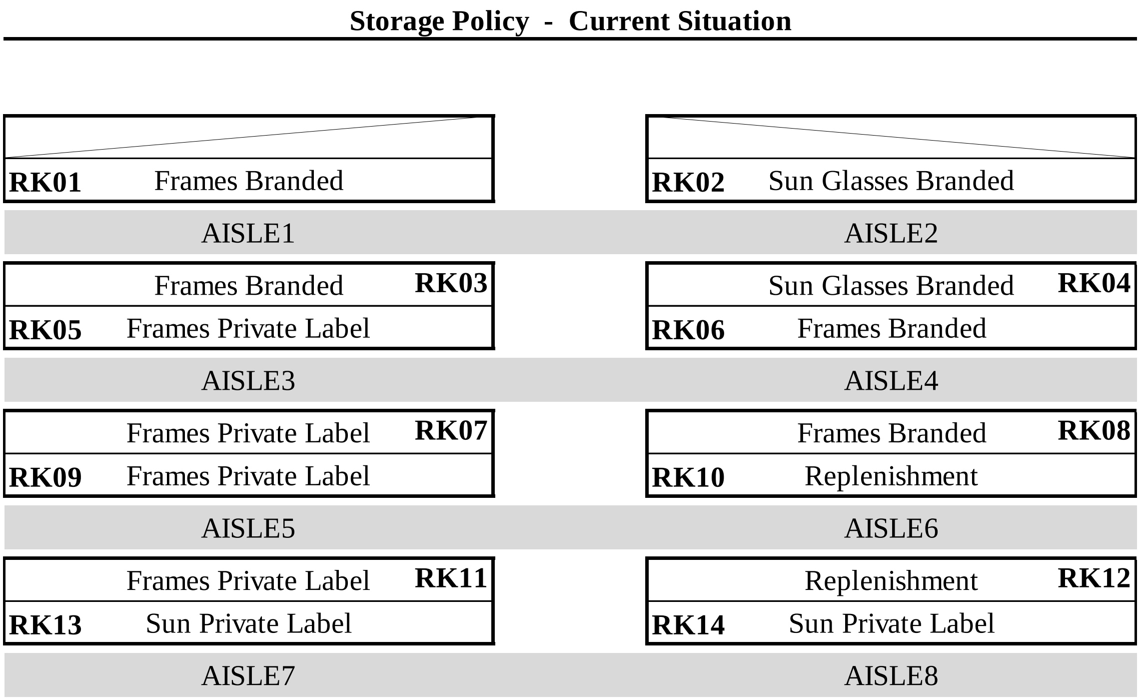

Figure 27 – Warehouse Current Storege Policy

This simulation generated 56 Replenishment Orders, according with parameterized distributions.

Work Entry Point 1

Number Entered	56
Number Lost	0
Net Number Entered	56

Figure 28 – Number Orders Entered

The three order pickers completed all the replenishment orders.

Work Complete

Number Completed	56
Time in System:	
Minimum Time in System	10,584
Average Time in System	158,888
Maximum Time in System	316,976
St Dev of	93,913

Figure 29 – Number Orders Completed

Representing an utilization of 64,73% of the system resources.

Resources

	Utilization %	Minimum Use	Current Use	Average Use	Maximum Use	Traveling %
Picker	64,743	0	0	1,942	3	0

Figure 30 – Resource utilization

Picker

Percentage of Time:

Utilization %	64,743
Traveling %	0

Units of Resource in use:

Current Use	0
Minimum Use	0
Average Use	1,942
Maximum Use	3

Charts:

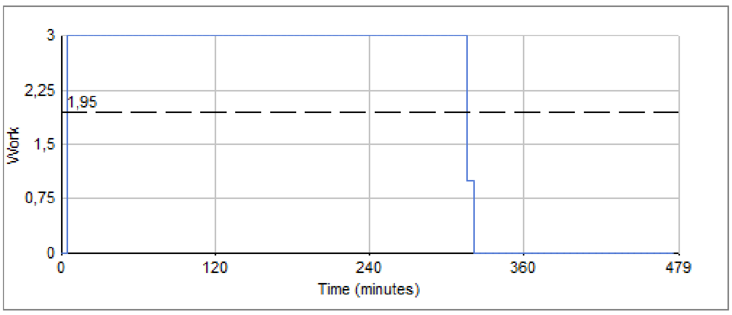

Figure 31 – Resource utilization

The results obtained are according with the reality observed in the field, and one can conclude that the total fulfillment of the replenishment orders is reached with the use of only near 65% of de picker’s time.

4.4.2 Storage Policy Alteration

The first alteration proposal regards a different Storage policy for the Replenishment Operation.

In fact when analyzing the Turnover of each SKU, one understands that Private Label Sunglasses SKU´s are ranked higher, representing 49,5% of Grand Total, followed by Branded Sunglasses, representing 21,8%, Branded Frames with 20,1%, and finally Private Label Frames, representing 8,6 %.

Regarding Storage Policy it is here proposed to maintain the consistency of Product Type (Frames and Sunglasses either Private Label or Branded), in order to simplify the picking operation. Nonetheless it is proposed that the four different Product Type combinations are stored closer to the depot, according with its Turnover. It can be considered a Class-Based Storage with two sorting dimensions: Type of Product and Turnover. Storage implementation strategy chooses was within-aisle.

From this policy comes the layout showed below:

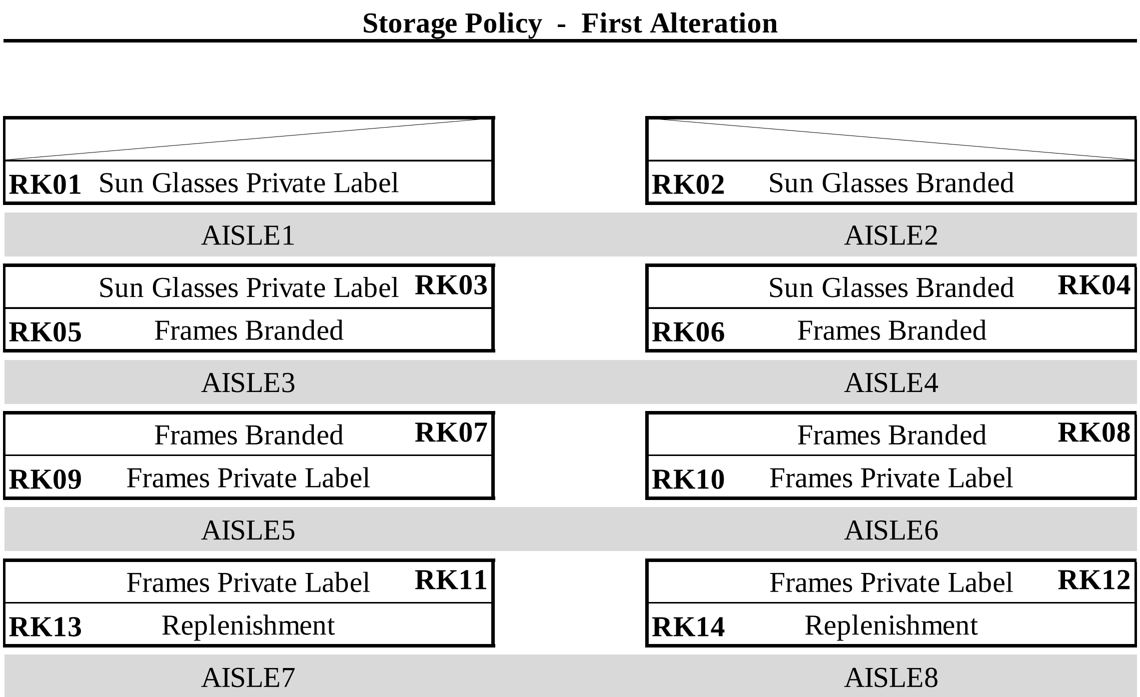

Figure 32 – Warehouse First Alteration on Storage Policy

For the same amount of Replenishment Orders entered and processed, the resource utilization only accounts for 55% of the pickers' working day, representing **an improvement of 15% in the warehouse operation.**

Therefore the simple alteration of the storage policy, along with a Golden Zone policy implementation, brings a significant increase in warehouse performance.

Resources

	Utilization %	Minimum Use	Current Use	Average Use	Maximum Use	Traveling %
Picker	55,151	0	0	1,655	3	0

Figure 33 – Resource Utilization

4.4.3 Picking Policy Alteration

A second alteration proposal comprehends the implementation of a batching policy, which is expected to reduce travelling times by retrieving two orders at the same time, with the help of picking carts.

Results obtained for the same resources utilization are presented below:

Picker

Percentage of Time:

Utilization %	44,261
Traveling %	0

Units of Resource in use:

Current Use	0
Minimum Use	0
Average Use	1,328
Maximum Use	3

Charts:

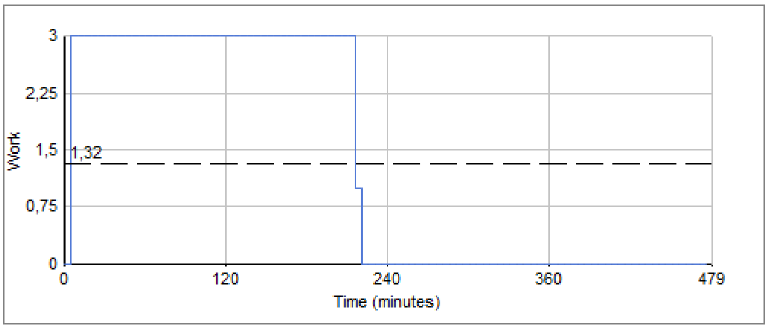

Figure 34 – Resource utilization

A considerable improvement is obtained, as there is, for the same amount of RO processed, a Resource utilization only of 44% of pickers time, representing **an improvement of 31,6% in the warehouse current operation** regarding to the as-is simulation.

5. Conclusions and Limitations/Future Work

5.1 Conclusions

GrandVision's management had the desire of rethinking and redefining Warehouse in all its structure.

More precisely, this master thesis focused in the redefinition of Replenishment Shops Operation.

It was studied, through simulation, the possibility of implementing a new and more efficient combination of Storage, Picking and Routing Policies.

Policies to be tested, were selected from previous research, and focused in Class-Based Storage Policy, Batching Picking Policy and Golden Zone Storage Implementation Strategy.

Formulated Hypotheses stated improvements for each one of these three changes.

Simulation models confirmed the Hypotheses of improvement as Storage Policy change brought an **improvement of 15% on Total Fulfillment Time** and Storage/Picking Policy changes presented an **improvement of 31, 6% on Total Fulfillment Time**; these values are not far from the studies of Peter and Aase (2004), where improvements from 17% to 22% are referred. Although it was implemented in the simulation models, the effect of Golden Zone Storage Implementation Strategy was not measured, as was not possible to isolate its effect.

As a final conclusion, GrandVision's management would beneficiate in implementing the changes proposed for Shop Replenishment Operation.

5.2 Limitations/Future Work

Although there was a hard work of several months collecting data on the field to support this master thesis, simulation modelling remains a representation of the reality, and therefore a list of limitations can be enumerated:

- Travel Times within Aisles were not considered as there was one Work Center per each aisle.
- Routing Policy in Current Situation was assumed as S-Shaped, when in reality was random.
- Sales Turnover was selected as slotting measure, which can raise two issues. The first: apart from everything points that for most of the SKU's, Sales Turnover and Warehouse Shipment Turnover match; it is known that there are some products, called obsoletes, which are sent to the shops but are not sold. The second: as Popularity is based in the number of hits of an SKU in picking lists; Sales Turnover represents a ratio per unit of time. The difference between this two slotting measures can be patent if there is good amount of cross-docking operations taking place, as the largest portion of stock of some SKU's are only in transit through the warehouse, and are not stored for Picking Operations.
- Sales Turnover was considered as an average of the entire year period, which ignores the effect of seasonality, especially present in sunglasses.
- Sensitive Analysis was not made regarding batching policies, order size and demand distribution.
- Trials were not run in the simulation, thus the results present are only referred to single case.
- Was not possible to isolate the effect of Golden Zone Storage Implementation Strategy.

All these limitations ask for a deeper future work.

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7. Appendix

7.1 Appendix 1 - Glossary

Key Words	**Definition**	**Source**
Access Efficiency	Corresponds to the resources consumed by the insertion (store) and extraction (order picking) processes.	Gu *et al.*(2007:5)
Aisle	Is the space in front of the rack where the order picking vehicle travels.	Cormier (2005:95)
AS/RS	Automated storage and retrieval system.	Cormier (2005:95)
Batch Picking	An order picking operation where multiple orders are picked simultaneously.	Van den Berg (1999:752)
Department	Concerns an entire area in the warehouse and its storage and material handling systems.	Gu *et al.*(2007)
Fast Pick/Forward Area	Where products are stored for easy retrieval by an orderpicker, often in smaller amounts in easily to access storage modules.	Rouwenhorst *et al.*(2000:516)
Item	Is an instance of a product.	Gu *et al.*(2007:8)
Order	Consists of a set of items destined to some customer and which must be retrieved from the warehouse.	Cormier (2005:95)
Order Line	Is a request by a customer for a particular item in a particular quantity.	Rosenwein (1996:657)

Order Picking	Order picking is the process by which products are retrieved from storage to satisfy customer demand	Vis and Roodbergen (2005:799)
Order Picking Vehicle	Can take several forms, for instance, a forklift truck, a hand cart, or, in the case of an AS/RS system, a S/R machine	Cormier (2005:95)
P/D Point	Pick-up/Drop-off point.	Petersen and Aase (2004:15)
Product		
Rack	Is a set of adjacent storage locations.	Cormier (2005:95)
Replenishment Process	The transfer of items from the reserve storage to the forward storage.	Rouwenhorst *et al.*(2000:516)
Reserve Area	Where products are stored in the most economical way (bulk storage area).	Rouwenhorst *et al.*(2000:516)
SKU	Customer orders consist of order lines, each line for a unique product or stock keeping unit (SKU).	De Koster (2007:483)
Slotting Measure	Are used to determine the order or ranking of the SKU's.	Petersen *et al.* (2005:998)
Storage	Concerns with the organization of goods held in the warehouse in order to achieve high space utilization and facilitate efficient material handling.	Gu *et al.*(2007:3)
Storage Assignment Strategy	Are used to determine how to assign to each SKU what storage locations.	Petersen *et al.* (2005:998
Total Fulfillment	Total travel and picking time.	Petersen *et al.* (2005:1002)

Time		
Warehouse	Warehouses are strategic infrastructures built with the prime objective of facilitate the movement of goods through the supply chain to the end consumer.	Baker et al.(2010:226)
Warehousing System	Refers to the combination of equipment and operating policies used in an item picking or storage/retrieval environment.	Van den Berg and Zijm (1999:521)
Wave Picking	A form of picking where each picker is responsible for SKU's in their zone for numerous orders.	Petersen and Aase (2004:12)
Zone	A pick zone is a subdivision of a department, a set of storage locations that are often arranged in close physical proximity, holding a limited subset of the SKU's.	Gu *et al.*(2007:4)
Zone Shape	Number of aisles per zones and length of aisles.	Gu *et al.*(2007:6)

7.2 Appendix 2 – Simul8 Models

Three Simul8 models are included in the CD, the first for the “Current situation”, the second for the “Storage Policy Alteration” and the third for the “Picking Policy Alteration”

7.3 Appendix 3 - Data Sheets

Data Sheets included in the CD, refer to 2011 Replenishment Orders and Assortment Data, as well as initial SKU layout and the small sample for picking times data.