An input and output Excel file for a material supply assignment model

MASTER THESIS

Universiteit Gent – Industrial Management

2011/ 2012

Sergi Fabregat Corominas

Supervisor: prof. dr. ir. H. Van Landeghem

Co-supervisor: dr. V. Limère

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Abstract

Summary

Nowadays companies need to have a competitive production system in order to face the high competition. As it increase a lot the costs, companies realize that a way for obtaining an advantage over their competitors is improving their logistics systems.

Although it is not a direct activity nearly linked to the company target, at the present time most of the companies have a specific department (it could be either of their own property or an external firm) in order to improve their logistics organizations and supply chain methods.

Even though it depends on the type of company that considered, is well known that logistics costs constitute around 10% of the final cost of the product. Because of this considerable percentage, the optimization cost study related with the supply chain has a lot of importance in the companies.

For all these reasons mentioned above, dr. Veronique Limère realized a study that will be presented in the second chapter of the thesis in order to optimize the cost of the distribution of the different parts to be treated in the different workstations in a typical automotive industry.

To achieve the objective of the study, a Mixed Integer Linear Programming Model (MILP) was developed previously and defined each of the parameters and variables that affect the final cost of the distribution. To obtain the optimal cost, this model informs, for each one of the parts to be treated, which of both material supply methods, bulk feeding or kitting must be used.

On the one hand, bulk feeding is the most simply and direct material supply system. In this type of supply method, parts are supplied in containers to the assembly line. Each container contains a large quantity of that type of part. Containers are stored at the border of the line (BoL) of each assembly workstation in order to satisfy the demand needed in each assembly line.

On the other hand, kitting system create heterogeneous packages by grouping together the exact components that are needed in a particular assembly operation. Each kit can containthe parts for one or more assembly operations. Kits are stored at the border of the line (BoL) of the assembly lines in order to satisfy the demand needed in each assembly workstation.

Based on the model mentioned, the main objective of this thesis is:

Objective 1: To develop a work tool for companies that are using the mathematical model designed by dr. Veronique Limère. This tool has to targets: On the one hand, it has to be able to obtain different results depending on the values of the parameters in order that the employees can compare them. On the other hand it has to be easy to use and it must give the results in a comfortable way in order to the employee can understand the necessary information faster.

Moreover, this thesis has a second objective in orther to put in practice the work tool mentioned in the first objective. It consists on:

Objective 2: Studying a particular company data. We will consider possible changes in the way to supply parts, from the moment that parts are in the warehouses to the moment that they are picket to be assembled. Results will be obtained and analysed for each modification considered.

To achieve these objectives the thesis follows the next structure: Firstly, in Chapter 1, an introduction of the sector and a brief explication of the thesis of dr. Veronique Limère are presented. In Chapter 2 is developed the tool for the companies and is explained how it has been developed. In Chapter 3 an extended analysis is realized and finally, in Chapter 4, conclusions are given.

Table of Contents

List of Figures

List of Tables

Notations

Sets

$\boldsymbol{I_b}$	Set of all parts supplied in small boxes
$\boldsymbol{I_p}$	Set of all palletized parts
$\boldsymbol{I}$	Set of all parts; $I = I_p \cap I_b$
$\boldsymbol{I_s}$	Set of all parts used at station s
$\boldsymbol{S}$	Set of all work stations s
$\boldsymbol{V_i}$	Set of variant parts of $i \in I$; the family of part i

Parameters

$\boldsymbol{a_i}$	Maximum number of units of a part i in one pick due to physical characteristics (weight, volume) of part i
$\boldsymbol{A^b}$	Capacity of the milk run tours for boxes (number of boxes per tour)
$\boldsymbol{A^k}$	Capacity of the milk run tours for kits (number of kits per tour)
$\boldsymbol{B^k}$	Batch size for assembling kits

$\boldsymbol{\Delta_{is}^{bulk}}$	Average distance for the operator at workstation s to pick from a bulk container of part i	(m)
$\boldsymbol{\Delta_{is}^{k}}$	Average distance for the operator in the supermarket to pick from a bulk container of part i to kit for station s	(m)
$\boldsymbol{\Delta^{k}}$	Average distance for the line-operator to pick from a kit	(m)
$\boldsymbol{d}$	Yearly demand for end product (=vehicle)	
$\boldsymbol{D^{b}}$	Distance of the milk run tour for boxes	(m)
$\boldsymbol{D^{k}}$	Distance of the milk run tour for kits	(m)
$\boldsymbol{D_{s}^{p}}$	Distance of transport between the pallet warehouse and workstation s	(m)
$\boldsymbol{D_{p}^{fact}}$	Corrector factor of the distance between the pallet warehouse and the workstation s	
$\boldsymbol{depth}$	The depth of the line - i.e. the perpendicular distance between the operator working at the product and the border of line	(m)
$\boldsymbol{f_{is}}$	Percentage of end products for which part i is assembled at station s (frequency)	
$\boldsymbol{FT^{k}}$	Fixed production time for each kit	(h)
$\boldsymbol{H^{b}}$	Vertical stacking height of boxes (units) on the BoL	
$\boldsymbol{L^{b}}$	Length of a box along the line	(m)
$\boldsymbol{L^{k}}$	Length of a kit container/rack along the line (we assume no stacking of kits containers)	(m)
$\boldsymbol{L^{p}}$	Length of a pallet along the line (we assume no stacking of pallets)	(m)
$\boldsymbol{L_{s}}$	Available length along workstation s	(m)
$\boldsymbol{L^{fact}}$		
$\boldsymbol{m_{is}}$	Number of units of part i assembled per vehicle (if the specific variant part i is used) at station s	
$\boldsymbol{n_{i}}$	Number of units of part i contained in the original packaging; packing quantity of part i	
$\boldsymbol{OC}$	Cost of labour (per hour) of an operator	(€/h)

$\boldsymbol{OCL}$	Cost of labour (per hour) of a logistic operator	(€/h)
$\boldsymbol{OV}$	Average walking speed of an operator	(m/h)
$\boldsymbol{pack_i}$	supplier packaging of part i {Box, Pallet}	
$\boldsymbol{q_{is}}$	Yearly usage of part i at station s; $q_{is} = m_{is} f_{is} d$	
$\boldsymbol{\rho^b}$	Expected capacity utilization of the milk run tours for boxes	
$\boldsymbol{\rho^k}$	Expected capacity utilization of the milk run tours for kits	
$\boldsymbol{R^{3PL}}$	Constant cost of the replenishment of the 3PL	(€)
$\boldsymbol{R^b}$	Constant cost for the replenishment of one box in the supermarket	(€)
$\boldsymbol{R^p}$	Constant cost for the replenishment of one pallet in the supermarket	(€)
$\boldsymbol{\tau^{bulk}}$	Average time to search for the required part from bulk stock at the line	(s)
$\boldsymbol{\tau^k}$	Average time to search for the required part from bulk stock in the supermarket	(s)
$\boldsymbol{\theta_{is}}$	Number of units of part i that will on average be picked in one pick when part i is kitted for station s	
$\boldsymbol{v_i}$	Number of units of part i that a kit can maximally hold; this categorical parameter represents the volume (small, medium, large, extra-large) of a part i {100, 20, 5, 1}	
$\boldsymbol{V^{fact}}$	Corrector factor of available volume in a kit	
$\boldsymbol{V^b}$	Velocity of the material handling equipment for milk run tours for boxes	(m/h)
$\boldsymbol{V^k}$	Velocity of the material handling equipment for the milk run tours for kits	(m/h)
$\boldsymbol{V^p}$	Velocity of the material handling equipment for pallets	(m/h)
$\boldsymbol{w_i}$	Weight of part i	(kg)
$\boldsymbol{w^k}$	Weight constraint on one kit unit; maximum weight per kit	(kg)

Variables

$\boldsymbol{K_s}$	Integer auxiliary variable Number of kits needed at stations s to assemble one vehicle	
$\boldsymbol{N_s^b}$	Integer auxiliary variable Number of facings needed to store boxes along station s (with vertical stacking of boxes)	
$\boldsymbol{x_{is}}$	Binary decision variable x_{is} = 1, if part i is bulk fed 0, if part i is kitted	

Cost and time factors

$\boldsymbol{C_{kit}}$	The yearly labor cost for kit assembly	(€)
$\boldsymbol{C_{pick}}$	The yearly labor cost for operator picking at the assembly line	(€)
$\boldsymbol{C_{repl}}$	The yearly labor cost for the replenishment of the supermarket	(€)
$\boldsymbol{C_{total}}$	The yearly labor cost	(€)
$\boldsymbol{C_{tpt}}$	The yearly internal transport cost	(€)
$\boldsymbol{C_{tpt}^{pallet}}$	The yearly cost for pallet transport	(€)
$\boldsymbol{C_{tpt}^{box}}$	The yearly cost for box transportation	(€)
$\boldsymbol{C_{tpt}^{kit}}$	The yearly cost for kit transport	(€)
$\boldsymbol{C^{3PL}}$	The yearly labor cost for the replenishment of the 3PL	(€)
$\boldsymbol{FC_{kit}}$	The yearly fixed cost to assemble all kits	(€)
$\boldsymbol{tp_{is}^{bulk}}$	Average time to pick a unit of part i from a bulk container at station s	(h)
$\boldsymbol{tp^k}$	Average time for the line-operator to pick a unit from a kit	(h)
$\boldsymbol{tk_{is}}$	Average time for the operator in the supermarket to pick a unit from a bulk container of part i to kit for station s	(h)
$\boldsymbol{VC_{kit}}$	The yearly variable cost to assemble all kits	(€)

Chapter 1

Introduction

In the field of the automotive industry, nowadays, it is required to get low prices and timely delivery in order to obtain an advantage against the other companies competing. For this reason, companies are trying to reduce their costs. On the one hand, companies try to reduce the costs directly related to the vehicle manufacture, as it could be the cost of the material of the different parts that conform the vehicle, or the cost of the energy consumed to assemble the parts (direct costs), On the other hand, companies also try to reduce those costs that also affects to the final cost even they are not a direct cost (indirect costs). In this type of costs it is included the costs related to material supply methods.

To reduce material supply costs, logistics departments have been searching the optimal way to supply the material to the different workstations. To achieve it, companies are investing in developing mathematical models that gives the better way to supply a component. These models have into account the part characteristics and plant design and they are developed to explain us how each of the parts needed in the floor shop has to be supplied. However, the part supply of mixed-model assembly lines is a largely unexplored field of research (Boysen and Bock, 2011).

Because of the reasons explained above, dr. Veronique Limère realized her own model presented on her Ph.D.: “To Kit or Not to Kit: Optimizing Part Feeding in the Automotive Assembly Industry”. In this thesis, we will use the mentioned model developed by dr. Veronique Limère to reach the objectives. Is for this reason that before presenting the model, we must know how automotive industries are organized and which different ways to supply material exists nowadays. Once we have all this information, we will be able to understand why the model has been developed like it is.

1.1 Material supply systems

In order to be able to understand the model, it is necessary to have a previous knowledge about the different ways that one can find in industry to supply the materials from the warehouses to the assembly line.

Every company is allowed to choose the way to supply the material as it thought it would be more efficient. Otherwise, it is well known that there are several supply systems methods that usually obtain the best results and are the most typical applied methods. These methods are explained below:

The first and most simple method is the bulk feeding or line stocking method. In this method containers are stored at the border of the line. Each container contains one different type of part. In Figure 1.1 we can see containers at the border of the line, each one with a different type of part needed. The amount of parts inside each container is not an exact quantity according to the schedule, so this method does not need previous handling operations.

***Figure 1.1**: Picture of a BoL with containers used in the line stocking method*

Next, we can find the downsizing method. In this case, parts are first repackaged into smaller containers before being supplied to the workstation. Compared to a line stocking system, downsizing needs a previous handling operation, which constitutes an extra spent time and, consequently, an extra cost. However the fact that parts are in a smaller bins will diminish the searching times and walking distances.

In Sequencing supply system, parts are supplied to the line at the moment that is needed. Moreover it is supplied the exact quantity needed according to the schedule, instead of storing the parts in containers at the border of the line. In this case, time spent on handling operations will be even higher than with downsizing. On the other hand, searching times and walking distances will be less than in downsizing.

Finally, the method that needs more previous work is the kitting method. Kitting is the practice of delivering components and subassemblies to the shop floor in predetermined quantities that are placed together in specific containers (Bozer and McGinnis, 1992). Instead of delivering the demanded parts of each station in huge containers with large quantities of parts, in a kitting system, the exact parts are first selected and pulled together in kit containers before they are delivered to the workstation. Every kit container can support more than one assembly operations. This method then also needs additional material handling activities, even more sophisticated than in downsizing and sequencing. Instead of it, cost related to searching time and walking distances will be eliminated.

Figure 1.2 (Limère, 2011) illustrates how parts are displayed at the border of the line depending on the material supply system. As it can be seen there is a significant reduction of parts if we compare line stocking vs. kitting, so operator walking distances will be reduced considerably and searching times will be eliminated if parts are sequenced (sequencing and kitting systems). However it can be easily seen that for displaying the material at the border of the line it is necessary more preparation time and handling activities in kitting, sequencing or downsizing compared with line stocking.

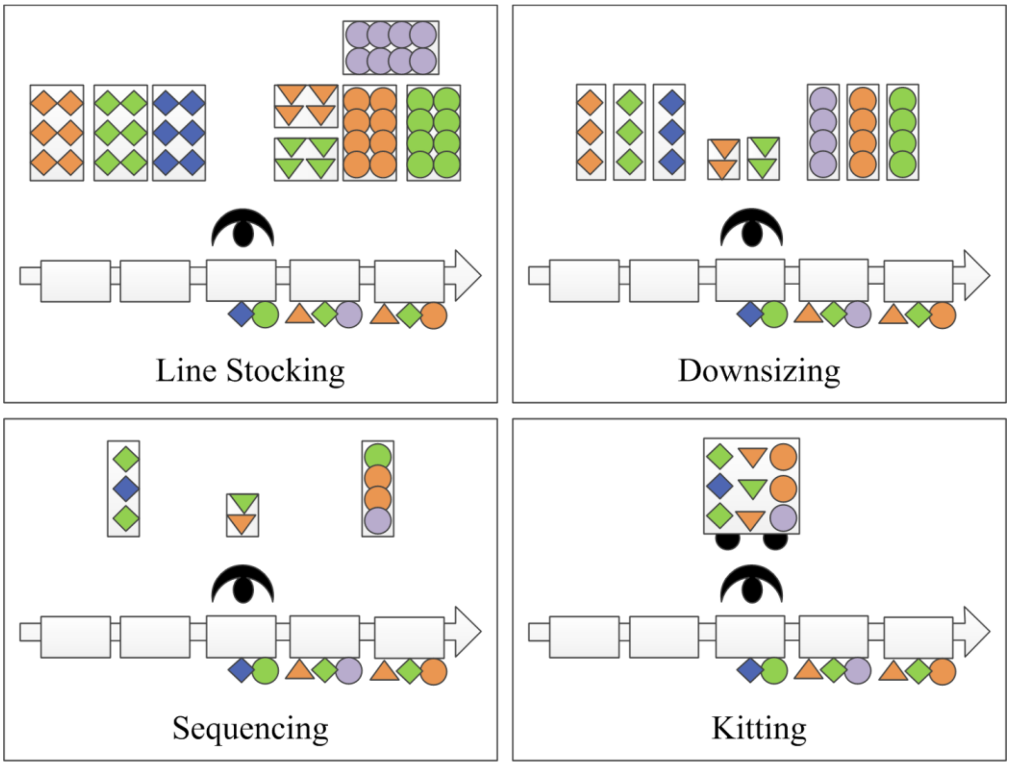

Figure 1.2: *Impact of different line feeding methods on the display of parts at the border of the line (Limère, 2011).*

There are 3 different ways to realize the handling operations:

- The supplier is the responsible to do them so, after producing the parts to be supplied, he has to make the kits according to the manufacturer preferences.
- The manufacturer realizes his owns kits once he has received the parts produced by the supplier
- A Third party logistics provider (3PL) is the responsible to realize the kits.

Figure 1.3 represents the basic flows of parts needed for each supply system. As we can observe, the line stocking method only has 3 stages instead of the 4 stages that the other methods have. It is like this due to the handling operations. This is the main advantage that line stocking has over the other supply systems. On the other hand, with the other 3 supply systems there is lower quantity of stock at the border of the line. It means that the operator walking distances will be reduced compared with the line stocking system. Moreover, because of the previous handling operations done before, searching times at the border of the line will be reduced or, in case of kitting and sequencing systems, it will be eliminated.

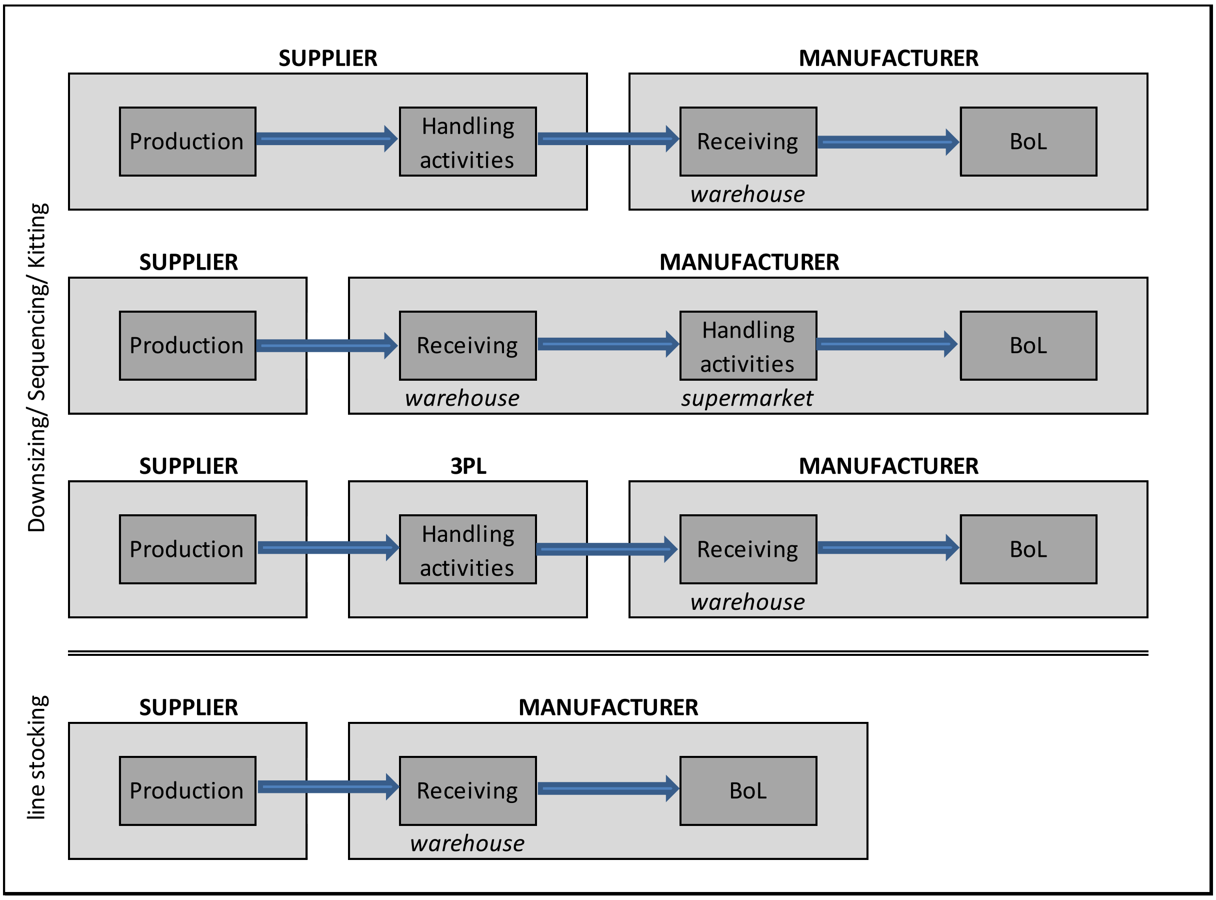

Figure 1.3: *Flow of material for the different supply methods.*

1.1.1 Main differences between the different part feeding systems

As mentioned before, the main advantage of line stocking compared with kitting system is the fact that there are no previous handling activities. However, in kitting systems the cost related to searching time is eliminated, which constitutes an advantage compared with line stocking method, in which it supposes an additional cost. Moreover, in situations that customers can choose from a huge range of different variant parts, e.g. types of mirrors, kitting could be the best solution. Otherwise, to be able to store all the different variant parts at the border of the line it would be needed a bigger plant.

In downsizing and sequencing systems these parameters represents either and advantage or a disadvantage depending on which of the two mentioned systems (kitting and line stocking) are we comparing them with. This happens because downsizing and sequencing are more moderate feeding systems and they have similarities with the other two methods in a moderate way. We could say that talking about characteristics of the method, they are in the middle of line stocking and kitting. Contrary, line stocking and kitting systems are opposite methods.

In Figure 1.4 we can appreciate the reduction or an increase of the cost depending on the parameter that we are talking about (material handling activities or walking distances plus searching time) depending on the supply system being used.

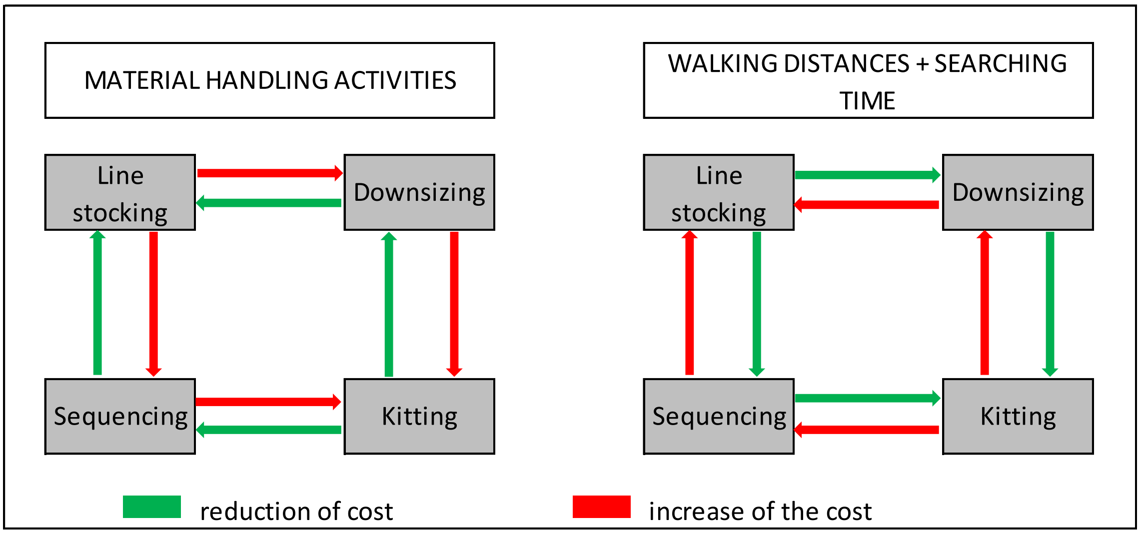

Figure 1.4: *Reduction or increase of the cost if there is a change on the supply method depending on the parameter.*

The same that happens with these two main parameters (material handling activities and the sum of walking distances and searching time) it happens with the rest of the parameters that affect to the final cost: A parameter that constitutes an advantage and consequently a reduction of the cost, for kitting it is a disadvantage –increase of the cost- for line stocking and vice versa. Dr. Veronique Limère takes into account the line stocking and kitting systems on her model, as they are the two most opposite methods.
In the next section, a comparative between line stocking and kitting is realized in order to have a better knowledge about them before reading the model.

1.1.2 Line stocking vs. Kitting system: Advantages and disadvantages

Once we know that the model is just taking into account line stocking and kitting systems, in this section presents which the advantages and disadvantages are for each type of method.

Talking about manufacturing productivity, part of the main differences that have been commented in the previous section which were the reduction of operation walking distances and the elimination of operator search times, there are other differences that must be known. First of all, an advantage of kitting system that is a consequence of the advantages commented, is the reduction of picking times because of the prepositioning. Because of its sophisticated working method, the material in a kit may also be used as a work instruction (Wanstrom and Melbo, 2009) and this will ease education of new staff (Ding and Puvitharan, 1990). Moreover, when rebalancing a line, cycle time feasibility (Swaminathan and Nitsch) has to be taken into account. The improved productivity at the line under a kitting system will then, ceteris paribus, result in shorter feasible cycle times (Limère, 2011). The last advantage related with manufacturing productivity is the fact that kitting gives to the operators a better ergonomic condition.

Talking about the advantages and disadvantages of kitting and line stocking at the border of the line, kitting system has a reduced stock, which permit to have an smaller border of the line. Moreover, the space required to manufacture is also more reduced than in line stocking. Finally, the number of kits provide immediate information regarding the WIP level, since each kits consists of a predetermined quantity of parts, and this leads to an improved control over the work-in-process (Ding and Puvitharan, 1990; Ding 1992; Choobineh and Mohebi, 2004).

Related with material handling activities, as it has been said before, line stocking system does not need this activity, so it constitutes an advantage respect kitting. In kitting, it is wasted a lot of time preparing the kits. Moreover, it is required an increased space in the stock room in order to prepare the kits, and this preparation suppose an increased risk of damaging parts because of the handling operations.

Regarding to the transport of the material, in line stocking system variable material has to be supplied to workstations in individual component containers, which decreases the efficiency of the plant and increases the risk of damage. In kitting, since kits are consumed in sync with the takt time, it is easier to schedule kit replenishments than to schedule bulk replenishments (Limère, 2011). This fact simplifies material flow.

In relation with the quality that each system gives, we must say that both methods lead some risk of damage or schedule problems. Whereas in kitting the operator does not need to search for the right part, in line stocking there is a risk of assemble a wrong part. Moreover, because of the long time that parts can spend at the border of the line in line stocking method there is a higher risk of damaging parts at the line. Otherwise, it does not constitute a problem as relevant as in kitting because there is safety stock to replace defective parts. In kitting, an error in kit preparation can easily produce an interruption of the production.

Finally, if we talk about manufacturing flexibility, kitting presents some disadvantages because it requires that a production sequence is determined beforehand (Limère, 2011). This means that it is need a long time between it is ordered and once it is assembled. Moreover, if there is schedule change, the whole kit may have to be returned and de-kitted (Limère, 2011).

Table 1.1 (Limère, 2011) shows a summary of the advantages and disadvantages of kitting and line stocking explained above.

	Line stocking	Kitting
Manufacturing productivity	(-) long operator walking distances (-) operator search times (-) longer cycle times (-) large containers negatively impact ergonomics	(+) reduced operator walking distances (+) elimination of operator search times (+) reduced picking times thanks to prepositioning (+) kit functions as a work instruction (+) shorter cycle times can be realized (+) improved ergonomic conditions
Border of line (BoL)	(-) excessive stock at the BoL (-) great manufacturing space requirement (-) bad control over WIP	(+) reduced stock at the BoL (+) reduced manufacturing space requirement (+) improved parts visibility and improved control over WIP
Material handling	(+) elimination of non-value adding material handling activities	(-) kit preparation consumes time and effort and is non-value adding (-) increased space requirement in the stock room; a kitting area is needed (-) an increased number of handling operations: increased probability of damaging parts (+) material is stored centrally: increased control and reduction of inventory at a given service level (-) kitting demands additional planning

Table 1.1: *Advantages and disadvantages of line stocking and kitting*

	Line stocking	Kitting
Internal transport	(-) variable material flows of individual containers (pull)	(+) control over materials flows of kits: synchronization of transport with takt times; simplified material flow and less damage
	(+) component containers are often denser than kit containers	
Quality	(-) risk of picking and assembling the wrong parts	(+) increase in product quality as the operator does not need to search for right parts
	(-) higher risk of damaging parts at the line	(+) parts are not lying idle in open packages at the line
	(+) safety stock at the line to replace defective parts	(-) errors in kit preparation: production will be interrupted or other kits may be cannibalized
	(-) if a shortage is detected too late, missing parts may cause production interruption	(+) quality checks earlier in the value chain
		(-) Temporary shortage of parts may force the user to kit short and doing so will reduce the overall efficiency of the operation
Flexibility	(-) product changeover is time consuming	(+) Product changeover is simplified
	(+) safety stock available at the line to respond to a schedule change	(-) If there is a schedule change, the whole kit may have to be returned and de-kitted
	(-) Kitting requires that a production sequence is determined beforehand	

Table 1.2: *Advantages and disadvantages of line stoking and kitting (continued)*

1.2 Contribution

After having a better knowledge of the subject we need to set our objectives and the content exposed in this thesis.

1.2.1 Objectives

In this thesis the main objective is to develop a work tool for companies using the mathematical model designed by dr. Veronique Limère. This tool has to permit to the employees to realize more accurate studies. We want to develop a tool in which we can obtain different results depending on the values of the parameters and compare them. Moreover it has to be easy to use and it must give the results in a comfortable way in order to the employee can understand the necessary information faster.

In the background, another objective is to put this tool in practice. A study of a particular company data will be realized. We will consider possible changes in the way to supply parts from the warehouses to the assembly line in order to put in practice the variance of the parameters. Results will be obtained and analysed for each modification considered.

1.2.2 Content

The remaining part of the thesis is divided in five more chapters. In Chapter 2, it is presented the mathematical model developed by dr. Veronique Limère. In order to understand it, all parameters and variables that are included in the model are first defined and explained. The whole information of this chapter is extracted from Veronique Limère's Ph.D. thesis: "To Kit or Not to Kit: Optimizing Part Feeding in the Automotive Assembly Industry" where the model is presented and also explained.

Chapter 3, presents all possible changes that are considered in this thesis in the way to supply the parts. We will also explain how it affects to the model.

In Chapter 4, the tool developed is presented. It is explained what the tool allows to do and which information it can give to the company that is using it. Moreover it is explained how it has to be used. Finally, an explication of how it is linked with Limere's mathematical model is given.

In Chapter 5 the tool developed is put into practice by using it with a specific data of a company. Results are given and explained in order to help the company to take decisions.

Chapter 6 concludes the thesis.

Chapter 2

Model review

As it is mentioned before, this thesis is based on a Ph.D. thesis and all the results are obtained from the model of this Ph.D. Is for this reason that in this section it is presented the model realized by Dr. Veronique Limère: "To Kit or Not to Kit: Optimizing Part Feeding in the Automotive Assembly Industry". This model was developed in order to obtain the way to find an optimal allocation of parts to the different supply methods and let us know which would be the total supplying cost of the company. To know about where the model comes from, it is described the different types of costs that can affect the final cost. The mathematical model includes the costs associated with the parts leaving the warehouse to the moment that parts are assembled.

In section 2.1 a detailed explanation of the material flow in each type of supply is given. In Section 2.2, the mathematical model is presented. All the information used in this chapter is taken from the Ph.D.: "To Kit or Not to Kit: Optimizing Part Feeding in the Automotive Assembly Industry" (Limère, 2011).

2.1 Material flows

In this section it is explained how is the supply process that follows parts from the moment that they are leaving the warehouse until they are assembled with the two supply systems studied. This section is intended to make understand all the parameters that are included in the model.

2.1.1 Line stocking

As explained before, this is the most direct method. Parts are supplied from the warehouse to the workstations in containers. Each container contains only one type of part. To realize the model, it is considered two kinds of containers: pallets and boxes. There are two different ways of transporting the packaging containers depending on the type of container.

- If the packaging container is a unit-load (pallet) it is transported by a forklifts and it is transported one by one. Figure 2.1 shows a forklift truck carrying a pallet.
- If the packaging container is a box, it is transported by a tugger train that carries out a milk run tour. Figure 2.2 illustrates a tugger train transporting boxes.

2.1.2 Kitting

In kitting system, parts are also supplied to the factory in pallets or boxes in which each container contains only one type of part and in the factory there is an area to realize the kits according to the schedule. In the study realized by dr. Veronique Limère it is assumed that the company studied works with an in-house kitting and there is a supermarket where operators walk to pick the parts that are needed for preparing the kit. It is also assumed that the central picking supermarket is logically organized in picking zones, where an aisle represents a zone which contains all variant parts that can be consolidated in a kit for a certain work station (Limère, 2011). Furthermore it is assumed that multiple kits of the same type are assembled in batches of five because five kits fit on one rack (Limère, 2011). The transport from the warehouse to the supermarket is realized, as in line stocking, in two different ways depending on the type of container:

- By forklift if the container is a unit-load (pallet). Figure 2.1.
- By a tugger train if the container is a box. Figure 2.2.

After preparing the kits in the supermarket they are transported in kits containers (each kit container can carry multiple kits of the same type) by a tugger train that realizes a milk run tour. As one kit is consumed per takt time, kit container replenishments are needed according to constant time intervals (Limère, 2011).

Figure 2.1: *Forklift truck carrying a pallet*

Figure 2.2: *Tugger train carrying boxes*

2.2 Mathematical model

In this section the mathematical model is given and parameters are defined in order to understand the model. This is a summary of the P.hD. based on: "To Kit or Not to Kit: Optimizing Part Feeding in the Automotive Assembly Industry" written by Dr. Veronique Limère, 2011. In this Ph.D. we can find an extended explication about why it is modelled like this. This model gives us the information of which supply method has to be applied in each of the parts in order to have the lowest cost.

The model is implemented using the modelling language AMPL 11.2 and solved with CPLEX 11.2.

2.2.1 Objective function

The Final Cost of the whole model is divided into four different types of costs: Picking cost at the line, internal transport cost to the line, the cost for kitting and finally the replenishment cost of the supermarket. With all that, the objective function of the model represented as:

$$\min C_{total} = C_{pick} + C_{tpt} + C_{kit} + C_{repl} \tag{2.1}$$

2.2.2 Picking cost

The labor cost for operator picking at the assembly line is given by the following expression:

$$C_{pick} = OC \sum_{s \in S} \sum_{i \in I_s} q_{is} \left(x_{is} \tau^{bulk} + 2\frac{p_{is}}{OV} + (1 - x_{is})\, 2\frac{\Delta_k}{OV} \right) \tag{2.2}$$

With,

$$p_{is} \geq \Delta_{is}^{bulk} - \left[\left(depth + \frac{L_s}{4} + \epsilon \right) (1 - x_{is}) \right] \quad \forall s \in S, \forall i \in I_s \tag{2.3}$$

$$p_{is} \geq 0 \qquad \forall s \in S, \forall i \in I_s \tag{2.4}$$

e Any small number

$$0 < \Delta_{is}^{bulk} \tag{2.5}$$

$$\left(depth + \tfrac{L_s}{4} + \epsilon\right) > \Delta_{is}^{bulk} \tag{2.6}$$

2.2.3 Transport to the line

The total transport cost is the sum of the costs for the different types of transportation: trough pallets, box or kits.

$$C_{tpt} = C_{tpt}^{pallet} + C_{tpt}^{box} + C_{tpt}^{kit} \tag{2.7}$$

With,

$$C_{tpt}^{pallet} = OC \sum_{s \in S} \sum_{i \in I_s \cap I_p} x_{is} \left(2 \frac{D_s^p}{V^p} \frac{q_{is}}{n_i} \right) \tag{2.8}$$

$$C_{tpt}^{box} = OC \sum_{s \in S} \sum_{i \in I_s \cap I_b} x_{is} \frac{\frac{D^b}{V^b} \frac{q_{is}}{n_i}}{A^b \rho^b} \tag{2.9}$$

$$C_{tpt}^{kit} = OC \sum_{s \in S} \frac{\frac{D^k}{V^k} K_s d}{A^k \rho^k} \tag{2.10}$$

2.2.4 Kitting Cost

The labor cost for Kit assembly is given by:

$$C_{kit} = OC \sum_{s \in S} \sum_{i \in I_s} \left[(1 - x_{is}) \, q_{is} \frac{\left(2\Delta_{is}^{k} / OV \right) + \tau^k}{\theta_{is}} \right] \tag{2.11}$$

With,

$$\theta_{is} = \max\left\{\min\left(\frac{q_{is}}{d}B^k, a_i\right), \frac{m_{is}}{\lceil m_{is}/a_i \rceil}\right\} \tag{2.12}$$

2.2.5 Cost of replenishment

The total cost of the replenishment of the supermarket can be defined as:

$$C_{repl} = \sum_{s\in S}\sum_{i\in I_s\cap I_p}\left[(1-x_{is})\frac{q_{is}}{n_i}R^p\right] + \sum_{s\in S}\sum_{i\in I_s\cap I_b}\left[(1-x_{is})\frac{q_{is}}{n_i}R^b\right] \tag{2.13}$$

2.2.6 Restrictions

The objective function is subjected to the constraints exposed below:

$$K_s \geq \sum_{i\in I_s}\left[(1-x_{is})\left(\frac{m_{is}w_i}{|V_i|}\right)\bigg/ w^k\right] \qquad \forall s\in S \tag{2.14}$$

$$K_s \geq \sum_{i\in I_s}\left[(1-x_{is})\left(\frac{m_{is}/v_i}{|V_i|}\right)\right] \qquad \forall s\in S \tag{2.15}$$

$$\sum_{i\in I_s\cap I_b}\left(\frac{x_{is}}{H^b}\right) \leq N_s^b \qquad \forall s\in S \tag{2.16}$$

$$N_s^b L^b + \sum_{i\in I_s\cap I_p} x_{is}L^p + K_s L^k \leq L_s \qquad \forall s\in S \tag{2.17}$$

$$\Delta_{is}^{bulk} \geq depth + \frac{N_s^b L^b + \sum_{i\in I_s\cap I_p} x_{is}L^p + K_s L^k}{4} \qquad \forall j\in S, \forall i\in I_s \tag{2.18}$$

$$\Delta_{is}^{bulk} - \left[\left(depth + \frac{L_s}{4} + \epsilon\right)(1-x_{is})\right] \leq p_{is} \qquad \forall j\in S, \forall i\in I_s \tag{2.19}$$

$$p_{is} \geq 0 \qquad \forall j\in S, \forall i\in I_s \tag{2.20}$$

Chapter 3

Possible logistic changes in the factory

As we have seen in the previous chapter, the mathematical model offers the opportunity to select, for each of the parts that have to be supplied, the material supply method which is most cost effective for the overall material delivery system. However, some considerations have been assumed with this model. In this thesis, we want to take into consideration some changes that the company could realize in the way of performing the parts supply.

In section 3.1 are presented the possible modifications that we want to consider. In section 3.2, we expose the changes realized in the mathematical model in order to study these considerations.

3.1 Modifications considered

As it has been explained, to create the mathematical model some parameters have been fixed and some characteristics of the way to supply the parts have been assumed to be as mentioned in the first and second chapter. The aim of this section is to analyse which variances an industry can suffer compared with the described situation.

Below are described the possible logistic modifications in the company.

3.1.1 New picking technology in the supermarket

Until this moment, it is assumed by the model that there is a central supermarket were picking operators walk to pick the needed parts (Limère, 2011). However, there are some technological management systems to increase the picking efficiency by minimize picking time and reduce the errors made by the operators, which would make reduce the costs. Three of the most known picking methods are the pick-by-voice, pick-by-light and pick-by-vision.

3.1.1.1 Pick –by-voice

This picking system is based on instructions that arrive through a radio terminal equipped by headphones and microphone. The instructions arrive through the headphone and are confirmed through the microphone. Consequently, the main characteristic of this picking system is the fact that operators are working with hands-free. It permits them to keep walking with the shopping cart while interacting with the terminal. Moreover, when the operator arrives to the pick position, he just has to leave the shopping cart and pick the needed part instead of pocketing the list or the screen carrying on his hands. When picking is finished the terminal informs the operator where the kits must be left.

Figure 3.1 shows an operator using the pick-to-voice system. It can be easily seen that he does not have to carry anything and has free hands to pick the parts.

These two advantages explained reduce the average time to search a part from bulk stock in the supermarket which, according to the formula 2.11, it reduces the average time allocated to picking one unit from a bulk container of part *i* to kit for station *s*. It reduces the kitting cost and, consequently, a lower final cost is achieved.

Figure 3.1: *Operator using the pick to voice system*

3.1.1.2 Pick –by-light

In this system, each stock location has assigned a display with a numeric or alphanumeric codification, a button for confirmation and a digital indicator to show the number of parts to pick. To use this system, the operator scans a barcode from an ordering box. It activates the displays of the parts needed to be picked. This system avoids the operator from carrying and consulting any paper or screen. Furthermore, a visual element is easier to detect than a code. Consequently, like in pick-to-voice, the searching time diminishes and it is obtained a reduced final cost. Figure 3.2 illustrates an operator using the pick-to-light display. We can see that it shows the number of parts needed to be picket, in this case, 12 parts.

Figure 3.2: *Display used in a pick to light system*

3.1.1.3 Pick –by-vision

This method guides the picker to each of the picking allocations trough virtual information in the display of the operator. In figure 3.3 we can see an operator using a pick-to-vision display.

It uses symbols like arrows or a tunnel made by circles that indicates the operator where the next part to pick is. Figure 3.4 shows the information given by the display. A virtual tunnel guides the operator to the part needed to be picked. Once the operator localizes it, a camera reads the barcode and the display lights the barcode indicating how many parts have to be picked; in this example, one part.

As in the other methods mentioned, the operator works with free hands and he does not need to waste time consulting other information, which reduce the final cost of the mathematical model by reducing the searching time.

Figure 3.4: *Display used in a pick-to-vision system*

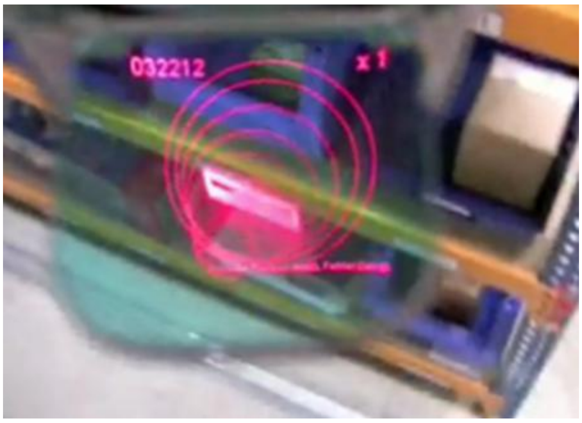

Figure 3.3: *Information given by the display*

3.1.2 Outsourcing

Figure 1.4 shows the three different candidates to realize the kitting activities. In the one hand, it can be made by the company supplied (in-house kitting). On the other hand the supplier can be the responsible to realize it. Finally, the third way to realize the kits is outsourcing it. A third party logistic (3PL), which is a company specialized in logistics, is contracted in order to realize the kits.

In the Ph.D. realized by Dr. Veronique Limère, is only considered the in-house kitting as a possibility to realize the kits. In this section we want to consider the possibility of outsourcing, where parts are kitted by a third party logistic (3PL). In order to be able to study if outsourcing could be more economical than in-house kitting, we have to analyse which differences are between this two methods. First of all, if the kit assembly activities are outsourced, the average time to search the required part is reduced due the fact that it is done by a company specialized in logistics. Moreover, the cost of labour (per hour) of an operator is lower than in industry. However, it has to be taken into account the cost of transport from the external company to the industry. Table 3.1 resumes the advantages and disadvantages of outsourcing. Finally, as the parts are moved from the warehouses to the 3PL, there is no cost of replenish de supermarket.

Outsourcing	In-house kitting
(+) Reduction of searching time in the supermarket.	(-) Longer searching time
(+) Lower cost the operator labour	(-) Higher cost of the operator labour
(-)Cost of transport from the factory to the 3PL and vice versa.	(+) No external transport
(+) No replenishment of the supermarket	(-) Cost of replenish the supermarket

Table 3.1*: Outsourcing vs. In-house kitting. Advantages and Disadvantages*

3.1.3 New transport equipment

Tugger trains and forklift truck are the responsible of the internal transport. Until this moment we assume that a specific tugger train and forklift truck is used. The tugger train doing the milk run tour has a velocity of 2412 m/h (V^b and V^k) and it is able to transport 60 boxes per tour (A^b) in case it is transporting boxes and 70 kits per tour (A^k) if it is transporting kits. The forklift truck has a velocity of 2880 m/h (V^p) and it transport the pallets one by one.

In this thesis, we want to consider the possibility of using different types of tugger trains and forklifts to analyse which characteristics are the most rentable. We will consider that the company uses shorter tugger trains, so the velocity will be higher and time of transport will be diminished and consequently, the cost of transport will diminishes too. However, it will have less capacity to carry the boxes or kits, which constitutes an increase of the cost on peak moments.

The milk run tours take places on constant interval times and the demand varies depending on the moment, so tugger trains are not always fully utilized. On average, the capacity utilization for box (ρ^b) is supposed to be 50% and 80% for kits (ρ^k). We assume that these two parameters remain constant. It is considered like this because in one hand, the fact that the tugger train is shorter would make increase the percentage of capacity occupied. However, on the other hand, the fact that the tugger train is faster suppose that it is able to complete more milk run tours in the same time and it would diminish the percentage of capacity occupied.

We will also consider the possibility that the company invests in faster forklifts.

3.1.4 Kits Batch size

On the transport from the supermarket to the assembly line, kits of the same type are assumed to be assembled in batches of five because five kits fit on one rack (Limère, 2011). However it could happen that sometimes racks cannot be full. In this thesis we will consider the kit batch size is not always 5 kits. It will have an impact in the kitting cost because it has an effect on the number of units of part *i* that will on average be picked in one pick (θ_{is}). However it just has an effect on it if two conditions are satisfied. As it is presented in Chapter 2, the opportunity for batch picking part *i* to assemble in a kit for station *s* is defined by:

$$\theta_{is} = \max\left\{\min\left(\frac{q_{is}}{d}B^k, a_i\right), \frac{m_{is}}{\lceil m_{is}/a_i \rceil}\right\} \tag{3.1}$$

With,

q_{is} Yearly usage of part i at station s

d Yearly demand for end product (= vehicle)

B^k Batch size for assembling kits

a_i Maximum number of units of a part i in one pick due to physical characteristics (weight, volume) of part i

m_{is} Number of units of part i assembled per vehicle (if the specific variant part i is used) at station s

When the following conditions are satisfied, the variance of the batch size has an effect on the kitting cost:

$$\frac{q_{is}}{d} * B^k < a_i \tag{3.2}$$

$$\frac{q_{is}}{d} * B^k > \frac{m_{is}}{\lceil m_{is}/a_i \rceil} \tag{3.3}$$

We will give an example to understand it. We suppose that one part is kitted but the batch size varies from 3 kits per rack to 10 kits per rack (we will not consider this dimensions on the study but they are useful to explain the impact of the kit batch size in the kitting cost). The other parameters (q_{is}, d, a_i, m_{is}) will be constant because we are working with the same part.

The following values are used in this example:

$\frac{q_{is}}{d}$=50%

$a_i = 4$

$m_{is} = 5$

Batch size (kits)	3	4	5	6	7	8	9	10
$\frac{q_{is}}{d} * B^k$	1,5	2	2,5	3	3,5	4	4,5	5
a_i	4	4	4	4	4	4	4	4
$\frac{m_{is}}{m_{is}/a_i}$	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
θ_{is}	2,5	2,5	2,5	3	3,5	4	4	4
Satisfies conditions?	NO	NO	NO	YES	YES	NO	NO	NO
Kitting cost	50,80	50,80	50,80	42,33	36,29	31,75	31,75	31,75

Table 3.2: *Example of kitting a particular part depending on the batch size.*

As we can see in the results shown in table 3.2 and can be appreciated in figure 3.5, there is a range of values where the opportunity for batch for a particular part remains constant and, consequently, as we can see in figure 3.6, the kitting cost for that part also is constant in certain values. This range corresponds to those values that do not satisfy at least one of the conditions 3.2 and 3.3 mentioned before, which corresponds to a batch size of 8, 9 and 10 kits and also a batch size ok 3, 4 and 5 kits. This fact demonstrates that the batch size value only affects to the cost of kit a part if condition 3.2 and condition 3.3 are satisfied.

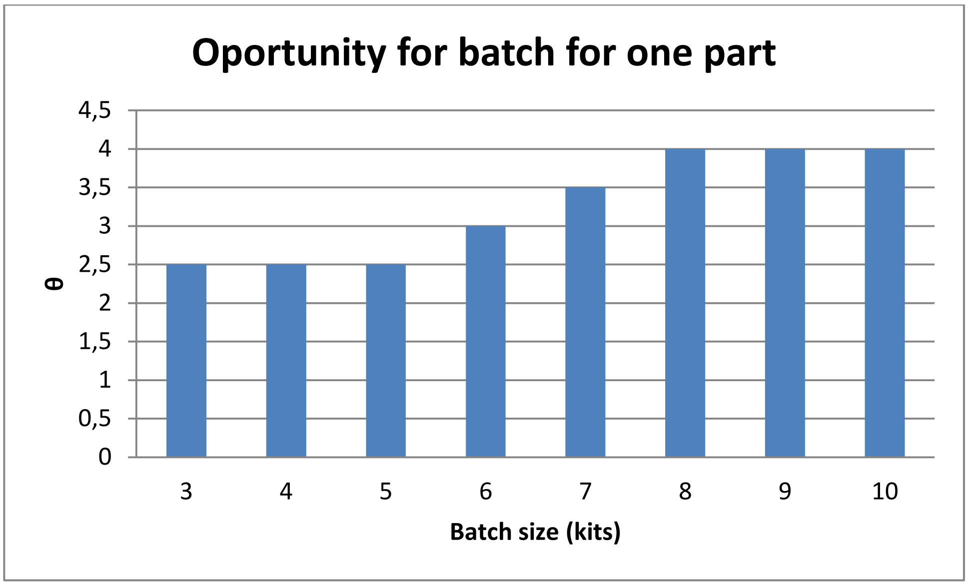

Figure 3.5: *θ value for a particular part depending on the batch size.*

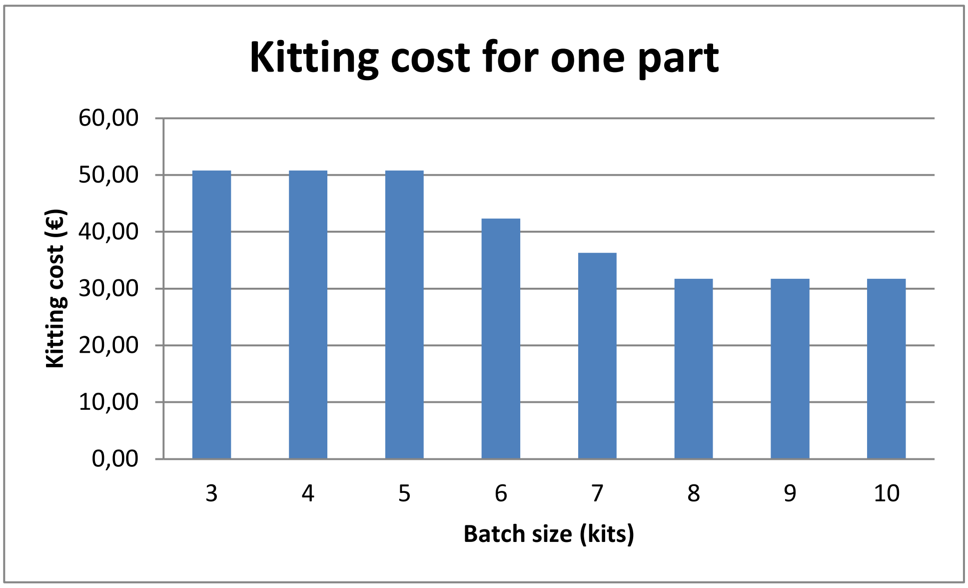

Figure 3.6: *Kitting cost for a particular part depending on the batch size.*

3.1.5 Length available at the workstation

The available length along a workstation is a restrictive parameter. In this thesis we want to study how it affects at the final cost. It is easy to understand that as a restrictive parameter, when the available length along the workstation is higher, the cost will be lower.

Normally, factories do not use the whole length of the workstation because a part of it is reserved for being used in special circumstances. We are going to study how it affects to the final cost and to the percentage of parts kitted if the company uses at least some of the space that is not being used.

3.1.6 Total volume of a kit

We are also going to consider the variance of the kits dimension. As a restrictive parameter, if the available volume increases, the final cost will diminish and vice versa.

In this thesis we want to consider that volume available in kits increases to see if it will suppose a significant reduction of the cost.

3.1.7 Other possible modifications

It could happen that companies realize changes in the disposition of the stores like the warehouses and the supermarket. If it happens the distance that the tugger train walk to realize the milk run tour and also the distance walked by the forklift from the warehouse to a station will vary. It can either increase or decrease depending on the new disposition. Moreover, because of the variance of the distance between the supermarket and the warehouses, the cost of replenishment of the supermarket will also vary according to the variance of the value that the constants of replenishment (R^b and R^p) acquire. For this reason we will consider the possibility that the mentioned parameters (D_s^p, D^k, D^b R^b and R^p) vary. We will also give the opportunity to vary the maximum weight per kit. The labour cost of an operator (per hour) could also vary depending on the company.

3.2 Changes on the mathematical model

To be able to consider all the possibilities explained on the section 3.1 of this chapter we have had to define new parameters and add them in the mathematical model. We also have defined a new cost.

3.2.1 Operator logistic cost

As it has been mentioned before, in this thesis we are considering the possibility that a Third Party Logistic realizes the kitting activity. As is it explained in Table 3.1 one of the differences between outsourcing and in-house kitting was the cost of labour of an operator. Therefore, to differentiate between the labour cost of a factory operator and the labour cost of an operator of the external company that realizes the kitting activities, a new parameter has been defined. Moreover the parameter that indicates the cost of labour of an operator (*OC*) has been redefined:

OC (€/h): Cost of labour (per hour) of an operator working in the factory.

OCL (€/h): Cost of labour (per hour) of an operator working in an external company.

Thereby, all the formulas of the costs mentioned in Chapter 2 remain the same excepting formula 2.11, which corresponds to the kitting cost. The new formula is:

$$C_{kit} = OCL \sum_{s \in S} \sum_{i \in I_s} \left[(1 - x_{is})\, q_{is} \frac{\left(2\Delta_{is}^{k} / OV \right) + \tau^{k}}{\theta_{is}} \right] \tag{3.1}$$

In which OCL is the parameter already defined and the other parameters and variables are the same that defined in Chapter 2.

3.2.2 Available length corrector factor

We would like to consider that the available length along the work station is not a constant value and we are going to study how it affects to the final results. In the Ph.D realized by dr. Veronique Limère it is supposed that the available length is 8 metres. In this thesis, in order to obtain different values, we have defined a correction factor which is multiplied per the available length supposed (8 meters).

L^{fact} *Available length corrector factor.*

Thereby, the restriction referred to the available space is modified:

$$N_s^b L^b + \sum_{i \in I_s \cap I_p} x_{is} L^p + K_s L^k \leq L_s L^{fact} \qquad \forall s \in S \qquad (3.2)$$

3.2.3 Available kit volume corrector factor

To be able to analyse which would be the reduction of the cost if available kit volume increases, we have defined a correction factor which is included in the restriction related with the kits volume

V^{fact} *Available volume correction factor.*

Thereby, the restriction is modified:

$$K_s \geq \sum_{i \in I_s} \left[(1 - x_{is}) \left(\frac{m_{is}/v_i}{|V_i|} \right) \right] / V^{fact} \qquad \forall s \in S \qquad (3.3)$$

As the kit can contain less, we also have to consider that the size of the kit is smaller. Therefore, we should also reduce the space it takes at the line (L^k). Thereby, the restriction of the space available is modified:

$$N_s^b L^b + \sum_{i \in I_s \cap I_p} x_{is} L^p + K_s L^k * V^{fact} \leq L_s \qquad \forall s \in S \tag{3.4}$$

3.2.4 Cost of replenishment of the 3PL

We have included a new cost in order to satisfy the transport between the factory and the 3PL and vice versa if the company is outsourcing the realization of the kits. If not, this cost will be zero. This cost, C_{3PL}, is determined by a constant cost for the replenishment of one box or pallet (we consider it is the same cost) defined as:

R^{3PL}(€) Constant cost for the replenishment of one box or pallet in the 3PL.

The cost of replenishment can then be defined as:

$$C_{3PL} = \sum_{s \in S} \sum_{i \in I_s} 2 \left[(1 - x_{is}) \frac{q_{is}}{n_i} R^{3PL} \right] \tag{3.5}$$

3.2.5 Forklift distance corrector factor

As have the possibility to modify the distance that the forklift has to realize we have defined a factor, which is multiplying with de this distance in the cost of transport of pallets.

Dp^{fact} Corrector factor of the distance between the pallet warehouse and workstation s

$$C_{tpt}^{pallet} = OC \sum_{s \in S} \sum_{i \in I_s \cap I_p} x_{is} \left(2 \frac{D_s^p}{V^p} * Dp^{fact} * \frac{q_{is}}{n_i} \right) \tag{3.6}$$

3.3 Conclusions

Some real situations are now considered and the model is now prepared to take into account the possibilities mentioned during the chapter. Therefore, companies that are interested on implant some of this considerations can now use the model. However, a work tool is needed to be developed in order to study the impact of these new considerations. In Chapter 4 we present this tool.

Chapter 4

Company work tool

In this chapter we present a tool that has been developed with the objective to be used by companies. It has been created in order to satisfy and analyse all the considerations exposed in Chapter 3. The target of this tool, a part of giving new possibilities to study that will be mentioned during this chapter, is to make the work more comfortable to the employee using it. For this reason, we have chosen Excel to be the software of our tool, as it is common software to be used in companies. To make it possible, we have linked the Excel file with the Run file of the mathematical model developed by dr. Veronique Limère, which is implemented using the modelling language AMPL 12.2 and solved with CPLEX 12.2.

Thereby, the employee introduces the parameter value needed to be studied in the excel file and, after executing the model, results are obtained on it.

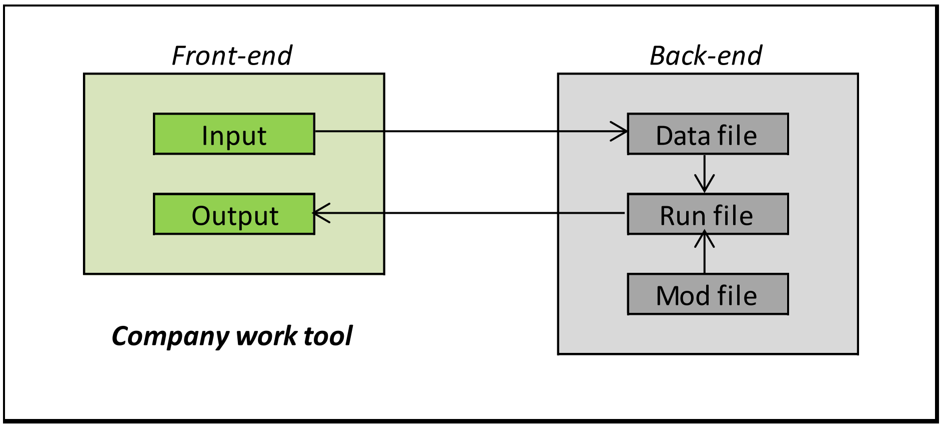

Figure 4.1: *Link between the Company work tool and the model*

In section 4.1 it is explained what the tool allows us to do and in section 4.2 we present the modifications realized in the files of the mathematical model. Finally, section 4.3 explains the steps to follow to use the tool.

4.1 Front-end: Excel file developed

In section 4.1.1 it is explained the structure of the files. In section 4.1.2 an explication of how the employee has to introduce the values of the parameters that the company wants to consider is given. Section 4.1.3 explains how the results are obtained.

4.1.1 Structure of the files

To develop our tool we have created two new excel files: The ACTIVATE_Company_Tool file and the COMPANY_TOOL file.

The first one is the one where the results obtained from executing the model are displayed. It is only there to let the COMPANY_TOOL file read the results obtained from it. It is needed because as the results comes from another program, excel does not allows to write on this file. It is just an "only read" file.

The second file, the COMPANY_TOOL, is the main part of the tool developed. On it we can find five sheets: COMPANY PARAMETERS, OBTAIN RESULTS, GRAPHS, txt and Values.

The first three sheets, which their names are written in capital letters, are the ones that the employee has to use. The two others (txt and Values) are information required but not to be modified.

In the 'COMPANY PARAMETERS' sheet we find the template that the employee has to fill in. Moreover there is a table where we obtain all the combinations of the parameter values, once we have filled the template. Finally, we also have a table that is needed only to calculate the values for all the possible combinations. These are intermediate results and do not have to be modified and do not give information. In next section the template is presented and an example of how to use it is given.

In the 'OBTAINRESULTS' sheet, we first find the lists of results obtained. Secondly there is the parameter's combination and the table of results. Finally it gives information about the feasibility of the solution.

The 'GRAPHS' sheet shows the results in graphs.

In the txt sheet there are copied the list of results obtained in the ACTIVATE_Company_Tool.

In the 'Values' sheet, the list of the 'txt' sheet is manipulated in order to transform the text in numerical values. To achieve it we have used the following excel formulas:

Formula	**Description**
=LEFT(txt!A1;SEARCH("=";txt!A1;1))	It writes the part of the text that is in the left of the equal (=). In this case it writes the name of the result.
=RIGHT(txt!A1;LEN(txt!A1)-SEARCH("=";txt!A1;1))	It writes the part of the text that is in the right of the equal (=). In this case it writes the value of the result
=SUBSTITUTE(B1;".";",";1)	It substitutes dots per comas
=VALUE(C1)	It convert a text in value

Table 4.1: *Formulas for obtaining the values of the results*

4.1.2 Input: Template

The input of the data in this tool is realized by filling a template according to the values needed to study in the different parameters. The parameters included in the template of the tool developed are:

OPERARI_COST	*OC (€/h)*
OPERARI_COST_LOGISTIC	*OCL (€/h)*
MAXIMUM_WEIGHT	w^k *(kg)*
MILK_RUN_TOUR_KIT	D^k *(m)*
MILK_RUN_TOUR_BOX	D^b *(m)*
SEARCH_TIME_KIT	τ^k *(s)*
SEARCH_TIME_BULK	τ^{bulk} *(s)*
BATCH_SIZE	B^k *(kits)*
LENGTH_FACTOR	L^{fact} *(-)*
TRANSPORT_VELOCITY_BOX	V^b *(m/h)*
TRANSPORT_VELOCITY_PALLET	V^p *(m/h)*
TRANSPORT_VELOCITY_KIT	V^k *(m/h)*
CAPACITY_MRT_BOX	A^b *(boxes)*
CAPACITY_MRT_KIT	A^k *(kits)*
CONSTANT_REPLENISH_BOX	R^b*(€)*
CONSTANT_REPLENISH_PALLET	R^p*(€)*
VOLUME_FACTOR	V^{fact} *(-)*
DISTANCE_PALLET_FACTOR	Dp^{fact} *(-)*
CONSTANT_REPLENISH_3PL	R^{3PL}*(€)*

The employee has to open the tool which is called COMPANY_TOOL.xls and fill the template. In order to analyse not only a unique result but also the differences in the result needed to be obtained depending on the variance of the parameter, the template is created as it is presented in table 4.2. As it can be appreciated, the employee has to fill three cells per each of the parameters in the template:

- The lower value, which corresponds to the lowest value wanted to be studied of that parameter (Column A in the excel file).
- The upper value, which corresponds to de highest value wanted to be studied of that parameter (Column B in the excel file).
- The step value, which corresponds to the difference between two consecutives values studied (Column C in the excel file).

Thereby, the tool allows us to give as many values as we want in each of the parameters included on the template. In the example of the table 4.2 we can appreciate that the OPERARI_COST parameter has a lower value of 30€/h and an upper value of 50€/h with a step value of 10€/h. It means that we will obtain results when the labour cost of an operator is 30€/h, 40€/h and 50€/h. We can also see in the table 4.2 that the OPERARI_COST_LOGISTIC has a lower value of 20€/h, an upper value of 40€/h and a step value of 10€/h. It means that we will obtain results when the labour cost of an operator working in the 3PL is 20€/h, 30€/h and 40€/h.

Moreover, once we have introduced the values, the template informs us about the number of groups of results we are going to obtain per each of the parameters and the number of groups of results we are going to obtain in total. As we can see in the example of the table 4.2 (in the fifth column), we are going to obtain 3 groups of results because of the OPERARI COST (which corresponds to values of 30€/h, 40€/h and 50€/h, as mentioned before) and 3 more groups of results because of the OPERARI COST LOGISTICS (values of 20€/h, 30€/h and 40€/h). In total, 9 groups of results are going to be obtained. To obtain the number of results per parameter and the total number of results we have used the excel formulas of the presented in table 4.3.

TEMPLATE

LOWER VALUE	UPPER VALUE	STEP VALUE	units	# of results	# total results
OPERARI_COST_lower	OPERARI_COST_upper	OPERARI_COST_step			9
30	50	10	€/h	3	
OPERARI_COST_LOGISTIC_lower	OPERARI_COST_LOGISTIC_upper	OPERARI_COST_LOGISTIC_step			
20	40	10	€/h	3	
MAXIMUM_WEIGHT_lower	MAXIMUM_WEIGHT_upper	MAXIMUM_WEIGHT_step			
30	30	2	Kg	1	
MILK_RUN_TOUR_KIT_lower	MILK_RUN_TOUR_KIT_upper	MILK_RUN_TOUR_KIT_step			
1640	1640	100	m	1	
MILK_RUN_TOUR_BOX_lower	MILK_RUN_TOUR_BOX_upper	MILK_RUN_TOUR_BOX_step			
1640	1640	100	m	1	
SEARCH_TIME_KIT_lower	SEARCH_TIME_KIT_upper	SEARCH_TIME_KIT_step			
1,08	1,08	0,01	s	1	
SEARCH_TIME_BULK_lower	SEARCH_TIME_BULK_upper	SEARCH_TIME_BULK_step			
1,08	1,08	0,01	s	1	
BATCH_SIZE_lower	BATCH_SIZE_upper	BATCH_SIZE_step			
5	5	1	kit	1	
LENGTH_FACTOR_lower	LENGTH_FACTOR_upper	LENGTH_FACTOR_step			
1	1	0,03125	-	1	
TRANSPORT_VELOCITY_BOX_lower	TRANSPORT_VELOCITY_BOX_upper	TRANSPORT_VELOCITY_BOX_step			
2412	2412	50	m/h	1	
TRANSPORT_VELOCITY_PALLET_lower	TRANSPORT_VELOCITY_PALLET_upper	TRANSPORT_VELOCITY_PALLET_step			
2880	2880	50	m/h	1	
TRANSPORT_VELOCITY_KIT_lower	TRANSPORT_VELOCITY_KIT_upper	TRANSPORT_VELOCITY_KIT_step			
2412	2412	50	m/h	1	
CAPACITY_MRT_BOX_lower	CAPACITY_MRT_BOX_upper	CAPACITY_MRT_BOX_step			
60	60	10	box	1	
CAPACITY_MRT_KIT_lower	CAPACITY_MRT_KIT_upper	CAPACITY_MRT_KIT_step			
70	70	10	kit	1	
CONSTANT_REPLENISH_BOX_lower	CONSTANT_REPLENISH_BOX_upper	CONSTANT_REPLENISH_BOX_step			
0,2	0,2	0,2	€	1	
CONSTANT_REPLENISH_PALLET_lower	CONSTANT_REPLENISH_PALLET_upper	CONSTANT_REPLENISH_PALLET_step			
1,2	1,2	0,6	€	1	
VOLUME_FACTOR_lower	VOLUME_FACTOR_upper	VOLUME_FACTOR_step			
1	1	0,1	-	1	
DISTANCE_PALLET_FACTOR_lower	DISTANCE_PALLET_FACTOR_upper	DISTANCE_PALLET_FACTOR_step			
1	1	0,3	-	1	
CONSTANT_REPLENISH_3PL_lower	CONSTANT_REPLENISH_3PL_upper	CONSTANT_REPLENISH_3PL_step			
0	0	0,1		1	

Table 4.2: *Example of the template used in the work tool developed.*

Name	Formula	Description
Number of results per parameter	=INT((B7-A7)/C7)+1	It gives the integer number of the difference between the lower and the upper value divided per the step value plus one
Total number of results	=PRODUCT(E7;E10;E13;E16;E19;E22;E25;E28;E31;E34;E37;E40;E43;E46;E49;E52;E55;E58;E61)	It multiplies the number of results per parameter of each parameter.

Table 4.3: *Formulas for obtaining the number of results given per parameter and the total number of results.*

4.1.3 Output: Table of results and graphs

Once the parameters are introduced and the program has been run we obtain the results. The following concepts constitute the group of results:

Total cost	*(€)*
Cost to pick from a bulk	*(€)*
Cost to pick from a kit	*(€)*
Cost of transport the pallets	*(€)*
Cost of transport the boxes	*(€)*
Cost of transport the kits	*(€)*
Cost of kitting	*(€)*
Cost of replenishment of pallets	*(€)*
Cost of replenishment of boxes	*(€)*
Cost of replenishment the 3PL	*(€)*
Percentage of parts kitted	*(%)*
Parts bulked	*(units)*
Number of kits used	*(units)*

Each of the results mentioned are obtained for all of the combinations of the values of the different parameters. In the example of the Table 4.2 all of the parameters are fixed in a value (the lower and the upper value are the same) excepting the OPERARI_COST and the OPERARI_COST_LOGISTIC. The first one is taking three different values which are 30€/h, 40€/h and 50€/h while the second one is also taking three values which are 20€/h, 30€/h and 40€/h. Thereby we will obtain 9 groups of results. It is easy to understand that the number of results obtained per each type of output is the product of the number of values that each parameter takes. In this example, 3*3=9 group of results obtained. Table 4.5 shows the different combinations of the values of each parameter for the example given in table 4.2. The first group of results obtained will be the one that the OPERARI_COST is 30 €/h and the OPERARI_COST_LOGISTIC is 30€/h, the second group of results will be that one that the OPERARI_COST is 30 €/h and the OPERARI_COST_LOGISTIC is 40 €/h and so on. Table 4.6 is the table that we would obtain in the work tool developed if we are using the values of the table 4.2. To fill this table a macro has been developed and it is explained in section 4.1.3.1. As we can see, the tool colours the columns of the parameters that are giving more than one group of results.

After executing the model, all the results are obtained in the excel file called ACTIVATE_Company_Tool.xls. The COMPANY_TOOL.xls file obtains the values from it. To obtain the results in a table another macro is developed and it is explained in section 4.1.3.2. Table 4.4 shows the table of the results obtained with the parameter values of the example given in table 4.2

Once we have the results in a table we obtain it automatically in graphs. As number of results obtained varies, we have created “names” with the *name manager* option. In each name we have assigned a formula. We have used the function COUNTA and the function OFFSET to create it. Next, we have assigned each “name” to its graph. Therefore, the number of values that appears in the horizontal axis varies depending on the number of results obtained.

The function COUNTA counts how many cells are occupied by a number while OFFSET counts how many numbers we want to obtain. An example is given in figure 4.2.

TABLE OF RESULTS

Num.	Num of parts	Total Cost	Cost pick bulk	Cost pick kit	Cost transp pal	Cost transp box	Cost transp kit	Cost of kitting	Cost Repl Pal	Cost Repl box	Cost repl 3PL	Percentage of parts kitted	Number of parts bulked	Number of kits used
Num.	card(COMBI) =	Total_Cost =	Cost_pick_bulk =	Cost_pick_kit =	Cost_Transp_pal =	Cost_Transp_box =	Cost_Transp_kit =	Cost_Kitting =	Cost_Repl_pal =	Cost_Repl_box =	Cost_Repl_3pl =	(sum{(i,s) in COMBI} (1 - x[i,	sum{(i,s) in COMBI} x[i,s]	sum{s in S} K[s] =
1	1773	363994	96257,1	42739,4	58865,4	41772,7	70118,2	38881,8	5907,47	9451,77	0	0,560068	780	55
2	1773	382271	102889	38753,7	58569,4	44045,8	70118,2	53045,1	6066,66	8783,13	0	0,556684	786	55
3	1773	397938	123980	29330	58999,8	51836,7	65018,7	56242,6	6038,74	6491,47	0	0,517202	856	51
4	1773	464837	104609	70577,5	79340,4	37054,7	105390	48478,8	5822,57	13564,4	0	0,593345	721	62
5	1773	486627	130510	55545	78312,2	56608,5	93490,9	56918,5	5991,47	9250,67	0	0,558376	783	55
6	1773	504743	137014	51759,2	78092,5	58680,2	93490,9	70845,7	6066,66	8793,63	0	0,557248	785	55
7	1773	563991	124793	91641,7	98784,4	41893,2	135987	50688,7	5857,7	14345,4	0	0,595601	717	64
8	1773	588036	141155	82403,1	99351,4	49798,2	127488	69099,9	5791,11	12950,3	0	0,577552	749	60
9	1773	609194	168309	66529,2	97722	71894	116864	72789,4	6036,78	9050,64	0	0,55894	782	55

Table 4.4: *Computational results obtained with the parameters values of table 4.2.*

```
=OFFSET(OBTAINRESULTS!$AK$7;0;0;COUNTA(OBTAINRESULTS!$AK$7:$AK$5005);1)
```

Figure 4.2: *Formula created for obtain the results in the graphs*

The first value (OBTAINRESULTS!$AK$7) indicates the cell that we are making reference. The second value (0) indicates the number of rows we want to move to the right. The third one (0) indicates the number of columns we want to move down. The fourth one (COUNTA(OBTAINRESULTS!$AK$7:$AK$5005)) indicates the number of rows that we have to return. In this case, as we are using the function COUNTA, this number will be the number of cells occupied from cell AK7 to cell AK5005. Finally the last value (1) indicates the number of columns to return.

Finally, the tool informs about the feasibility of the solution. It could be that there is no feasible solution. It could happen for example if we reduce the length available along the station, because even if we kit everything for reducing the space needed at the border of the line, we could not have enough space. After experimenting many times with the tool, we have noticed that when a solution is unfeasible, we obtain that the cost of transporting kits is zero and, at the same time, the cost of picking from a kit is higher than zero, which is non-viable. In order to make that the work tool recognises unfeasible solutions and it can advise to the employee of this situation we have developed the formula presented in figure 4.3, which has the same meaning of the algorithm presented in figure 4.4.

```
=IF('COMPANY PARAMETERS'!H15=" ";" ";IF(AG7>0;IF(AJ7>0;"feasible";"UNFEASIBLE!!");IF(AJ7=0;"feasible";"UNFEASIBLE!!")))
```

Figure 4.3: *Formula for recognizing the feasibility of the results.*

```
Algorithm – Recognizing the feasibility
if all results are checked do
   Do not write anything
else
   if cost to pick from a kit>0 do
      if cost to transport a kit>0 do
         Write "feasible"
      else
         Write "UNFEASIBLE!!"
      end if
   else
      if cost to transport a kit=0 do
         Write "feasible"
      else
         Write "UNFEASIBLE!!"
      end if
   end if
end if
```

Figure 4.4: *Algorithm for recognizing the feasibility.*

		OPERARI_COST_LOGISTIC (€/h)		
		20	30	40
OPERARI_COST (€/h)	30	#1	#2	#3
	40	#4	#5	#6
	50	#7	#8	#9

Table 4.5: *Matrix of the combinations of the values that the different parameters take according to the example of the table 4.2.*

Parameter's values combinations

Obtain Combinations

#	OC	OCL	w^k	D^k	D^b	τ^k	τ^{bulk}	B^k	L^{fact}	V^b	V^p	V^k	A^b	A^k	R^b	R^p	V^{fact}	Dp^{fact}	R^{3PL}
Number of result	Operari Cost	Operari Cost Logistic	Maximum weight	Milk Run Tour Kit	Milk Run Tour Box	Search Time Kit	Search Time Bulk	Batch Size	Length Factor	Transport Velocity Box	Transport Velocity Pallet	Transport Velocity Kit	Capacity MRT Box	Capacity MRT Kit	Constant Replenish Box	Constant Replenish Pallet	Volume Factor	Distance Pallet Factor	Constant Replenish 3PL
1	30	20	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0
2	30	30	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0
3	30	40	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0
4	40	20	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0
5	40	30	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0
6	40	40	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0
7	50	20	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0
8	50	30	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0
9	50	40	30	1640	1640	1,08	1,08	5	1	2412	2880	2412	60	70	0,2	1,2	1	1	0

Table 4.6: *Combinations of the parameter values according to the example given in table 4.2.*

4.1.3.1 Macro for obtain parameter values combination

In order to obtain the value of the parameters for all the possible combinations in the right order according to the lower, upper and step values given to each parameter, we have developed a macro named OBTAINCOMBINATIONS. To execute it we have to click the OBTAIN COMBINATIONS button. Next, we have to introduce in the window that appears, the number of results we are obtaining. The macro creates a table with 19 columns (each one corresponds to a parameter) and the same number of rows that number of results is going to be obtained. Each column is filled with integer numbers depending on two values: The number of times to repeat the integer and the number of integers to use. Figure 4.5 gives an example.

Number of times to repeat the integer: 2 Number of integers to use: 4 Sequence obtained in this column with the macro: 0, 0, 1, 1, 2, 2, 3, 3

Figure 4.5: *Example of results obtained with the macro OBTAINCOMBINATIONS*

The sequence obtained with the macro is repeated as many times as needed in order to fill the number of rows needed.

The number of times to repeat is obtained by multiplying the results obtained per parameter of the previous parameters (the ones that are in the right of the parameter being studied in table 4.5). The number of integers to use is the same as the number of results obtained per the parameter being studied. If for example, the OPERARI_COST has a lower value of 30, an upper value of 50 and a step value of 10. We will obtain results when the OPERARI COST is 30, 40 and 50 (3 results obtained per this parameter), so the number of integers to use it will be 3 (integers 0,1 and 2).

As we have said, the macro gives integer numbers but does not gives the real values of the parameters. In order to obtain the real values of the parameters we have implemented a new function. An example is given in figure 4.6. It multiplies the values obtained with the macro per the step value and sums the lower value. Like this, in the first row of the table we will obtain the lower value plus zero times the step value. In the second one we will obtain the lower value plus one time the step value. In the third one we will obtain the lower value plus two times the step value. We will keep obtaining results until the row number becomes higher than the total number of results to obtain. Figure 4.7 shows the algorithm developed in order to obtain all the possible parameter's values combinations. It represents the combination of the results obtained by the macro and the formula of figure 4.6.

```
=SI($H15=" ";" ";$A$7+AC17*$C$7)
```

Figure 4.6: *Formula for obtaining the parameter values from the values obtained with the macro*

Where H15 is the cell which indicates the number of the combination, A7 correspond to the cell of the lower value, AC17 is the value obtained in the macro and C7 is the cell which contains the step value.

Algorithm-Obtain all parameters combinations

```
while there is new parameter do
    Write the lower parameter value
    if number of results ≤ #total results do
        if there is right parameter do
            while there is right parameter do
                if (#results right parameter>1) do
                    if right parameter value ≥ above right parameter value do
                        Write above parameter value
                    else
                        if (above parameter value + step parameter value) ≤ upper value do
                            Write (above parameter value + step parameter value)
                        else
                            Write lower parameter value
                        end if
                    end if
                else
                    Actualize right parameter value
                end if
            end while
        else
            if (above parameter value + step parameter value) ≤ upper value do
                Write (above parameter value + step parameter value)
            end if
        end if
    end if
    Actualize new parameter

end while
```

Figure 4.7: *Algorithm for obtaining all the parameters combination*

Table 4.7 is presented in order to understand the names defined in the algorithm.

Parameter's values combinations Obtain Combinations

#	OC	OCL	w^k	D^k	D^b	τ^k	τ^{bulk}	B^k	L^{fact}	V^b	V^p	V^k	A^b	A^k	R^b	R^p	V^{fact}	Dp^{fact}	R^{3PL}
Number of result	Operari Cost	Operari Cost Logistic	Maximum weight	Milk Run Tour Kit	Milk Run Tour Box	Search Time Kit	Search Time Bulk	Batch Size	Length Factor	Transport Velocity Box	Transport Velocity Pallet	Transport Velocity Kit	Capacity MRT Box	Capacity MRT Kit	Constant Replenish Box	Constant Replenish Pallet	Volume Factor	Distance Pallet Factor	Constant Replenish 3PL
1																			1
2																			
3																			
4											3	5	7						
5											2	4	6						
6																			
7																			
8																			
9																			

Table 4.7: *Explication of how the table is filled*

Number (1) indicates where the algorithm starts and the arrows indicate the order to fill. If (2) is the cell being studied by the algorithm, then (3) is the *above parameter value*, number (4) is the *right parameter value*, (5) is the *above right parameter value.* If the *right parameter value* is actualized, then, (6) becomes the *right parameter value* and (7) becomes the *above right parameter value*.

4.1.3.2 Macro to obtain the results

In order to obtain the results in columns we have developed a macro named OBTAINRESULTS. This macro places the results from the LIST OF RESULTS to the TABLE OF RESULTS. As each type of result is repeated every 23 cells the macro is ordered to actualize the row every 23 reads of values. It is activated with the OBTAIN

RESULTS button. Figure 4.8 shows the algorithm developed in order to obtain the results in the table.

Algorithm – Obtaining results in table

Row := 1
Read first result
While there are more results below to read **do**
  Column := 1
  While Column ≤ 23 **do**
    Write result in Position (Row, Column)
    Column := Column + 1
  End while
  Row := Row + 1
End while

Figure 4.8: *Algorithm for obtaining results in table*

4.2 Back-end: Model files

There are three files necessaries to execute de model: The model file, the data file and the run file.

In order to obtain all the result in the way explained in the previous section and to obtain them in the excel file we have modified the files of the mathematical model.

4.2.1 Model file: Defining the parameters of the template

The model file contains the mathematical model developed by dr. Veronique Limère which is constituted by the objective function, the constraints, the variables and the parameters. As we have created three new parameters for each of the parameters of the template (lower value, upper value and step value) we have defined them in the model file. Figure 4.9 shows an example.

```
param OPERARI_COST_lower;
param OPERARI_COST_upper;
param OPERARI_COST_step;
```

Figure 4.9: *Definition of the three parameters created in the template. OPERARI COST*

4.2.2 Data file: Reading the template

To make possible that the model runs with using the values we have created a link between the template filled by the employee and the model programmed. First of all we have named all the small tables created for each parameter of the template with the *name manager* option of excel. Table 4.8 shows the table for the OPERARI COST.

OPERARI_COST_lower	OPERARI_COST_upper	OPERARI_COST_step
20	30	5

Table 4.8: *Small table for the OPERARI COST named "OPERARI_COST":*

Secondly, we have ordered to the data file to read all these tables. For it, we have first defined the table by mentioning it with the name given with the *name manager* of excel software in order it can be read. Figure 4.10 shows an example of how to a table and how to order to read it.

```
table OPERARI_COST IN "ODBC" "COMPANY_TOOL.xls" "OPERARI_COST": [],
OPERARI_COST_lower, OPERARI_COST_upper, OPERARI_COST_step;

read table OPERARI_COST;
```

Figure 4.10: *Example of the definition of a table and the order to read it. OPERARI COST.*

As the run file receive the information from the data file and the model file, it is ready to obtain the results and write them in the excel file.

4.2.3 Run file: Algorithm designed and writing the output

In the run file we have first created sets for the 19 parameters of the template. Then, we have ordered them to takes as value all the values defined by the lower value, the upper value and the step value. Figure 4.11 shows an example.

```
set OPERARI_COST;
let OPERARI_COST := OPERARI_COST_lower..OPERARI_COST_upper by OPERARI_COST_step;
```

Figure 4.11: *Example of a creation of a set and the values that it takes. OPERARI COST.*

Next, we have developed a "for loop" for each of the parameters. Each loop has an auxiliary variable assigned and, at first, it takes the lower value of the parameter. After the loop has been run once the auxiliary variable value is actualized by adding the value of the step. If the auxiliary variable remains inside the interval defined by de lower and the upper value written in the excel file then, it lets to the parameter takes the value of the auxiliary variable. If not, this "for loop" is finished. In order to obtain all the results for all the possible combinations, each loop is inside another loop.

Moreover, a conditional condition has been created in order to differentiate between if the company is making in-house kitting or outsourcing. If it is in-house kitting, the parameter that corresponds to the operator cost of the external company (OCL) is taking the value of the parameter corresponding to the cost of the operator working in the factory (OC). However, if the company is outsourcing, it takes a different value.

Finally, we have ordered to the run file to display the results in the excel file. Figure 4.12 shows the algorithm developed.

Algorithm- Obtain results

```
Create sets for all the parameters
Assign each set values from the lower value to the upper value with a step value
 for operari cost  in OPERARI COST do
 OC:= operari cost
  for operari cost logistic  in OPERARI COST Logistic do
   if it is outsourcing do
    OCL:=operari cost logistic
    Continue
   if no then
    OCL:=operari cost
    Continue
   for maximum weight in MAXIMUM WEIGHT do
    w_k:=maximum weight
    for milk run tour kit in MILK RUN TOUR KIT do
     D_k:= milk run tour kit
     for milk run tour box in MILK RUN TOUR BOX do
      D_b:= milk run tour box
      for search time kit in SEARCH TIME KIT do
       ts_k:= search time kit
       for search time bulk in SEARCH TIME BULK do
        ts_b:= search time bulk
        for batch size in BATCH SIZE do
         B_k:= batch size
         for length factor in LENGTH FACTOR do
          L_fact:= length factor
          for transport velocity box in TRANSPORT VELOCITY BOX do
           V_b:= transport velocity box
           for transport velocity pallet in TRANSPORT VELOCITY PALLET do
           V_p:= transport velocity pallet
            for transport velocity kit in TRANSPORT VELOCITY KIT do
             V_k:= transport velocity kit
             for capacity MRT box in CAPACITY MRT BOX do
              A_b:= capacity MRT box
              for capacity MRT kit in CAPACITY MRT KIT do
               A_k:= capacity MRT kit
               for constant replenish box in CONSTANT REPLENISH BOX do
                R_b:= constant replenish box
                for constant replenish pallet in CONSTANT REPLENISH PALLET
               do
                 R_p:= constant replenish pallet
                 for volume factor in VOLUME FACTOR do
                  V_fact:= volume factor
                  for distance pallet factor in DISTANCE PALLET FACTOR do
```

```
                    Dp_fact:= distance pallet factor
                    for constant replenish 3pl in CONSTANT REPLENISH 3PL do
                     R_3pl := constant replenish 3pl
                     Display results
                    End for
                   End for
                  End for
                 End for
                End for
               End for
              End for
             End for
            End for
           End for
          End for
         End for
        End for
       End for
      End for
     End for
    End for
   End for
  End for
```

Figure 4.12: *Algorithm for obtaining the results*

4.3 Instructions to use it

For using the work tool you have to follow these instructions:

1. **Fill the template:** Open the COMPANY_TOOL.xls file and fill your template by giving a lower value, an upper value and a step value to each parameter.
2. **Obtain all the possible parameter's values combinations**: Push the OBTAIN COMBINATIONS button. It will appears a window with a message which says: "Introduce the number of results" as it shows figure 4.13. Write on the space available the total number of results (number that appears in cell F6). Press ENTER. You will obtain all the possible combinations of the parameters values.

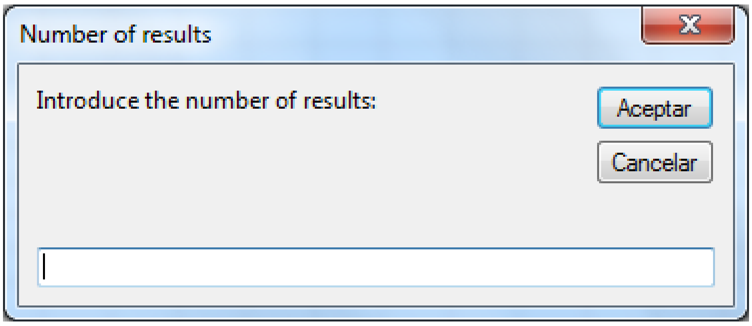

Figure 4.13: *Window to introduce the number of results.*

3. **Save the template:** Save and close the COMPANY_TOOL.xls file.
4. **Reset the input file:** Delete the Input.xls file, make a copy of the Input-Copy.xls file and rename it as Input.xls in order to reset it.
5. **Change the directory of the command window:** Open the command window and change the directory to the directory where you have the model files (write: cd *name_of_the_directory and press the ENTER button*)
6. **Choose AMPL:** Write: "ampl" and press the ENTER button in order to let it know that you are using AMPL language.
7. **Execute the model:** Write *include code_opt_lin.run* to execute the model in order to obtain the results.
8. **Activate the tool:** Open the ACTIVATE_Company_Tool.xls file. This file is where the de results are obtained and from where the COMPANY_TOOL.xls reads the results. Leave it open.
9. **Obtain results:** Open the COMPANY_TOOL.xls file, go to the OBTAINRESULTS sheet and push the OBTAIN RESULTS button.
10. **Obtain the results in graphs:** Open the GRAPHS sheet to check the results obtained in graphs.

Chapter 5

Computational results

In this chapter are presented all the computational results of the considerations made in Chapter 3. After having developed the work tool, we are going to use it to be able to analyse the impact that the possible changes in the supply chain has to the final cost. We will also analyse if it repercutes on the percentage of parts kitted. All the results are obtained from a particular input data. It means that, if another company is using the tool, results will vary according to their type of parts. In this particular case, if we consider that parameters are taking the values of the thesis “To kit or not to kit: Optimizing part feeding in the Automotive Assembly Industry” by dr. Veronique Limère (Table 5.1), the results obtained are the ones that are shown in table 5.2.

In the following sections, different studies are realized in order to analyse the impact of the parameter’s values in the costs and in the percentage of parts kitted.

Name	Short	Value
OPERARI COST	OC	30 €
OPERARI COST LOGISTIC	OCL	-
MAXIMUM WEIGHT	w^k	30 kg
MILK RUN TOUR KIT	D^k	1640 m
MILK RUN TOUR BOX	D^b	1640 m
SEARCH TIME KIT	τ^k	1,08 s
SEARCH TIME BULK	τ^{bulk}	1,08 s
BATCH SIZE	B^k	5 kits
LENGTH FACTOR	L^{fact}	1
TRANSPORT VELOCITY BOX	V^b	2412 m/h
TRANSPORT VELLOCITY PALLET	V^p	2880 m/h
TRANSPORT VELOCITY KIT	V^k	2412 m/h
CAPACITY MRT BOX	A^b	60 boxes
CAPACITY MRT KIT	A^k	70 kits
CONSTANT REPLENISH BOX	R^b	0,2
CONSTANT REPLENISH PALLET	R^p	1,2
VOLUME FATOR	V^{fact}	1
DISTANCE PALLET FACTOR	Dp^{fact}	1
CONSTANT REPLENISH 3PL	C^{3PL}	1

Table 5.1: *Initial values of the parameters*

Cost	Value
Total Cost	382271 €
Percentage of kitting	55,6684%
Pick from bulk at the line	102889 €
Pick from kit at the line	38753,7 €
Cost of transport Pallet	58569,4 €
Cost of transport Box	44045,8 €
Cost of transport Kit	70118,2 €
Picking Cost	53045,1 €
Cost Replenishment Pallet	6066,66 €
Cost Replenishment Box	8783,13 €

Table 5.2: *Costs values according to the parameters values of Table 5.1*

5.1 New picking technologies

According to the technologies mentioned in Chapter 3, we will assume two possibilities. Firstly, we will suppose that the company only applies this technology in the supermarket. Secondly, we will consider that this technology is also applied in the assembly line.

5.1.1 In the supermarket

We consider that searching times in the supermarket diminishes if new picking technologies are used. As there is not accurate information about which of the three technologies mentioned in chapter 3 (pick-by-voice, pick-by-light and pick-by-vision) reduces more the picking time, we assume that all three can reduce the same time. Figure 5.1 shows the evolution of the total cost with a value of searching time in the supermarket from 0.54 seconds to 1.08 seconds with a step of 0.01 seconds. As we can clearly appreciate the cost increases linearly as the value of the searching time increases. When searching time increases 0.1 seconds, the final cost increases 0.24%. If we suppose that using a new picking technology in the supermarket supposes to half the searching times, it means that the total cost decreases with 4938€, which constitutes a 1,29% in the reduction of the cost (from 382271€ to 377333€).

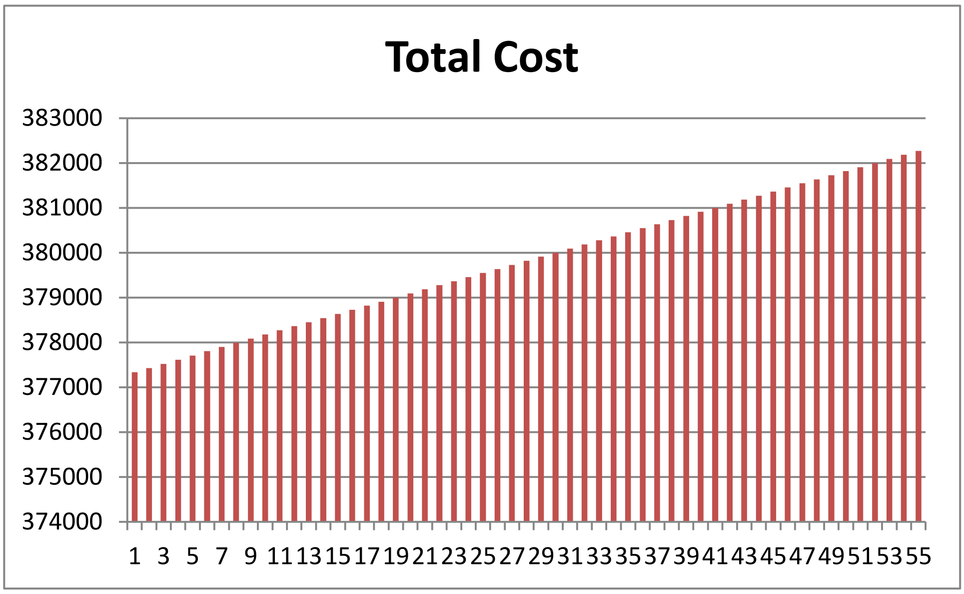

Figure 5.1: *Effect of the searching time in the supermarket in the total cost.*

While the searching time in the supermarket increases, the percentage of parts kitted obviously decreases since the time of preparing the kit is lower, which encourages kitting more parts. In figure 5.2 we can see 6 "steps of values" each step represents that one more part is being kitted. However, the number of kits used remains constant in 55 kits.

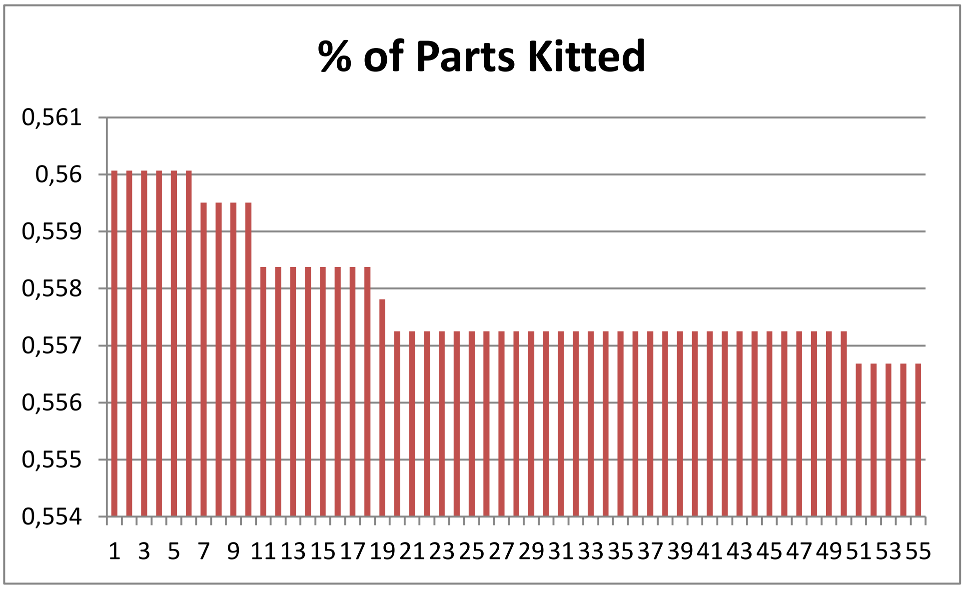

Figure 5.2: *Effect of the searching time in the supermarket in the percentage of parts kitted.*

The picking cost from kits in the assembly line increases when the searching time in the supermarket decreases due to the fact that more parts are kitted. At the same time, cost of pick from a bulk in the assembly line decreases because some parts that where in bulks are now in kits.

Kitting cost tends to decrease while searching time in the supermarket is reduced. It seems logical because if searching time decreases means that the time to kit diminishes. However, the fact that more parts are kitted makes this cost increase. The sum of the two factors leads to a decrease of the kitting cost because searching times has more effect in the cost. As we can see in Figure 5.3 cost of kitting decreases when searching time in the supermarket becomes lower. However, we can appreciate that in some points of the graph, there is a change in the slope because a new part is being kitted.

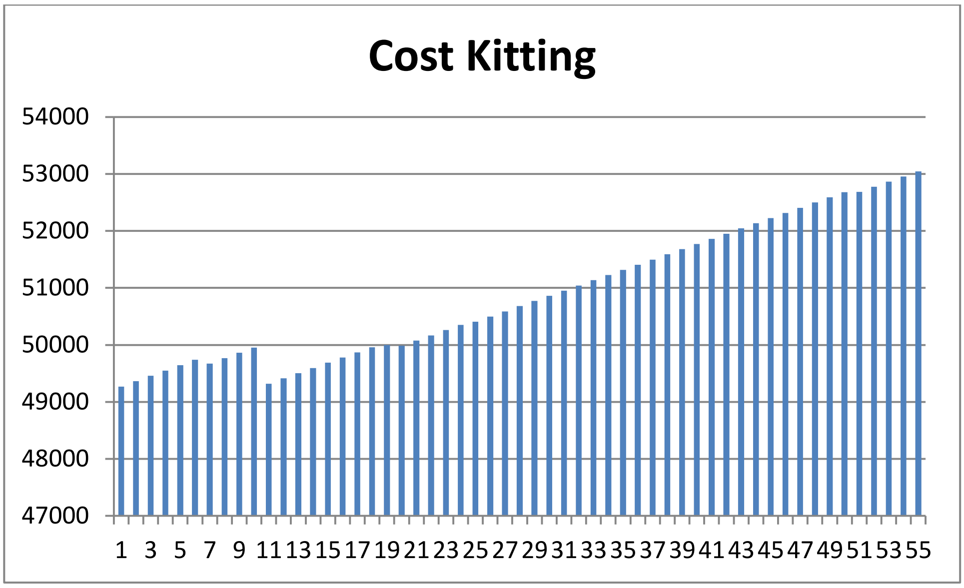

Figure 5.3: *Effect of the searching time in the supermarket on the cost of kitting.*

Kitting transport cost remains constant because the number of kits is the same. Either cost of replenishment of pallets or cost of replenishment of box varies every time there is a change in the percentage of parts kitted. When cost of replenishment of pallets increases, the cost of transport pallets to the line decreases because pallets that were transported to the line are now transported to the supermarket because that parts have now to be kitted and vice versa. The same happens with boxes.

5.1.2 In the supermarket and in the assembly line

In this case we are simulating that new technologies are already being used in the supermarket and we want to analyse the impact of implementing them in the assembly line. For this reason, the searching time in the supermarket has been fixed in 0,54 seconds and searching time in the bulks of the assembly line goes from 0,54 seconds to 1,08 in steps of 0,01 seconds.

Logically, the total cost decreases when we reduce the searching time (figure 5.4) because it reduces de cost to pick a part from a bulk. For this reason, the total cost of picking from a bulk tends to decrease when the searching time in bulks decreases. However, if there is a change in the number of parts kitted, then it could happen that the cost of picking from a bulk increases, as we can see in figure 5.5. We can notice that every time that it happens, there is a step in the percentage of kitting (figure 5.6). When the searching time change from 0,67 seconds to 0,66 seconds (point 14), the number of kits used diminishes in one (from 55 to 54). This fact leads to an important reduction in the percentage of parts kitted and, consequently the cost of pick from a kit at the line and the cost ok kitting diminishes, as less parts are kitted. For the same reason both constants of replenishment of the supermarket (pallets and boxes) also decreases in that point. Also because of the reduction in number of kits used, cost of transport kits diminishes and costs of transport pallets and boxes increase.

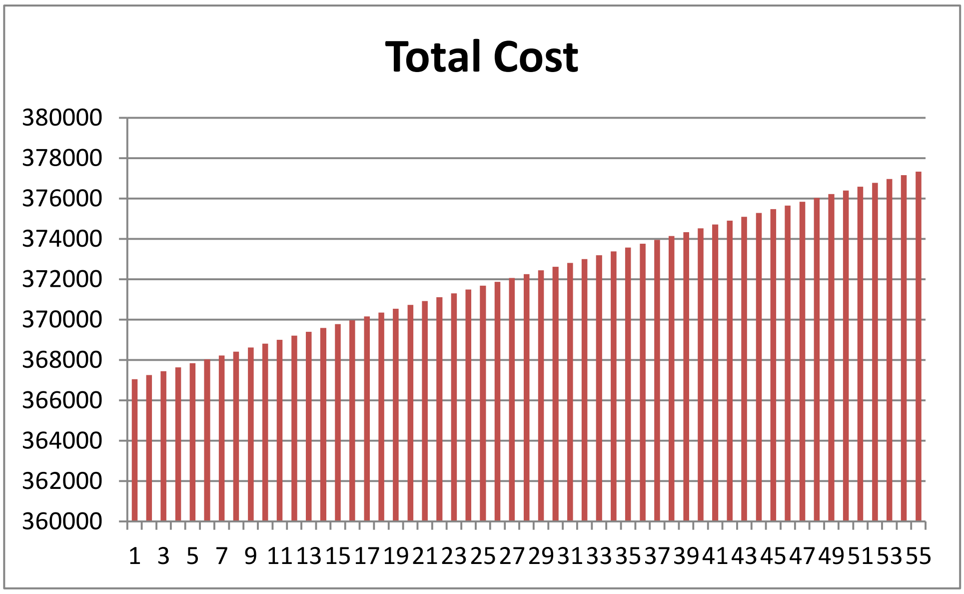

Figure 5.4: *Effect of the searching time at the line in the total cost.*

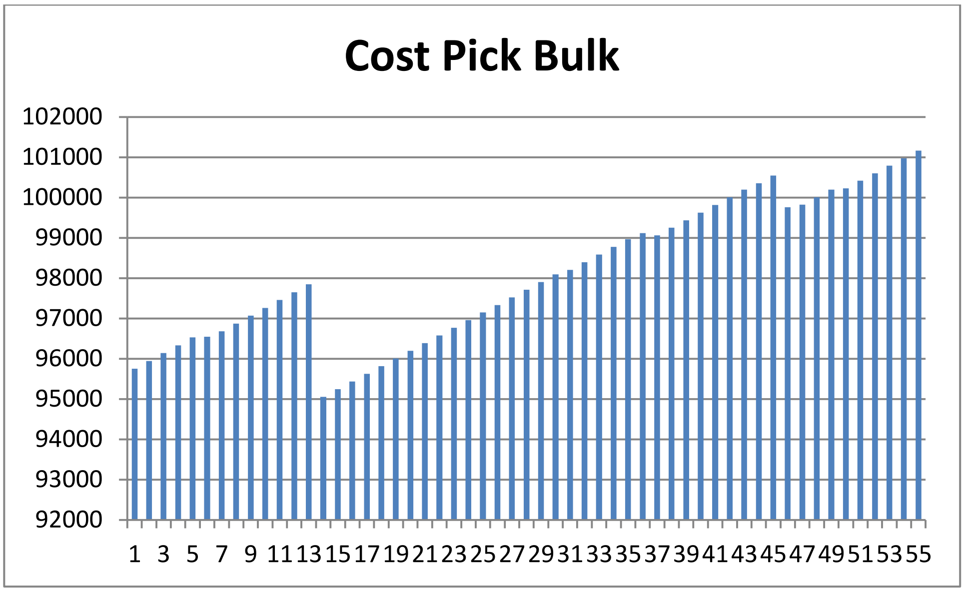

Figure 5.5: *Effect of the searching time at the line in the cost to pick from a bulk.*

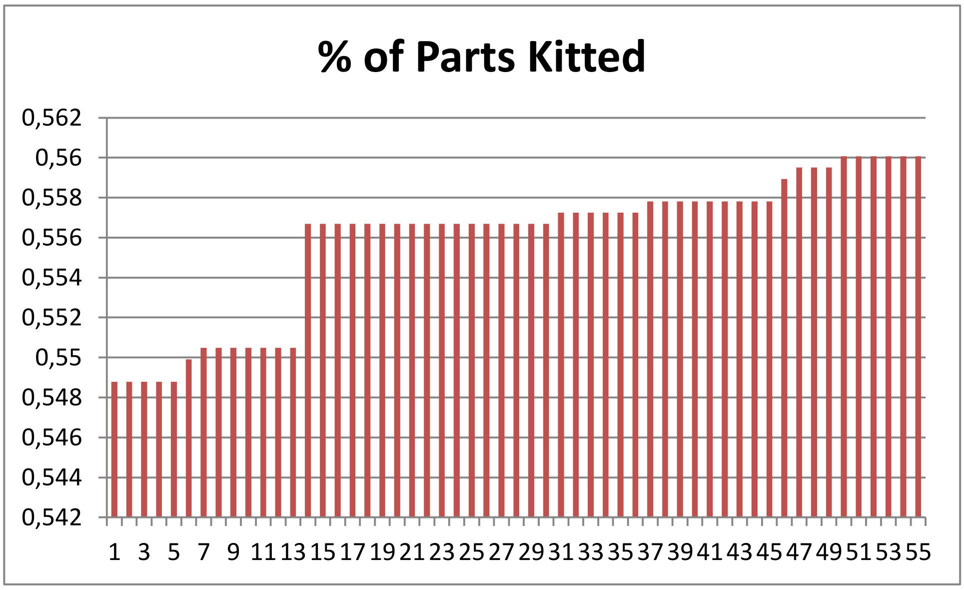

Figure 5.6: *Effect of the searching time at the line in the percentage of parts kitted.*

5.2 Outsourcing

We consider that for simulating an outsourcing situation with our model the labour cost of the operator working in the 3PL has to be lower. Moreover, searching time in the supermarket has also to be lower as the bests technologies are being used in the 3PL. Finally, we have to take into account the fact that parts needed to be kitted have to be transported from the factory to the 3PL and, once they are in kits, return them to the factory. It involves adding a new cost of external transport. However, as the supermarket has not to be replenished, costs of replenishment disappear.

First of all, we will study how the reduction of the labour cost of an operator affects and then the impact of de distance between the 3PL and the factory.

5.2.1 Impact of the labour cost

To simulate it we will study how the results varies if the value of the labour operator cost of the 3PL varies between 15 and 30 euros (this last value is the labour cost for an operator from the factory) with an interval between costs of 1€. Assuming that the 3PL, as a specialized in logistics, uses the best technologies (pick to voice, pick to light or pick to vision) we will half the value of the searching time in the supermarket (0.54 instead of 1.08 seconds).

Logically, the value of the total cost decreases when the labour cost of the operator of 3PL becomes lower, as we can see in figure 5.7. Considering that the labour cost in the 3PL is 20 €, the final cost is reduced in 17368€ (from 377333€ to 359965€, which supposes a reduction of 4,6%. Kitting cost also decreases because the cost to kit a part is directly proportional to the labour cost of the 3PL operator. However, as we can see in Figure 5.8 it is not linear. It is explained with Figure 5.9 in which we can notice that percentage of kitting increases if the operator cost working in the 3PL diminishes due to the fact that is cheaper to kit parts, so it makes kitting cost decrease. The cost of pick from a kit increases all the time as there are more parts kitted when the labour cost diminishes. Contrary, the cost of pick from a bulk decreases. The cost to transport kits increases as the number of kits used also tends to increase during the entire interval. The cost of transport boxes tends to decrease as more parts are kitted, which leads to an increase of the cost of replenishment of boxes. In the case of pallets, it tends to increase while the labour cost decreases from 30 to 20€, but from that point, it decreases again.

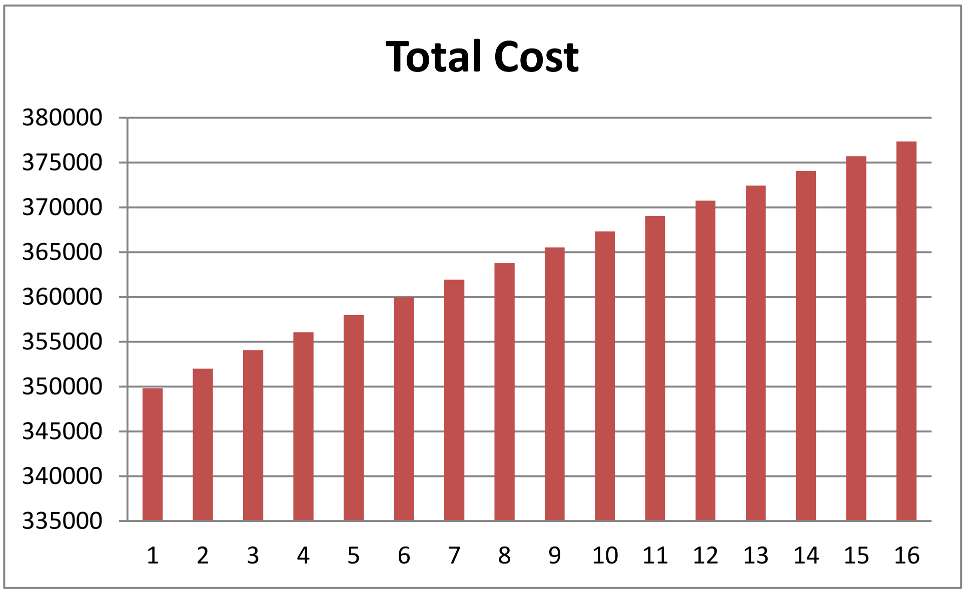

Figure 5.7: *Impact of the kitting labour cost of an operator in the total cost.*

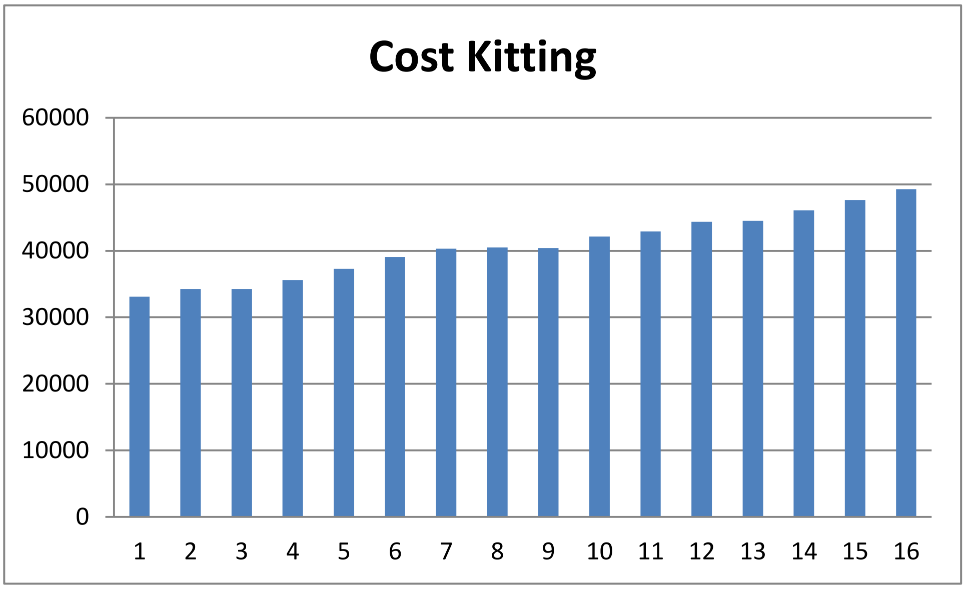

Figure 5.8: *Impact of the kitting labour cost of an operator in the kitting cost.*

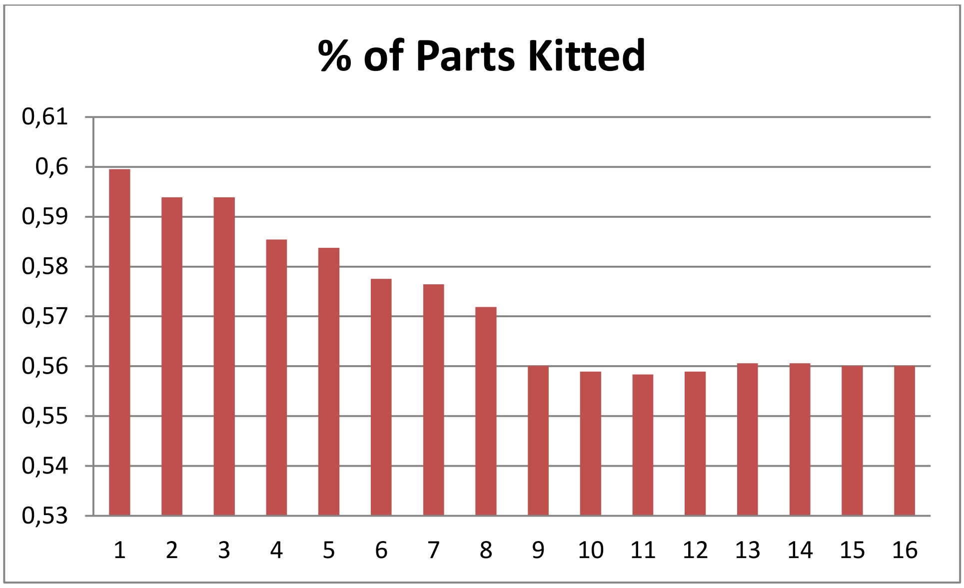

Figure 5.9: *Impact of the kitting labour cost of an operator in the percentage of parts kitted.*

5.2.2 Impact of the distance

In order to take into account the external transport, a new cost has been defined. This cost varies according to a constant (R^{3PL}), which represents the cost of transporting a part. The value of this cost depends on the velocity of the truck transporting the part, the labour cost of the operator driving the truck and de distance between the factory and the 3PL. Assuming that the labour cost is always the same and the truck always goes at the same velocity, the constant defined is directly proportional to the distance. To see the impact of the distance we have obtained the results given by the model for values of the constant between 0 and 1 in steps of 0,1. We suppose for an outsourcing situation a labour cost of an operator working in the 3PL of 20€/h and a searching time in the supermarket of 0.54s, as best technologies are being used. Moreover, both constants of replenishment of the supermarket (boxes and pallets) are zero because kits are not being made in the supermarket.

When the distance of the external transport increases, the percentage of kitting decreases (figure 5.9) as it suppose more expensive to realize this transport and it discourages to kit. The total cost obviously increases (figure 5.10) but it is not linear because, as less parts are being kitted, the external transport costs affects to less parts. For this reason, as the distance increases, the cost difference is smaller.

The picking cost from a kit decreases and the picking cost from a bulk increases also because of the reduction of parts kitted. For the same reason, the kitting cost also decreases as the distance becomes bigger. Costs of replenishments of the supermarket are zero because parts are carried directly from the warehouses to the 3PL. Instead of it, cost of replenishment of the 3PL appears, and as we can see in figure 5.13 it tends to increase with the distance but, as number of parts kitted decreases with the distance, it does not increase linearly. The cost of the internal transport of kits tends to increase as there are more kits to be transported. Cost of transport boxes decreases and cost of transport pallets increases, which probably means that most of parts now kitted come from boxes.

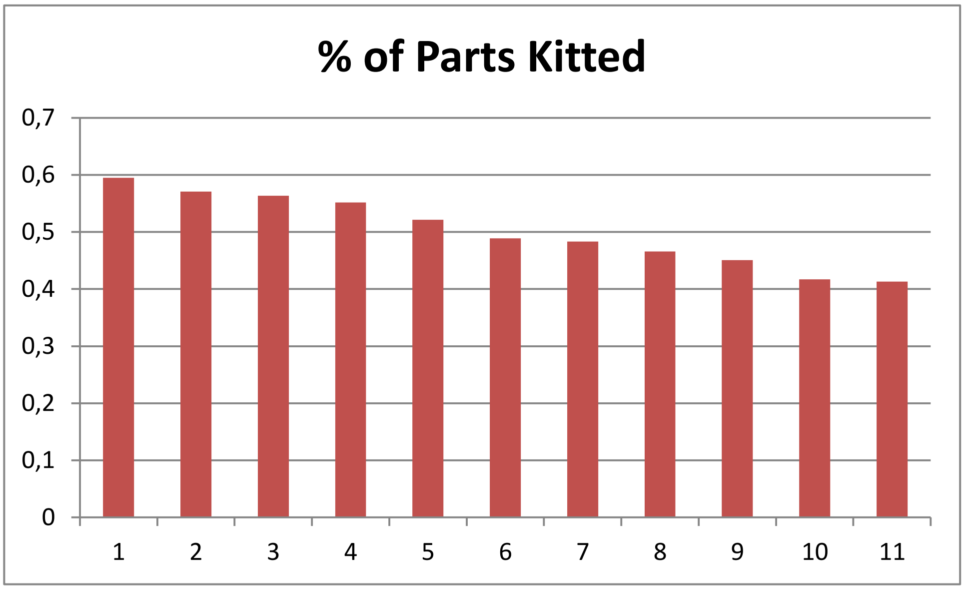

Figure 5.10: *Impact of the distance between the warehouse and the 3PL in the percentage of kitting.*

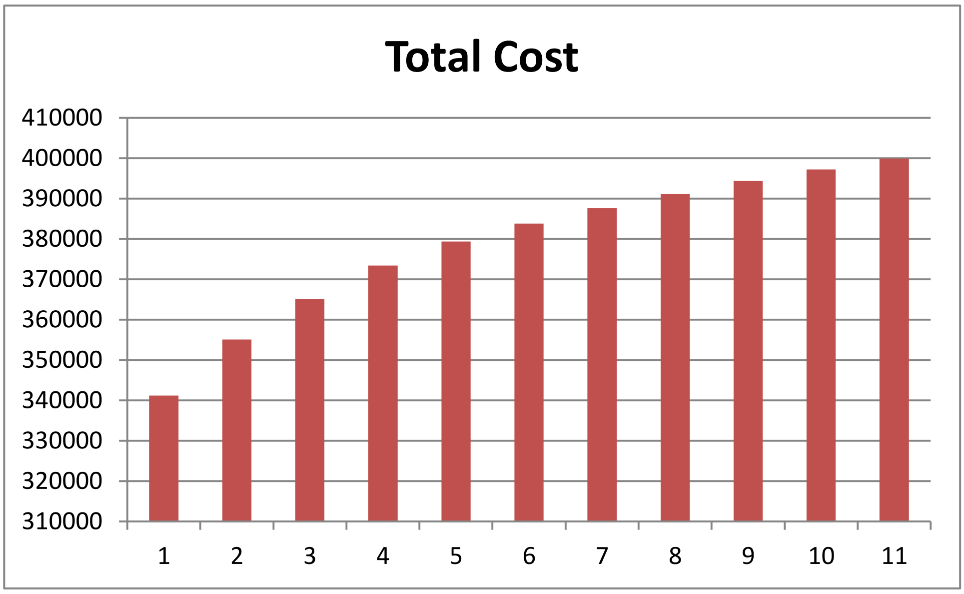

Figure 5.11: *Impact of the distance between the warehouse and the 3PL in the total cost.*

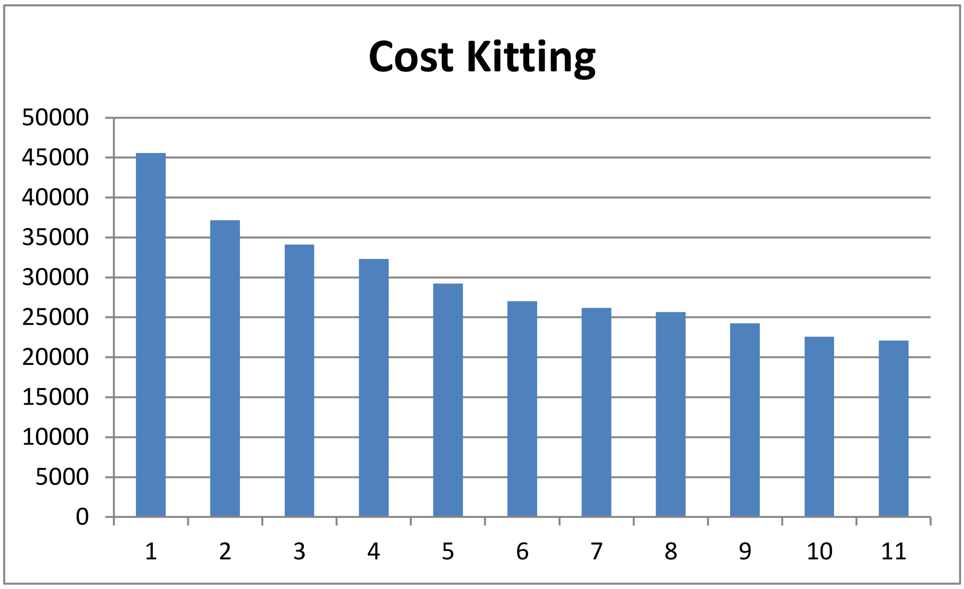

Figure 5.12: *Impact of the distance between the warehouse and the 3PL in the kitting cost.*

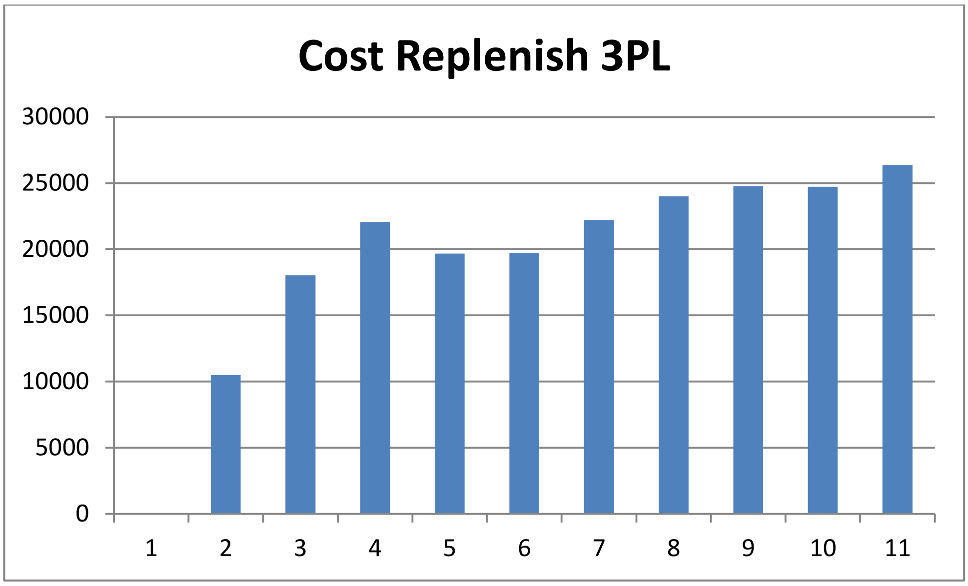

Figure 5.13: *Impact of the distance between the warehouse and the 3PL in the cost of replenish the 3PL.*

5.2.3 Comparison with the initial situation

If we compare outsourcing with in-house kitting, considering that parameters appropriated for each situations are those shown in table 5.3 and assuming that the 3PL company is really close from the factory (R^{3PL}=0) we obtain the results shown in table 5.4.

Parameter	In-house kitting	Outsourcing
OCL	30	20
τ^k	1,08	0,54
R^b	0,2	0
R^p	1,2	0

Table 5.3: *Parameter values for each method*

Result	In-house kitting	Outsourcing
Total Cost	382271€	341166€
% of kitting	55,7%	59,5%

Table 5.4: *Outsourcing vs. in-house kitting*

It corresponds to a save of 41105€ (10.7% of the total cost).

As we have seen in figure 5.11 the value for R^b in which we will obtain the same cost as in in-house kitting is a value between 0,4 and 0,5. In order to obtain the value of R^b that gives the same total cost of in-house kitting we will zoom in this range. We have obtained the results with values of R^b every 0.01 in the range mentioned. For a value of R^b between 0.46 and 0.47 we obtain the same cost in both systems. We interpolate and we obtain R^b=0.46286. In this situation the total cost would be the same in both cases and the percentage of parts kitted is 50.93%.

5.3 New transport equipment

In this section we will consider that characteristics of the transport vehicles vary. We will study the impact that these characteristics have on the costs and on the percentage of parts kitted.

5.3.1 New forklift equipment

In this case we are studying the variance of the costs and percentage of parts kitted when the forklift velocity varies from 2880 m/h to 3880 m/h in steps of 50m/h. If the velocity of the forklifts that transports the pallets increases, obviously the total cost decreases. It decreases in 15312€. As we can see in figures 5.14 and 5.15 total cost decreases almost as the same manner as the transport of pallets cost. It does not decrease exactly in the same manner because when the velocity is “too slow” (from 2880m/h to 3130m/h, point 6) there are 55 kits (figure 5.16) and the percentage of parts kitted varies (figure 5.17), but with a higher velocity (from 3130m/h to 3880m/h) one kit less is used and the percentage of kitting remains constant in 55,89%, which makes that, in this interval, the variance of the total cost and the transport of pallet cost is the same. As it does not have an important impact on the percentage of parts kitted, the other costs almost do not vary. We observe that in the first range of velocities, whereas the velocity increase, more boxes are being used to replenish the supermarket substituting pallets, so the cost of replenishment of boxes increases and the cost of replenishment of pallets decreases.

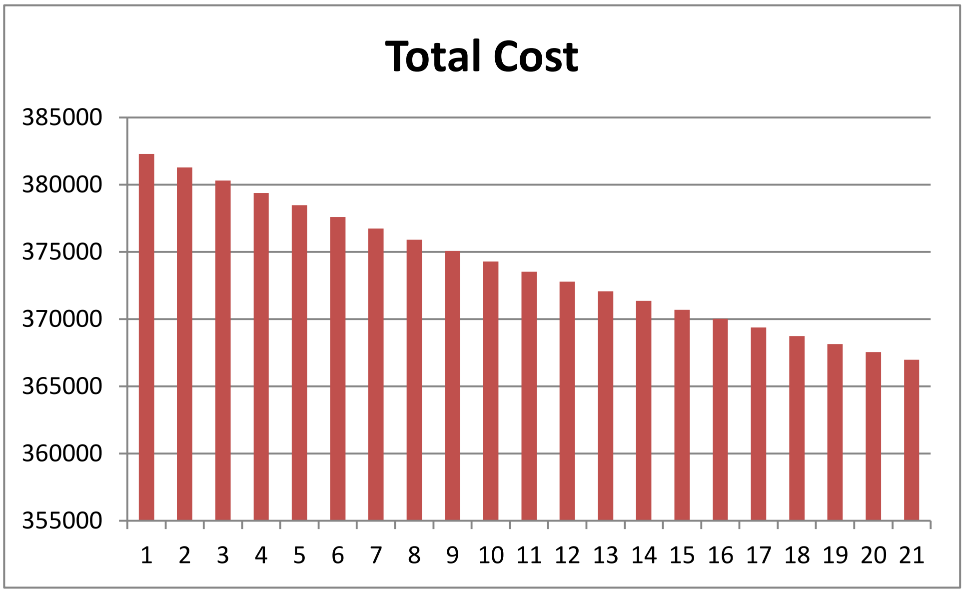

Figure 5.14: *Impact of the forklift velocity in the total cost*

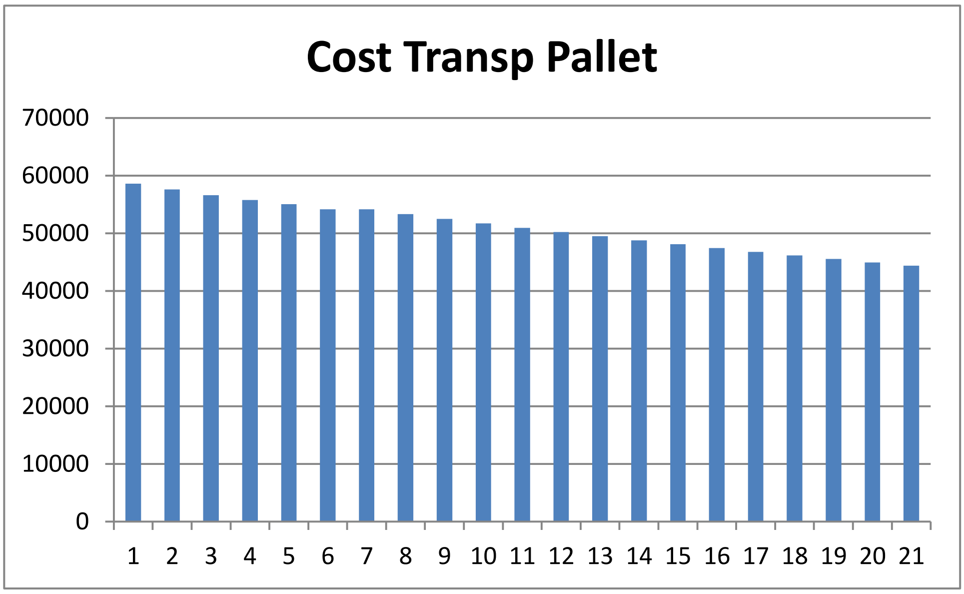

Figure 5.15: *Impact of the forklift velocity in the cost of transport pallets*

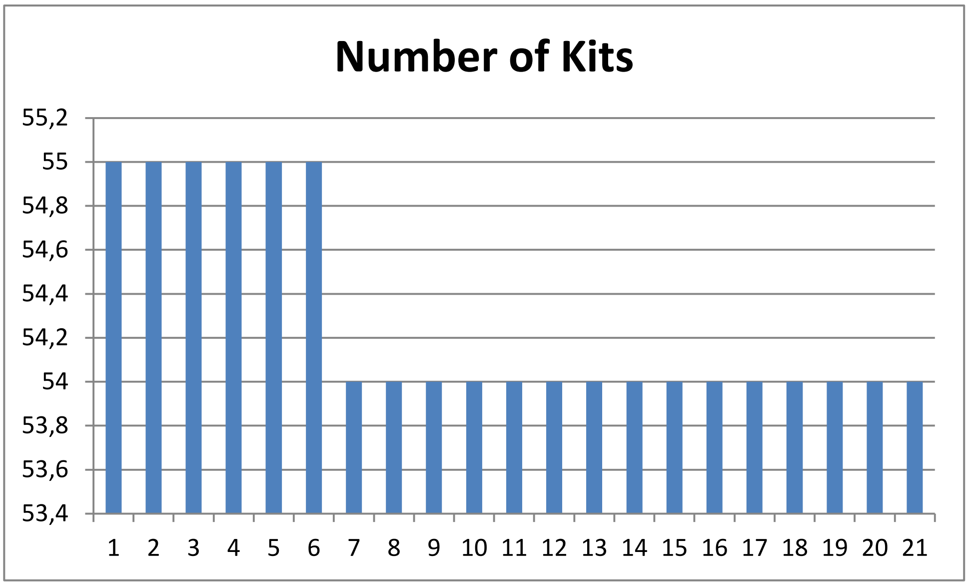

Figure 5.16: *Impact of the forklift velocity in the number of kits used.*

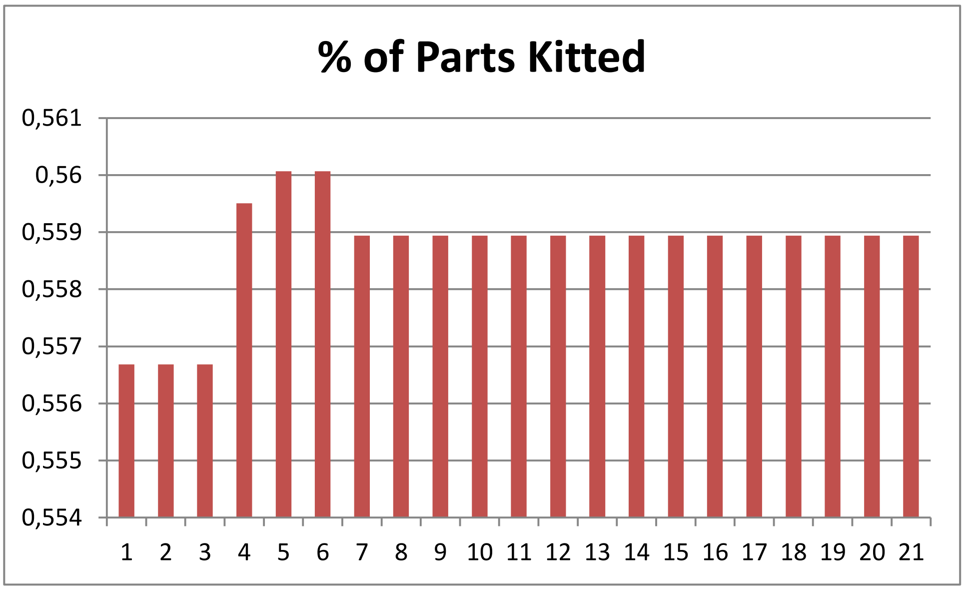

Figure 5.17: *Impact of the forklift velocity in the percentage of parts kitted.*

5.3.2 New tugger train for kits

We consider that tugger trains can drive faster if the number of kits carrying is lower. In this section we suppose that the capacity of the tugger train diminishes from 70 to 60 kits (12 batches of 5 kits instead of 14 batches). We have analysed the variances of the costs with velocities between 2412m/h and 3412m/h in steps of 50m/h. In figure 5.18 we can see that for a velocity higher than 2862 m/h the total cost is lower than in the initial situation (382271€). The cost of transport kits tends to decreases even if the percentage of parts kitted increases (figure 5.19 and figure 5.20). The fact to can carry faster the kits makes increases the kitting cost (figure 5.21) because more parts are kitted. It increases every time that a new kit is used (figure 5.22). The same happens with the cost of pick from a kit at the line and the opposite happens with the cost of pick from a bulk, which explains that parts that were bulked are now kitted. Every time that a new kit is used, at least one of the costs of replenishment of the supermarket (box or pallet) increases in order to satisfy the demand of this kit.

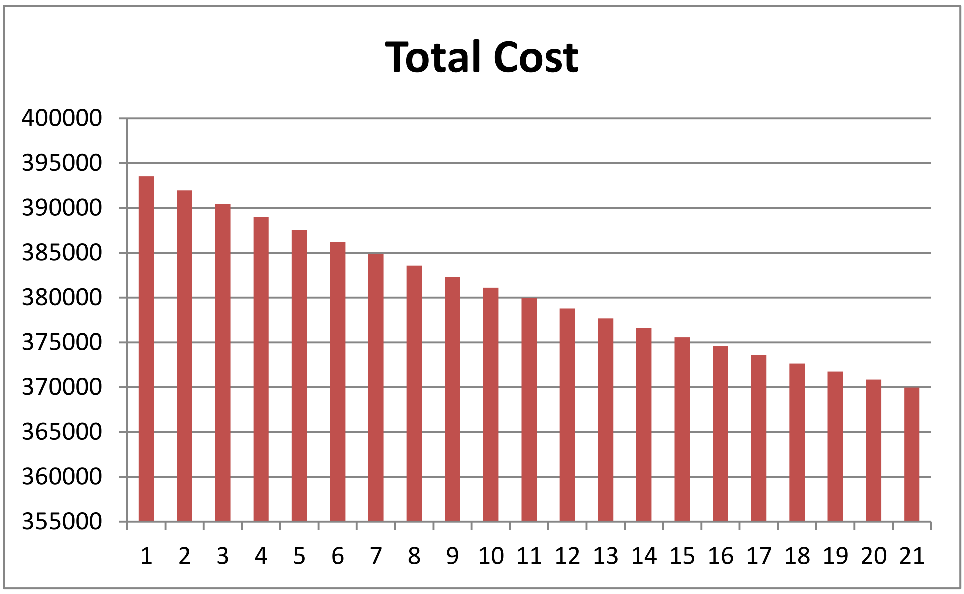

Figure 5.18: *Impact of the kits tugger train velocity in the total cost*

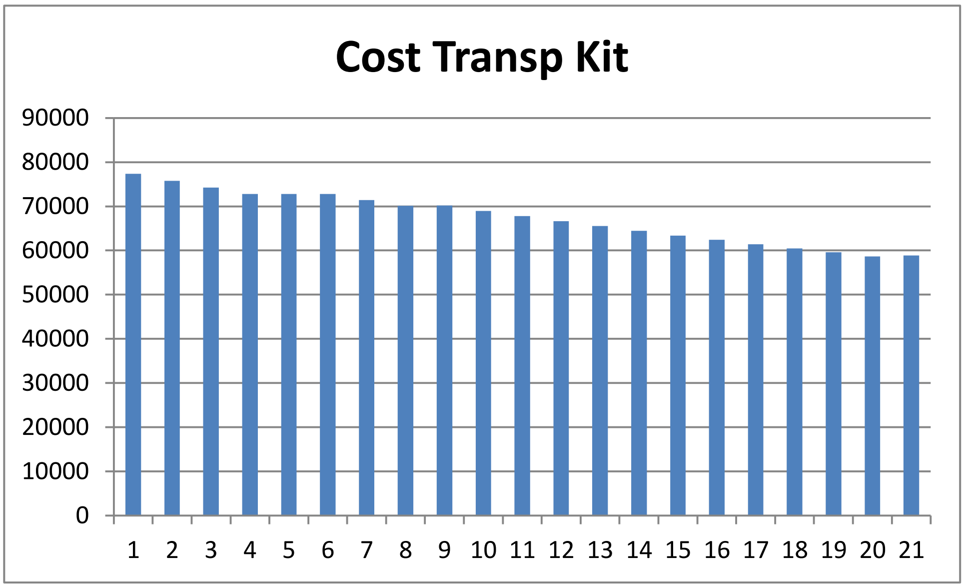

Figure 5.19: *Impact of the kits tugger train velocity in the cost of transport the kits.*

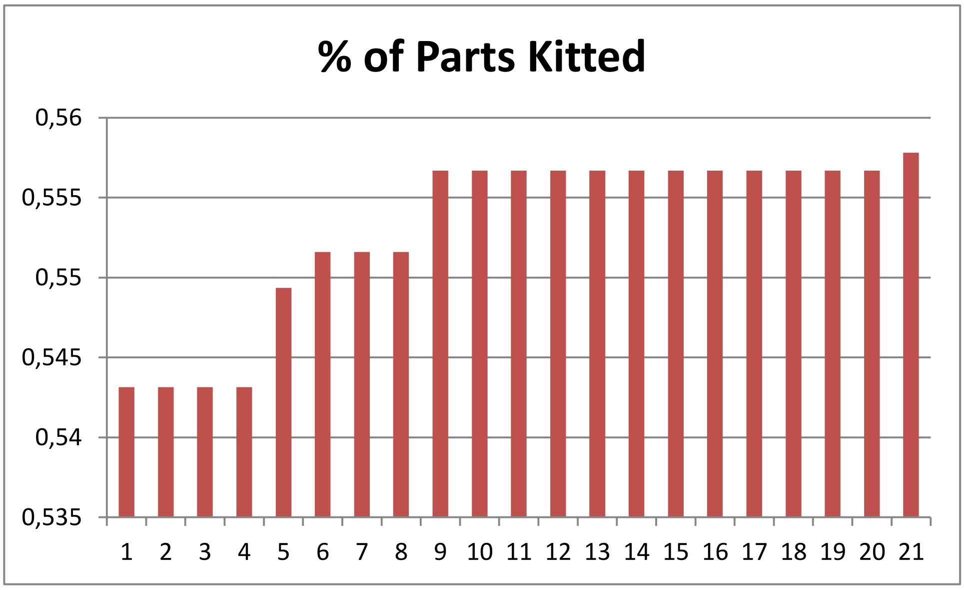

Figure 5.20: *Impact of the kits tugger train velocity in the percentage of parts kitted*

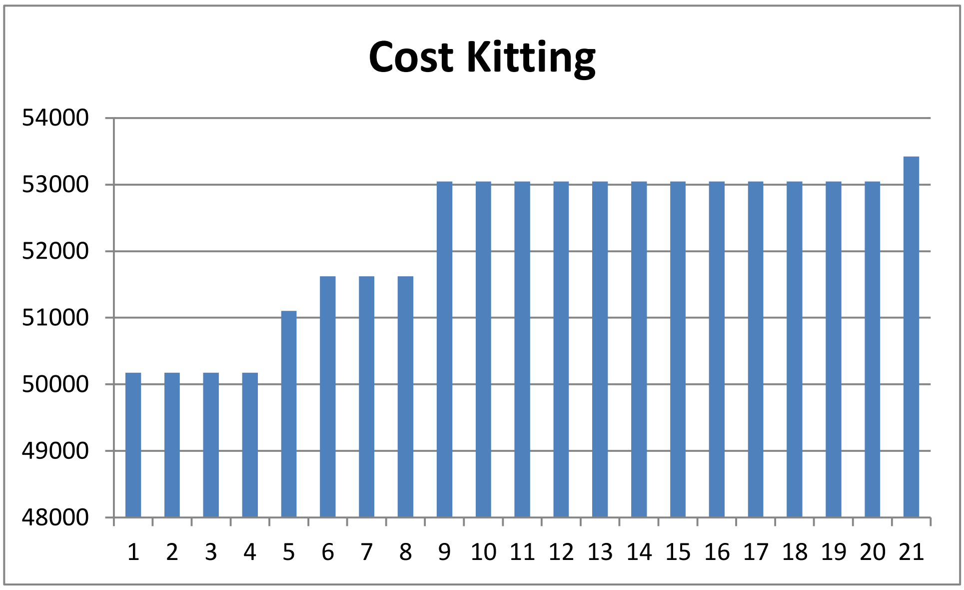

Figure 5.21: *Impact of the kits tugger train velocity in the kitting cost*

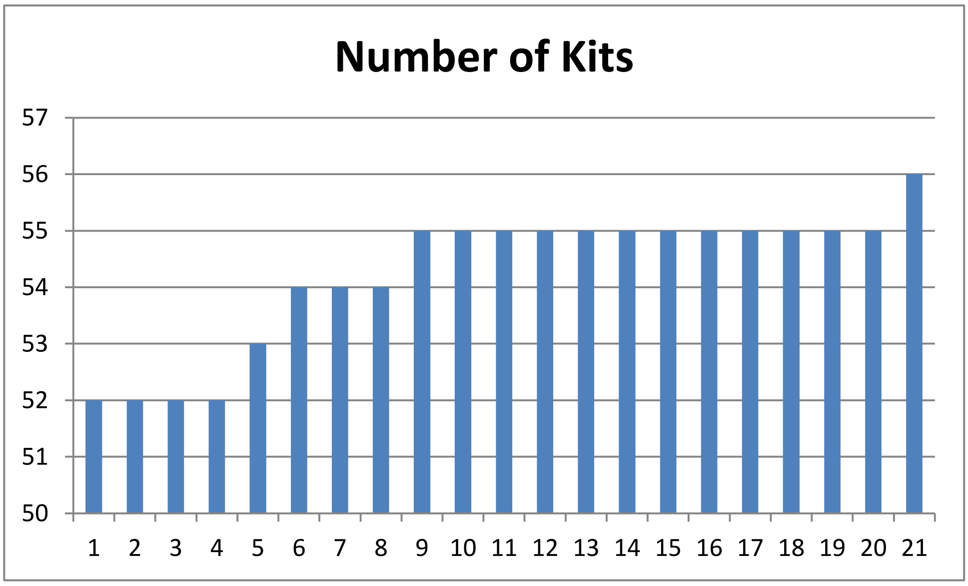

Figure 5.22: *Impact of the kits tugger train velocity in the number of kits used*

5.4 Kit batch size

We have studied the variances in the costs if we reduce the batch size from 5 to 1 kits. Figure 5.23 shows that when the batch size is reduced the total cost increases 2328€. The percentage of kitting tends to decrease but it does not suppose a significant change (figure 5.24). As the percentage of kitting does not suffer significant changes the kitting cost increases almost as the same manner as total cost (figure 5.25). This also means that in this situation (with this specific parts and family parts) the opportunity for picking multiple units of a part at once is, in most of the times, affected for the batch size (restrictions 3.2 and 3.3 are satisfied). The other costs do not suffer important modifications.

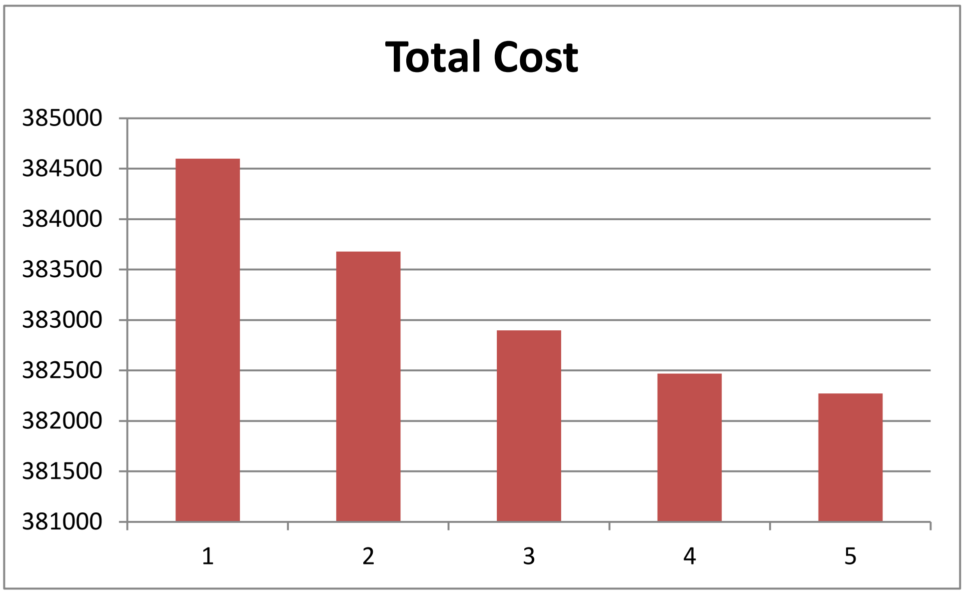

Figure 5.23: *Impact of the kit batch size in the total cost.*

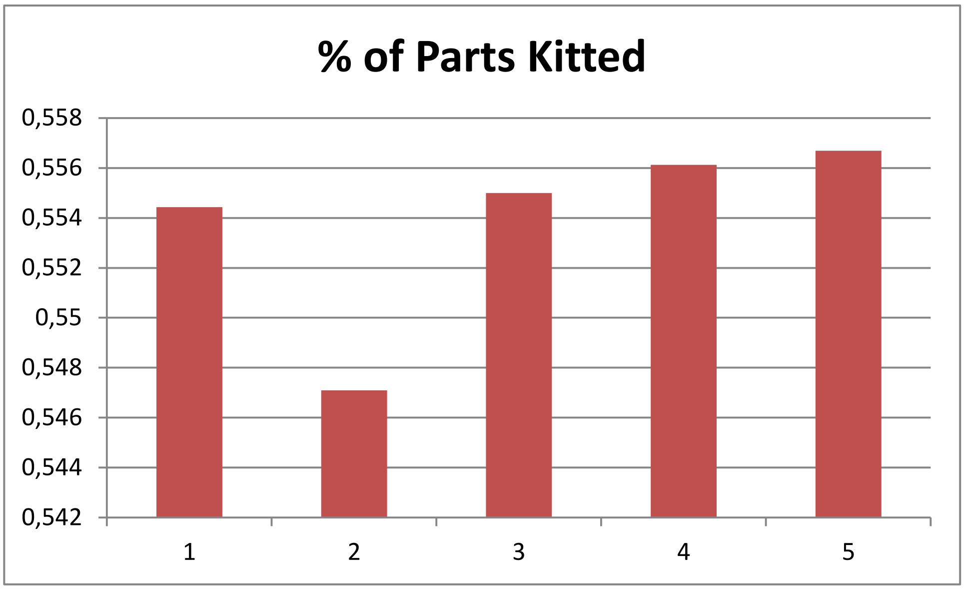

Figure 5.24: *Impact of the kit batch size in the percentage of parts kitted.*

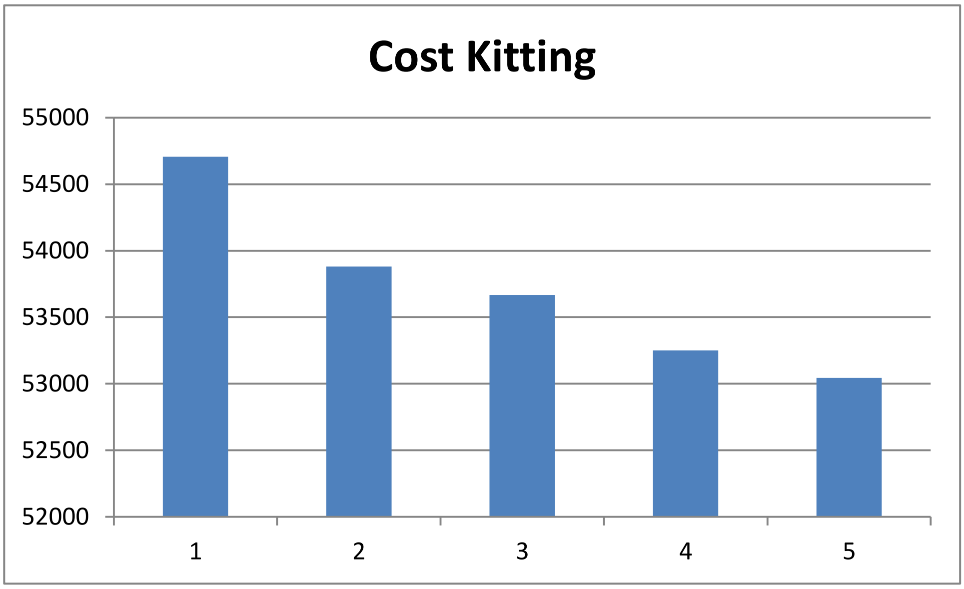

Figure 5.25: *Impact of the kit batch size in the kitting cost*

5.5 Available space at the border of the line

As mentioned in chapter 3, we will study how the cost varies is if we vary the available length at the border of the line. Not all the space available is always used and we want to study how important it could be in the total cost to use more space.

To study it we have obtained the results when the length factor varies from 1 to 2 in steps of 0.125. As the standard size is 8 meters (Ph.D. of dr. Veronique Limère), it means that we are obtaining the results in steps of 1 meter from 8 to 16 meters.

As this change permits a bigger slack to the restriction (2.13), the total cost will always decrease. However, we can see in Figure 5.26 that, as the space available value becomes bigger, the impact in the cost is smaller.

For this reason we have reduced the interval from 8 to 12 meters giving the results obtained every half meter. As it happens the same that in the first study (the impact in the cost is much more significant in the first meters), we have reduced again the interval from 8 to 10 giving the results every 0.25 meters (which corresponds with a lower value of 1 in the length factor, an upper value of 1.25 and a step value of 0.03125). We can see in figure 5.27 that if the available space at the border of the line is extended in 2 meters (from 8 meters to 10), we obtain a save of 11143€, which suppose a 2.9% of the total cost. Moreover, only extending half a meter the length (until 8.5 meters) we will also have an important save (5220€, that corresponds to a 1.36% of the total cost). The percentage of parts kitted tends to decrease (figure 5.28) as more space is available and more bulks can be allocated at the border of the line. As it, the number of kits used also decreases (figure 5.29).

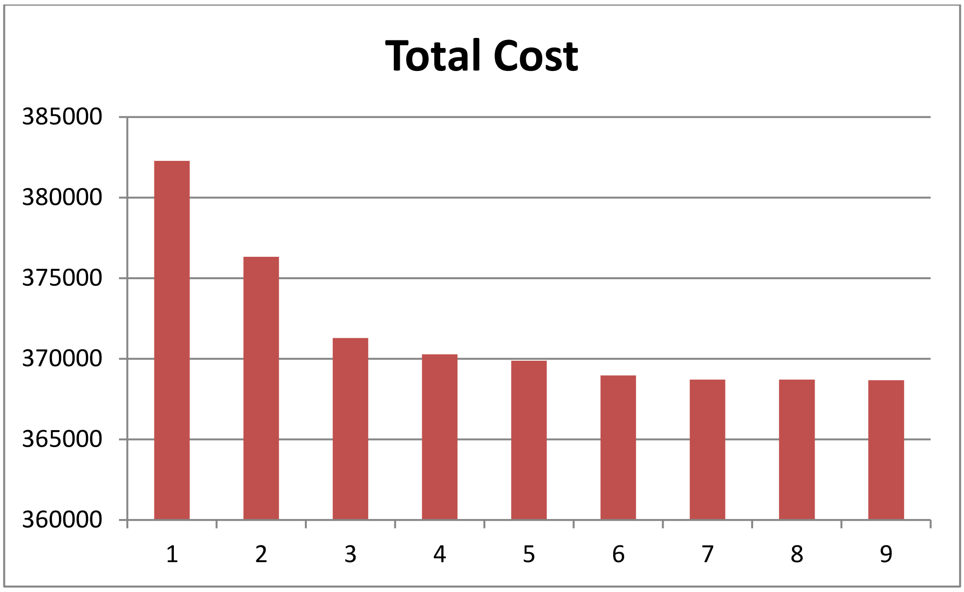

Figure 5.26: *Impact of the space available at the station in the total cost (from 8 to 16 meters).*

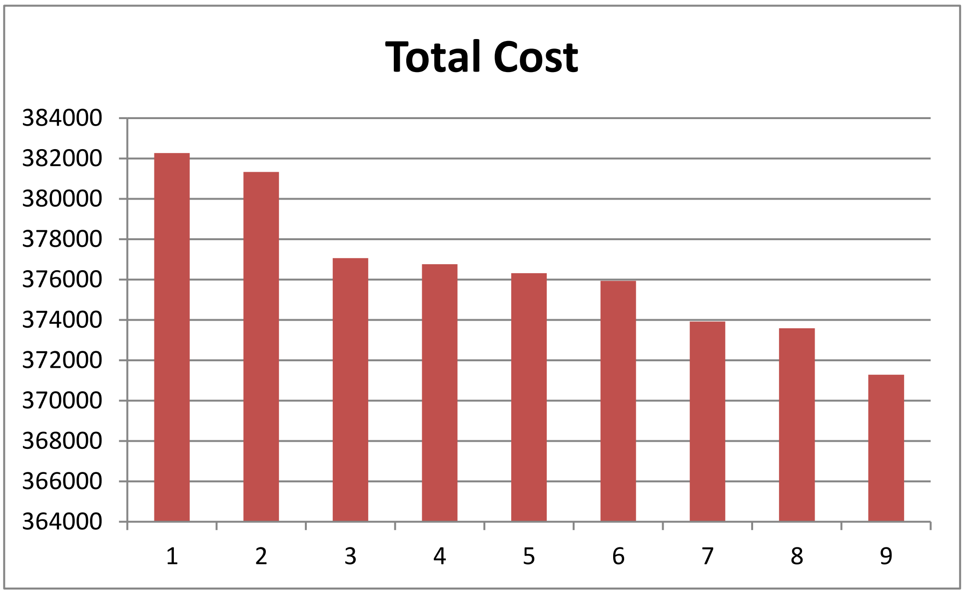

Figure 5.27: *Impact of the space available at the station in the total cost (from 8 to 10 meters).*

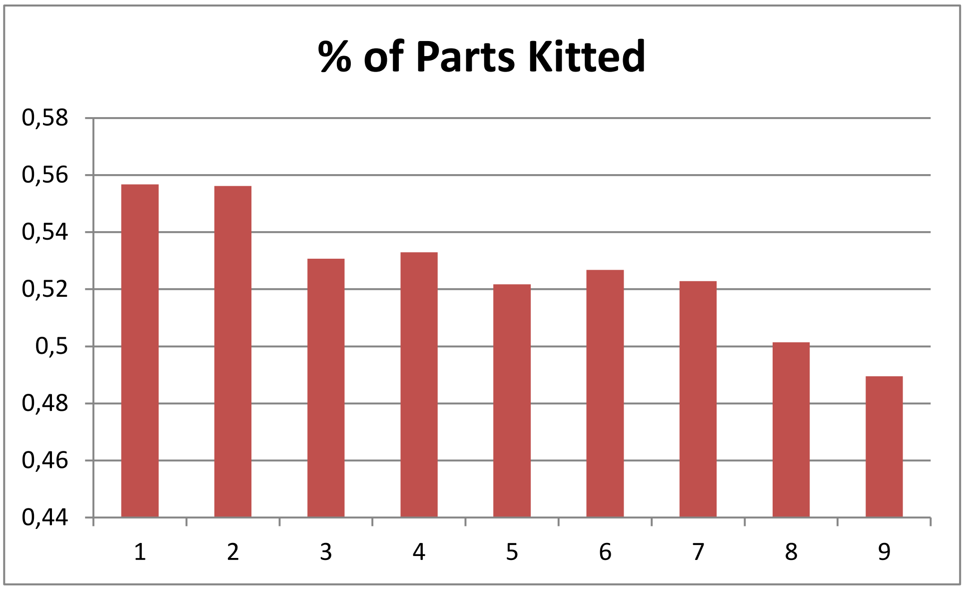

Figure 5.28: *Impact of the space available at the station in the percentage of parts kitted (from 8 to 10 meters)*

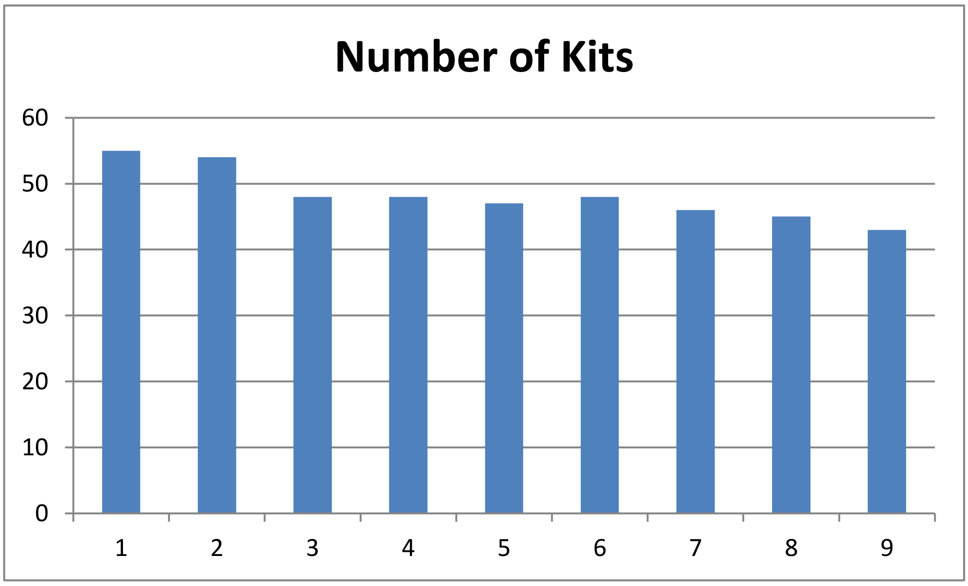

Figure 5.29: *Impact of the space available at the station in the number of kits used (from 8 to 10 meters).*

5.6 Total volume of a kit

We want to know how the volume of a kit affects to the costs and to the percentage of parts kitted. If not all the volume of the kits can be occupied, maybe there are some parts that do not fit in the kits, or maybe we cannot kit all the parts that we would like to kit because there is not enough space for all the kits at the border of the line. To see it, we have modified the volume factor. We have analysed the evolution of the results when the volume factor increases from 0.5 to 1 in steps of 0.1. This means that we will obtain the results for kit volume going from the 50% of the original volume to the 100% of the original volume, in steps of 10%.

We observe in figure 5.30 that total cost increases every time we reduce the volume. If we half the volume of the kit, the cost increases in 47076€, which suppose a 12.31% of the total cost. The number of kits used increases when the kit volume decreases. However the percentage of parts kited decreases, maybe because it supposes a high spending of space at the border of the line. Both costs of replenish tends to decrease as less parts are kitted.

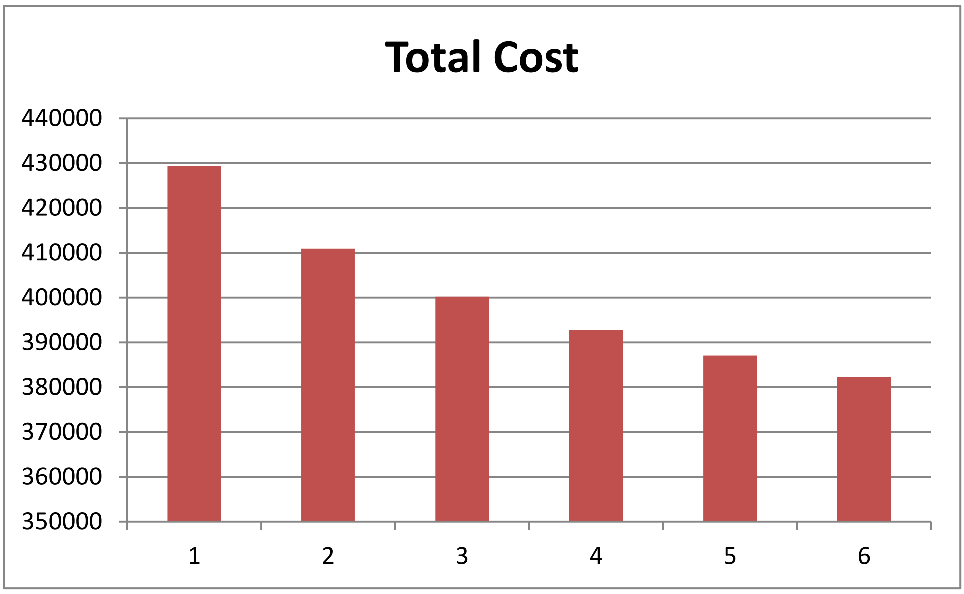

Figure 5.30: *Impact of the volume available in a kit in the total cost*

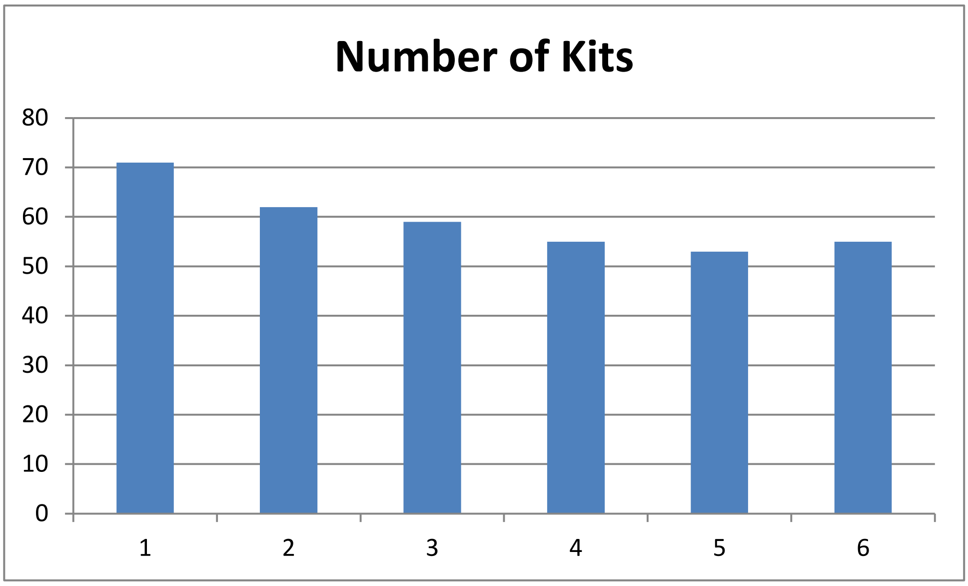

Figure 5.31: *Impact of the volume available in a kit in the number of kits used*

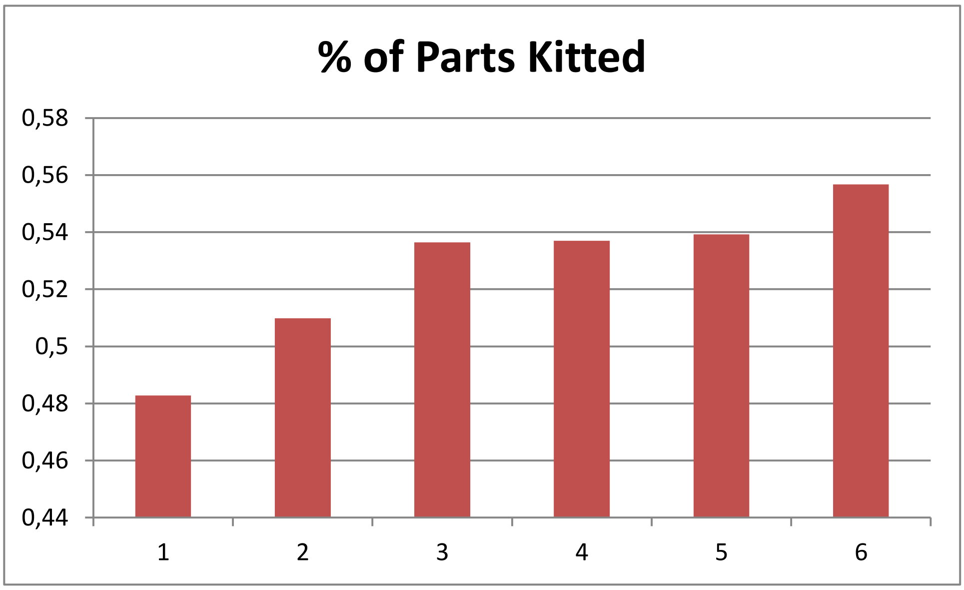

Figure 5.32: *Impact of the volume available in a kit in the percentage of parts kitted*

Chapter 6 **Conclusions**

This thesis is a further research of the Ph.D. realized by Veronique Limère: “To Kit or Not to Kit: Optimizing Part Feeding in the Automotive Assembly industry”.

On the one hand, this thesis deals with the development of a tool in order to facilitate and make more comfortable the work for the employees of a company using it. The work tool is created to complement the mathematical model realized in the Ph.D. mentioned before. For this reason it can only be used in factories where the mathematical model is implemented. This model supports the best choice between two supply systems: bulk feeding and kitting.

On the other hand, in this thesis we have considered the possibility that factories can suffer some modifications in the way they supply the materials. We have used the tool to analyse the differences that these modifications can lead.

Answering to the first point, the tool developed satisfies all the requisites needed:

First of all we have to mention the fact that it has been developed in an excel file. Excel is one of the most used programs in companies. Therefore it the makes work of the employee more comfortable. Moreover the fact that the employee using the tool only has to fill a template to obtain the results makes it even more comfortable.

Secondly, as it has been required, it allows us to study how the costs and the number of parts kitted varies when one or more parameters also varies between two values (lower value and upper value) with an interval between two consecutives values (step value). It let us now the tendency that results follows.

Finally, it gives us the results in a sheet and also in graphs, which helps the employee to analyse the results. Moreover, it informs about the feasibility of the solution.

In order to answer the second point, we have used the tool to realize a study with the data of a particular company. If all the others parameters keep the original value, we have concluded that:

If we are using a new picking technology in the supermarket, for every 0.1 seconds that the searching time is reduced, we have a saving of 0.24% of the total cost, and the percentage of parts kitted tends to increase while we reduce the searching time.

The reduction of the labour cost for kitting operations if the company is outsourcing (from 30€ to 20€), reduces de total cost in a 4.6%. Moreover, if the distance between the factory and the 3PL increases, the total cost tends to increase, and the percentage of parts kitted tends to decrease.

Increasing the forklift velocity diminishes the total cost in 15.312€ and it is directly proportional to the velocity, as the time that the operator spends on transporting the pallets is lower. However, it does not have a significant repercussion in the number of parts kitted. The same happens if we increase the velocity of the tugger train transporting kits.

Reducing the batch size from 5 kits to 1 kit does not lead to a significant change in the percentage of parts kitted. Moreover, the reduction of the total cost only changes in 2328€.

Increasing the available length along the workstation reduces the total cost, as it is a restrictive factor. However, for every half meter it increases, the reduction that the total cost suffers is less. Increasing the length available from 8 to 8.5 will suppose a reduction of a 1.26% of the total cost. On the other hand, the percentage of parts kitted, tends to decrease in a considerable value if the space available increases.

The total cost increases every time the kit volume is reduced. If we half the volume of the kit, the total cost increases in a 12,31%. The percentage of parts kitted diminishes in a significant way (from55.66% to 48.27%).

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