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# CIGI 2021

## Logistics Network Design in a Product-Service System case

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**Résumé** – De nos jours, les entreprises proposent de plus en plus d’offres intégrant des produits et leurs services associés plutôt que de vendre uniquement des produits. Les producteurs proposent alors des services comme la reprise, la gestion des consommables et des déchets ou encore la maintenance. Dans ce cas, ils doivent développer des réseaux logistiques pour supporter les activités associées à ces services. L’objectif de ce travail est de mener une étude de conception de réseaux logistiques dans le cadre de l’économie d’usage pour une entreprise en croissance. Pour ce faire, nous avons bâti un modèle de données permettant de représenter le cas étudié, et utilisé un programme d’optimisation afin de concevoir différents scénarios de réseaux logistiques permettant de répondre aux besoins de l’entreprise partenaire. Ce travail a permis de fournir aux entreprises une représentation du réseau logistique en fonction des activités de l’entreprise concernée, ainsi qu’une estimation des coûts globaux du système.

**Abstract** – Nowadays, companies offer more and more not just to sell products, but rather integrated products and services bundles. Producers offer then services as take-back, waste and refill management or even maintenance. In this case, they have to develop logistic networks to support the activities related to these services. The aim of this work is to carry out a study to design logistic networks as part of the Product-Service System for a growing company. To do so, we built a data model to represent the studied case and used an optimization program in order to design a logistic network compliant to the needs of the partner company. This work allowed us to provide a representation of the logistic network according to the activities of the company, as well as an estimation of the global costs of the system.

**Mots clés** – Economie d’usage, Conception de réseaux de service, Optimisation, Réseaux de logistique et transport, Entreprise en croissance.

**Keywords** – Product-Service System, Service networks design, Optimization, Logistics and transport networks, Growing companies.

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### 1 INTRODUCTION

The aim of this work is to carry out a study, with the help of modelling and optimizing tools, to build a logistics and transport network that will support the activities of a company which has adopted the Product-Service System (PSS) business model. In addition, the network to be built is aimed at an on-growing company, so it will have to evolve according to the expansion of the company’s activities. We use a two-year-old start-up company located in Grenoble metropolitan area as a case study for the problem we explored, and they provided a certain amount of data used to experiment the method developed. At the time of the study, the company has one production site in the Grenoble metropolitan area. They have products located on more or less ten towns in France and wish to expand its activities on the French metropolitan territory in a five-years-horizon.

#### 1.1 Context and Challenges

The business model studied is based on the PSS concept. This implies that the company does not sell the product, but its functions and services. This type of business model has the potential of improving product and service management for the company and product and service quality for its customers, but also sustainability. Companies are indeed responsible for a larger part of the life cycle of the product, which implies a better resource and waste management. In our case, the product offered by the company is similar to a vending machine. It

requires little care, except for maintenance and consumable refurbishment. The company offers a two-year rental agreement, during which the company is responsible for the wellness of the product, and in particular its installation and maintenance. This means that every time a failure occurs on an installed product, the company has to repair it within a certain time span. This business model is, according to the literature [Reim et al., 2015], a use-oriented PSS.

All the installation and maintenance activities are currently operated from the production site at the company. This strategy seems to be viable for a small amount of products, but it can quickly be expensive in terms of transport costs as and when the company’s activities expand. The company has indeed planned to install a given number of new products every year for a time horizon of five years. To sustain this expansion, the company wants to know how to design its logistics network in order to fulfil the distribution and maintenance functions. Therefore, a method is developed to design a logistics network to be used in such a context. The network will have to support the installation and maintenance activities at each phase of the company’s growth while optimizing the overall costs of the system. To do so, the main decisions to take are where to place the facilities serving the maintenance and distribution functions, and how much workforce to hire at every facility. The components of the problem must be clearly modelled in order to meet the requirements of a PSS business model. For instance, the company is required to repair every failure with a full service

level since with the PSS business model the company is responsible for the wellness of the product.

This work is to help a company with such business model take strategic decisions on its logistics network when designing a PSS offer.

### 1.2 Methodology

In order to help the company make good quality decision, we set up the following methodology. The first step is to study the academic work published on this topic. This will allow to position our work and have an insight on how related problems are handled. This study is presented in Section 2. Then, an important step is to formalize the problem. First, the problem has to be clearly defined. Then, we can express the requirements mathematically by building a data model in Section 3 and an Integer Linear Program (ILP) in Section 4 to represent and solve the problem we address. As the core problem we want to address is locating facilities and allocate customers to these facilities, we wrote the ILP based on an Uncapacitated Facility Location which target is precisely to answer such questions. Next, the relevance of the model has been tested on the data provided by the company. The experimental results on the case study are presented in Section 5. Thus, a sensitivity analysis has been conducted evaluate the robustness of the solutions. This sensitivity analysis also give insight on which parameters can influence the results. This is presented in Section 6. Finally, we explored the possibility of outsourcing some activities in order to suggest recommendations to the company. This is detailed in the Section 7.

## 2 RELATED WORK IN THE LITERATURE

The PSS business model studied is based on the fact that the producer keeps the ownership of the product and is responsible for its proper functioning. It is very similar to the business model of vending machines, as in this case the machine is made available in a public place and its owner has to refurbish it and repair it in case of failure. It is also close to the activities implemented in the context of reverse logistics, because in this case a product which has already been sold is reinjected in the supply chain to be resold are reused. After-sales services are also close to use-oriented PSS, because it implies replacing or repairing a product returned by a customer. This is why we chose to explore the literature related to these topics, in addition to articles related to the PSS.

### 2.1 Product-Service System

Several aspects of the PSS have been studied in the literature, and we focused on the ones related to our problem. On the logistics network design, [Sun et al., 2019] determine the configuration of a multi-level logistics network using a Location-Inventory problem modelled with a Mixed Integer Linear Program (MILP). Concerning costs estimation, [Shen et al., 2017] suggested a methodology to identify, classify and calculate costs inherent to a PSS business model.

Activities related to maintenance have been studied from different angles. [Derrouiche and Dubruc, 2014] designed a method to set up maintenance processes as part of a PSS offer. [Kuo, 2011] studied the parameters influencing the feasibility of such a business model. [Kuo et Wang, 2012] designed a model based on Multi-Attribute Utility Theory to optimize the service level of a network with several types of maintenance. [Rezapour et al., 2016] used a stochastic approach considering demand and production uncertainties to determine the optimal quantities of spare parts, semi-finished and finished goods to produce in order to satisfy the demand. [Xia et al., 2017] developed a model

allowing to optimize the preventive maintenance planning for leasing contracts. [van Ooijen et al., 2019] identified the parameters of the transport between customers and repair centres in order to determine the best strategy to adopt with a transport service provider.

### 2.2 Vending Machines

The literature about logistics aspects of the vending machine business model is mainly focused on tactical aspects. [Rusdiansyah and Tsao, 2005] built a non-linear mixed integer program called Integrated Inventory and Periodic Vehicle Routing Problem with Time-Window to answer the problem of periodic refurbishment of the vending machines. [Kim and Yoo, 2012] addressed the manpower question and built a non-linear program to calculate how many permanent and temporary technicians to hire in order to fulfil the tasks related to preventive and curative maintenance.

### 2.3 After-Sales Services

Literature on after-sales services is mainly focused on operations aspects. On another hand there are also a few studies pertaining to the information system required by such a business model. For example, [Sagama et al., 2016] studied several scenarios to determine the optimal preventive-curative maintenance strategy for a wind farm. [Chen et al., 2009] focused on the set up of an information system supporting after-sales maintenance.

### 2.4 Reverse Logistics

The literature related to reverse logistics is mainly about take-back activities. Most of the references are focused on the design of logistics networks required for such activities, and the most common approach is to use a model of Facility Location Problem type. Researchers use several declinations of this type of problem, like Uncapacitated Facility Location [Srivastava, 2008]), Capacitated Facility Location with a deterministic [Melo et al., 2009] or stochastic [Listes and Dekker, 2001] approach to optimize the positioning of the facilities.

Other approaches have also been used. [Cruz-Rivera and Ertel, 2009] used a Fixed Charge Facility Location model to place waste collecting facilities. This problem is also addressed with different strategies like discrete event modelling [Kara et al., 2007] or continuous optimization ([Fleischmann, 2001]).

About maintenance activities, [Amini et al., 2005] use a What-if analysis to decide where to stock spare parts, and a Facility Location based Integer Linear Program (ILP) to place technicians dedicated to maintenance.

### 2.5 Conclusion and Positioning

To the best of our knowledge, articles studying maintenance and PSS either concentrate on preventive maintenance, or search to optimize the parameters of an existing system, rather to build a new system supporting maintenance activities for a PSS business model. Articles pertaining to the other topics we identified as relevant are more focused on tactical or operational problematics than on strategical ones.

The problem addressed by our study is designing a logistics network for maintenance and distribution as part of a PSS. These three aspects (*i.e.* maintenance, logistics network design and PSS) have all been studied, but not altogether to the author's knowledge.

Furthermore, we need to consider the growing aspect of the network for a start-up company. To the best of our knowledge, the literature about this is rather scarce and does not apply to the case we study.

Facility location problems are sometimes extended to consider other logistics problematics. We can cite Location-Inventory, where facility location questions are integrated with inventory management decisions. We can also cite Location-Routing, where the routing between facilities is jointly addressed with their location.

In our case, these aspects are not taken into account, mostly because of the lack of data provided by the case study company. In fact, as the company is still relatively young, the current available data they have provide small amount of maintenance, installation and refurbishing demand.

### 3 DATA MODEL

To address the problem identified, we choose to adapt an Uncapacitated Facility Location (UFL) based Integer Linear Program (ILP) to our study. The UFL-ILP model lends well to the case study. As we stated before, the company currently operates all of the distribution and maintenance activities from its production site, in the Grenoble metropolitan area. But with the expansion of its activities, this strategy will be very expensive, mostly in terms of transport costs. As a result, the problem we address is how to locate maintenance and distribution sites on the covered territory so that the overall costs of the system will be optimized.

This requires building a data model which will represent the system and be the input of the UFL-ILP set up. The aim of this section is to explain this model.

#### 3.1 Geographical repartition

To decide where to place facilities, there is a need to know where the customers – respectively the products – will be located. The start-up company does not have this information, at least not in long term. We propose to build an expansion scenario based on their commercial strategy over the French metropolitan territory. With the business plan on five years the company provided, this time horizon has been selected as well.

The initial state for the expansion was the roster of cities in which the company had already placed products in 2019. All these cities have been classified by region, and then the roster has been completed with the most populated cities of each French region, so that it contains three cities per region (Figure 1). The repartition of cities obtained is rather consistent with the French population density in 2019 (Figure 2). To be as close as possible of this repartition, several big regional cities such as Clermont-Ferrand, Limoges, Perpignan and Chambéry have been added to the roster and obtain the final geographical scenario (Appendix 1).



Figure 1. Map of the selected cities

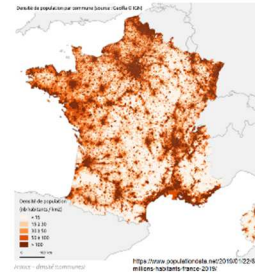


Figure 2. French population density in 2019

To decide in which year the products will be placed in the cities for the first time (i.e. activation year; in other words, year in which there is new clients in these cities), we apply a random draw to these cities and obtain a classification of the cities per activation year (Appendix 2).

#### 3.2 Products repartition

To design an efficient logistics network, we also have to determine how much products will be located in the cities each year. To do so, the repartition of the products is modelled based on the initial state, communicated by the company. We estimate the number of products to be placed in every city each year using two parameters, that are the occupation rate (i.e. number of products in the city on total number of commercialised products the year before) and the population rate (i.e. population of the city regarding to the total population in the activated cities of the year in question). For each city  $j$ , every year  $t$ , let  $\gamma_j^t$  and  $\delta_j^t$  be respectively those parameters, which are positive if the city is activated and zero otherwise. Those parameters are weighted by the proportions  $\alpha_1$  for the population rate and  $\alpha_2$  for the occupation rate. For every year  $t$ , let  $BP^t$  be the total number of products in all the cities (given by the company). So, for the city  $j$ , the year  $t$ , the number of products will be calculated as follows:

$$n_j^t = BP^t (\alpha_1 \times \delta_j^t + \alpha_2 \times \gamma_j^t).$$

Let us take a simple example to illustrate this formula. For a year  $t$ , let's assume we will have  $BP^t = 150$  new products on the entire territory. Let's assume there was 50 products installed the year  $t - 1$ , and that the total population of the territory is 10000. Let's select a city  $j$  in which there is already  $n_j^{t-1} = 10$  products. This city has 1000 inhabitants.

As a result, its occupation rate and population rate will be the following:

$$\gamma_j^t = \frac{10}{50} = 0.2,$$

$$\delta_j^t = \frac{1000}{10000} = 0.1.$$

Let us weight those parameters equally, in other words  $\alpha_1 = \alpha_2 = 0.5$ . Finally, the number of products to be placed in the city  $j$  at year  $t$  will be:

$$n_j^t = 150 (0.5 \times 0.1 + 0.5 \times 0.2) = 22.5.$$

We chose to round down non-integer numbers to the nearest integer, so here:

$$n_j^t = 22.$$

#### 3.3 Product ageing and breakdown modelling

We choose to set up a model in which the products will have an evolutive failure rate according to their ageing. Three age categories are defined for the products: young products (from 0 to 1 year old), medium-aged products (from 1 to 2 years old) and old products (more than 2 years old). This choice of categories is also defined regarding the 2 years rental duration.

The failure rate will be shared in two types of failures: the short ones and the long ones. Each failure type has its own component cost, repair duration and proportion of the failure rate. This proportion will also evolve with the age of the product (i.e. the older the product will go, the more long or serious failures it will have). Let  $t_{pm}$  be the type  $p$  failure rate of a product of age  $m$ , and  $\beta_{pm}$  the proportion of failure of type  $p$  for a product of type  $m$ . The number of failures of type  $p$  for a product of type  $m$  will be as follows:

$$nbp_{pm} = t_{pm} \times \beta_{pm}.$$

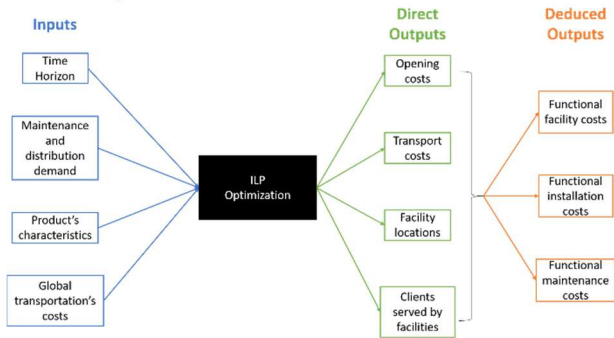
### 3.4 Cost structure

To define the cost estimation purpose of our work, we had to set up a cost modelling of the system. To do so, all the costs that the system could entail are cataloged and classified into categories. This allows to identify which activity would be the most expensive.

**Table 1. Costs details**

Cost	Notation	Detail
Structural facility cost	$coe_i$ for each facility $i$	Opening cost of a facility (one-year rent and agency fee on the first year), calculated by the UFL-ILP
Structural installation cost	$cti$	Transport costs related to installation (one direct round trip per new product installed), calculated by the UFL-ILP
Structural maintenance cost	$ctm$	Transport costs related to maintenance (one direct round trip per failure), calculated by the UFL-ILP
Functional facility cost	$cfi_i$ for each facility $i$	Depreciation costs of the technician's trucks, rental expenses, electricity fees
Functional installation cost	$cins$	Technician's wage during the installation
Functional maintenance cost	$cmal$	Component cost, technician's wage during the maintenance

Two types of costs were distinguished: structural costs, which are related to the design of the network and are calculated by the UFL-ILP, and functional costs, which are calculated from the network obtained by the solving of the UFL-ILP. Each one of these cost types are subdivided into three categories: facility cost, installation cost and maintenance cost. These costs are detailed in Table 1. Figure 3 summarizes schematically the inputs and outputs of the model.



**Figure 3. Diagram of the inputs and outputs of the model**

## 4 INTEGER LINEAR PROGRAM

To model our logistics network design problem, we choose to formulate it as an Uncapacitated Facility Location based ILP (UFL-ILP) as follows.

### 4.1 Problem Data

$T$  – Time horizon.

$T = \llbracket 1, T \rrbracket$ .

$T_1 = \llbracket 2, T \rrbracket$ .

$I$  – Set of potential facilities.

$J$  – Set of customer cities.

$M$  – Set of product types.

$P$  – Set of failure types.

$t_{ins}$  – Installation time.

$\mathcal{R}$  – Action range (i.e. maximal duration between a failure and its repair).

$d$  – Annual availability of a technician in hours.

$\forall i \in I, co_i$  – Opening cost of the facility  $i$ ,

$fa_i$  – Agency fee of the facility  $i$ .

$\forall i \in I, \forall j \in J, ct_{ij}$  – Transport cost from  $i$  to  $j$ ,

$dt_{ij}$  – Transport duration from  $i$  to  $j$ .

$du$  – Mean time to do a direct round trip from a facility to a customer (this is the sum of all transport durations on the number of possible trips).

$\forall t \in T, \forall j \in J, n_j^t$  – Number of products in the city  $j$  the year  $t$ .

$\forall t \in T, \forall j \in J, \forall m \in M, n_{jm}^t$  – Number of products of type  $m$  in the city  $j$  the year  $t$ , especially,

$\forall t \in T, \forall j \in J, \forall m \in M, n_{j0}^t$  – Number of new products in the city  $j$  the year  $t$ .

$\forall p \in P, ti_p$  – Repair time for a failure of type  $p$ .

$\forall p \in P, \forall m \in M, nbp_{pm}$  – Number of failures of type  $p$  for a product of type  $m$ .

### 4.2 Decision Variables

$\forall t \in T, \forall i \in I, ntech_i^t$  – Number of technicians to be hired the year  $t$  at the facility  $i$ .

$\forall t \in T, \forall i \in I,$

$$y_i^t = \begin{cases} 1 & \text{if the facility } i \text{ is opened the year } t, \\ 0 & \text{otherwise.} \end{cases}$$

$\forall t \in T, \forall i \in I, \forall j \in J,$

$$x_{ij}^t = \begin{cases} 1 & \text{if the facility } i \text{ serves the customer } j \text{ the year } t, \\ 0 & \text{otherwise.} \end{cases}$$

### 4.3 Objective function

$$z = \min \sum_{t \in T} coe^t + cti^t + ctm^t + \sum_{t \in T} \sum_{i \in I} w ntech_i^t$$

### 4.4 Constraints

$$coe^0 = \sum_{i \in I} (co_i + fa_i) y_i^0; \quad (1)$$

$$\forall t \in T_1, coe^t = \sum_{i \in I} co_i y_i^t + fa_i (y_i^t - y_i^{t-1}); \quad (2)$$

$$\forall t \in T, cti^t = \sum_{i \in I} \sum_{j \in J} 2n_{j0}^t ct_{ij} x_{ij}^t; \quad (3)$$

$$\forall t \in T, ctm^t = \sum_{i \in I} \sum_{j \in J} 2ct_{ij} x_{ij}^t \sum_{m \in M} n_{jm}^t \sum_{p \in P} nbp_{pm}; \quad (4)$$

$$\forall t \in T, \forall i \in I, n_{tech_i^t} \geq \frac{1}{d} \left[ (t_{ins} + du) \sum_{j \in J} n_{j0}^t x_{ij}^t + \sum_{p \in P} (t_{ip} + du) \sum_{j \in J} \sum_{m \in M} n_{jm}^t n_{pjm} x_{ij}^t \right]; \quad (5)$$

$$\forall t \in T, \forall i \in I, \forall j \in J, x_{ij}^t \leq y_i^t; \quad (6)$$

$$\forall t \in T, \forall j \in J, \sum_{i \in I} x_{ij}^t = 1; \quad (7)$$

$$\forall t \in T, \forall i \in I, \forall j \in J, 2dt_{ij} x_{ij}^t \leq \mathcal{R}; \quad (8)$$

$$\forall t \in T_1, \forall i \in I, y_i^t \geq y_i^{t-1}. \quad (9)$$

Constraints (1), (2), (3) and (4) define the different costs (facility, installation, maintenance) of the problem while constraint (5) set the number of technicians necessary. Constraint (6) ensures that the customer cities are served only by opened facilities. The customer cities are served by one and only facility is ensured by constraint (7). Constraints (6) and (7) are the constraints coming from the classic UFL model. Constraint (8) allows to respect the action range, and finally constraint (9) ensures that an opened facility stays open the next year.

## 5 EXPERIMENTAL RESULTS

The problem has been modelled and solved using the data characterizing the company. The UFL-ILP have been run on CPLEX (12.6.2 Version), with an Intel Core i7-8550U CPU and 8Gbytes of usable RAM. The runs lasted less than one second for each data instance.

### 5.1 Data Generation

A time horizon of five years, an action range of 48 hours (quality of service), an installation time of half an hour are used. These parameters are deduced from the data provided by the partner company. The annual technician's availability of 1470 hours is used, calculated from the mean annual days of work of a technician worker. The charged wage per hour of the technicians is set to 19.45€, based on the mean wage of a technician. Three age categories have been defined for the products, and two failure types, again based on the data of the company (Tables 2 and 3).

**Table 2. Failures' Characteristics**

Failure type	Short	Long
Repair time	1h	2h
Component cost	32€	120€

**Table 3. Products' Characteristics**

Age category	Young	Medium	Old
Failure rate	0.33	0.38	0.45
Long failure proportion	0.8	0.75	0.7
Short failure proportion	0.2	0.25	0.3

For the data pertaining to the facilities, we choose to locate facilities only on the cities where products are located (cf. section 3.1), except for Luxembourg for which we could not find sufficient information. The number of client cities is 41, and the number of candidate cities for facilities is 40. For each candidate city to locate a facility, we search for an available suitable facility and use its annual rent as opening cost. If the

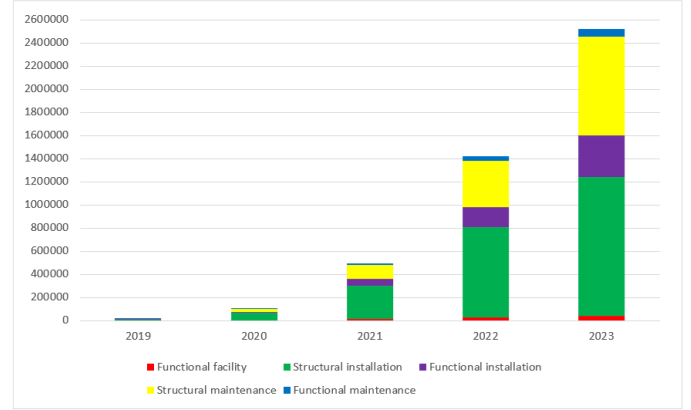
facility is opened for the first time, the real estate agency costs are also considered in the opening cost.

For the functioning cost of the facilities, the annual electricity consumption cost are calculated and added to the annual charges paid to the real estate agency.

### 5.2 Centralized Solution

The first step is to solve the problem using the strategy currently in process at the company. It consists in operating all the activities from the production site (centralized solution). In this part, there is only one possible facility, and the UFL-ILP will not decide where to locate the facilities. It will just calculate the costs and the number of technicians to hire.

Figure 4 shows a representation of the results per cost category and per year.



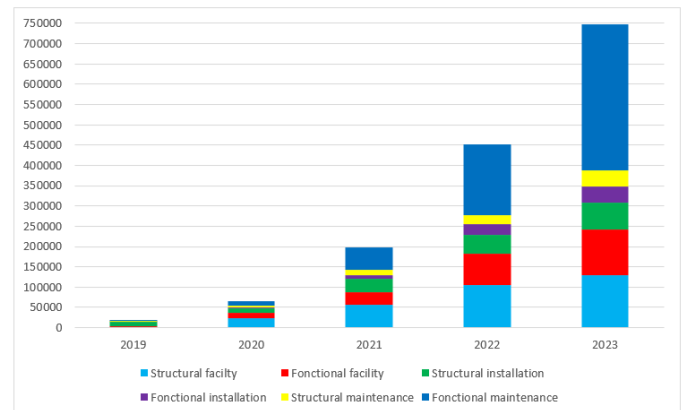
**Figure 4. Centralized solution's cost repartition**

In this solution, there is no structural facility cost, because no facility is opened, so there is no rent fee. We observe that the most expensive costs are the structural installation cost and the structural maintenance cost, which represent the transport costs of the system.

### 5.3 Decentralized solution

In this part, the program is run with the possibility of opening several facilities, to answer the problem first defined (*i.e.* design the logistics network).

Figure 5 shows a representation of the results per cost category and per year. Maps showing the network obtained each year are available in Appendix 3.



**Figure 5. Decentralized solution's cost repartition**

In this solution, the most expensive costs are the functional maintenance cost and the structural facility cost.



Figure 6. Comparison of the two solutions

#### 5.4 Comparison of the Solutions: Centralized vs. Decentralized

After we ran the program for the two solutions and calculated all the costs, the results have been compared to identify which solution would be the most interesting for the company. Figure 6 shows the cost comparisons for each activity and for the total costs over 5 years of the business plan.

The centralized solution is more interesting in terms of facility cost. Indeed, only the Grenoble site is opened every year, but its opening cost is set to zero because the site already exists. Regarding this, the facility cost is reduced in the centralized solution. But this facility cost savings is low compared to the savings made on installation and maintenance costs in the decentralized solution. As the facilities are closer to the customers thanks to the decentralized logistics network, the transport costs are indeed much lower than in the centralized solution. Finally, the total costs (bottom right chart) of the decentralized system are lower (and even three times lower in 2023) when compared to those of the centralized one.

Table 4. Variations of the failure rate

Age category	Young	Medium	Old
Variation 1	0.25	0.30	0.37
Variation 2	0.30	0.35	0.42
Variation 3	0.35	0.40	0.47
Variation 4	0.40	0.45	0.52

The failure types proportions,  $\beta_1$  and  $\beta_2$ , are related by the formula  $\beta_1 + \beta_2 = 1$ . Table 5 details the values of  $\beta_1$  used in the sensitivity analysis depending on the products' age category.

Table 5. Variations of the failure types' proportions

Age category	Young	Medium	Old
Variation 1	0.60	0.55	0.50
Variation 2	0.70	0.65	0.60
Variation 3	0.80	0.75	0.70
Variation 4	0.90	0.85	0.80

## 6 SENSITIVITY ANALYSIS

A sensitivity analysis has been conducted to identify which parameters could influence the results. We have chosen to vary four parameters: the action range, the products repartition in the cities, the failure rate, and the failure types proportion regarding the failure rate.

### 6.1 Parameters

The action range was initially 48 hours, which is a specification of the company's rental contracts. We choose to run the program with an action range of 24 hours, 20 hours and 10 hours.

The product repartition depends on two parameters, the population rate and the occupation rate. These parameters are respectively weighted by the values  $\alpha_1$  and  $\alpha_2$ . These values are initially set to  $\alpha_1 = 0.1$  and  $\alpha_2 = 1 - \alpha_1 = 0.9$ . The program is run using  $\alpha_1 = 0.2$  to  $\alpha_1 = 0.9$  incremented of 0.1 each time and with the corresponding values for  $\alpha_2$ .

Table 4 details the values used for the failure rate depending on the products age category.

### 6.2 Results

The results of the sensitivity analysis are detailed in Table 6. A '0' means that none of the variations influences the result. A '+' and a '++' mean that respectively one and two variations influence the result. A '+++' means that at least three variations influence the result. Looking at the results, it is to note that the most influencing parameters are the products repartition and the failure rate. Each variation of these parameters has indeed a significant impact on most of the cost types.

About the action range, this parameter impacts the result only when it is set to 10 hours (otherworldly divided by nearly 5 from 48h). Thus, we can conclude that the solution is not very sensitive to this parameter, except if this constraint becomes very strong, that is to say in the hypothesis of a high quality service.

Finally, the failure types proportions impact only the functional maintenance cost. This can be explained by the fact that these parameters do not appear in the UFL-ILP, and hence have no influence on the structural costs.

**Table 5. Variations of the failure types proportions**

	Structural costs			Functional costs		
	Facilities	Installation	Maintenance	Facilities	Installation	Maintenance
Action range	+	+	+	+	0	+
Products repartition	+++	+++	+++	+++	++	++
Failure rate	+++	+++	+++	+++	0	+++
Failure types proportions	0	0	0	0	0	+++

## 7 OUTSOURCING AND RECOMMENDATIONS

For the start-up company, different configurations (centralized vs. decentralized, with outsourcing or not) of the logistics network are designed. We try to find which one is the most interesting for the company in terms of costs. The first step is the identification of the network configuration, the different service activities and the outsourcing options available for each one.

### 7.1 Logistics Network Structure

As stated before, the logistics network can be centralized or decentralized. To compare both options, we totalize of the structural and functional facility costs.

### 7.2 Installation Service

This concerns the installation of the products at the clients' premises. This includes the transport of the product from the company to the installation site, and the installation intervention. This can be outsourced or not. To compare both situations, an offer made by a logistics service provider is used. We classify the costs of the provider's offer into categories and calculate the invoice for the company. Then, we calculate what it would cost to the company if it were internalized, using the same cost classification.

### 7.3 Maintenance Service

This is about the products maintenance at the clients' premises (i.e. failure repair). This includes the intervention cost, the component cost, and the technician's transport cost. This activity is necessarily internalized because it is a core component of the company's service and product offer.

### 7.4 Transport of Products

The transport of products is subdivided in two components.

- The upstream transport includes the way from the company to the facility inventory. This subcomponent is considered only when we choose a decentralized network.
- The downstream transport includes the way from the facility inventory to the customer. In case of a centralized network, this is the way from the production site to the customer's premises.

If the installation service is outsourced, the service provider manages this part, and so we do not have to make a decision on this. Otherwise, we can choose to outsource it or not. To estimate the cost invoiced by a transport provider, the transport costs we calculated for the UFL-ILP are used, and are increased by 15% to consider the functioning fees and the margin of the carrier.

### 7.5 Recommendations

Six different scenarios are built using all the possibilities we enumerated and calculated the overall costs of each one. Based on this comparison, the least expensive configuration was the

one with a decentralized network, internalized installation service and outsourced transport. In this configuration, the company is in charge of the facility, installation and maintenance activities. The service provider will manage the upstream and downstream transports. The cost of this configuration is close to the one of the configurations in which we have a decentralized network, with outsourced installation.

As the outsourced transport costs are an estimation, the study could be more precise if we considered a real carrier's offer, so that the choice between those two scenarios could be more reliable.

## 8 CONCLUSION

The aim of our work was to design a logistics network dedicated to a growing company which uses a PSS business model.

To reach this goal, a complete methodology have been built based on a data model representing the system, the product life cycle and the expansion strategy of the company over its 5 years business plan. This data model has been used as an input for our adaption of an Uncapacitated Facility Location based ILP which allowed to design optimized logistics networks and estimate the overall system costs.

We completed the study by a report on the different strategies that the company could adopt. The comparison of these strategies leads to recommendations for the company regarding outsourcing possibilities.

The goals of this study have been globally answered, but the work we carried out can be extended.

First, we built a linear life cycle model for the products. As the product of the company are still young, there is a lack of data about the way they will work with the time. A more complete life cycle analysis on the products could help to understand better how they evolve, and then offer a more precise model in terms of maintenance activities.

Then, with the upcoming expansion of the company, more data will be available. This can allow to consider other aspects of the problem which are currently overlooked, such as vehicle routing for simultaneous installations or maintenances at the clients' premises or spare parts and consumable refurbishment management at the facilities. We could use more sophisticated models as Location-Inventory-Routing Problems to address these aspects altogether.

Furthermore, as stated before, the outsourced transport costs are estimated, this can be further refined with real offers to better specify our recommendations.



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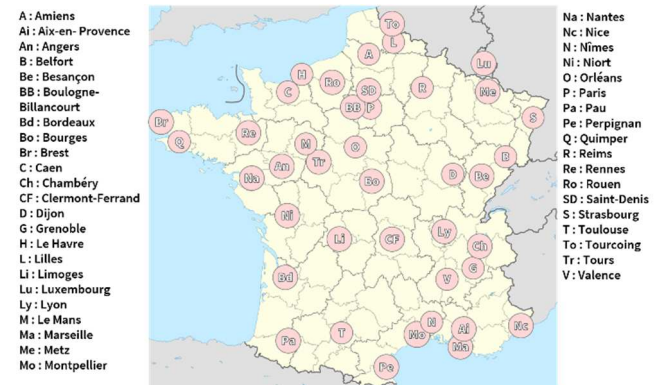
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**10 APPENDICES**

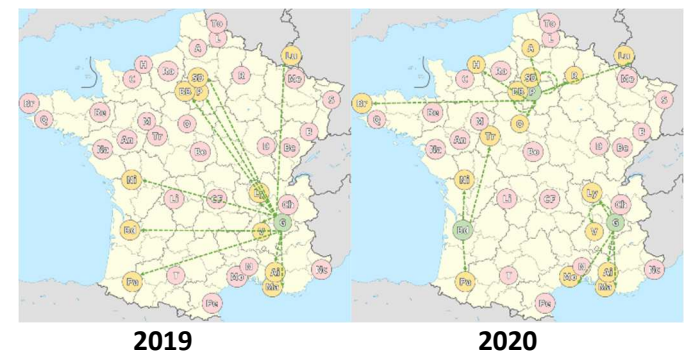
*10.1 Appendix 1 – Final Geographical Scenario*

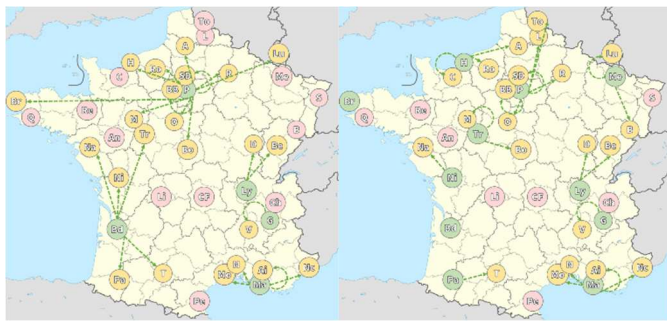


*10.2 Appendix 2 – Roster of Cities per Activation Year*

	Cities
2019	Lyon, Grenoble, Valence, Paris, Boulogne-Billancourt, Saint-Denis, Bordeaux, Pau, Niort, Marseille, Aix-en-Provence, Luxembourg
2020	Brest, Tours, Orléans, Reims, Amiens, Le Havre, Montpellier
2021	Dijon, Besançon, Bourges, Rouen, Toulouse, Nîmes, Nantes, Le Mans, Nice
2022	Belfort, Metz, Caen, Lille, Tourcoing
2023	Rennes, Quimper, Strasbourg, Angers, Limoges, Clermont-Ferrand, Chambéry, Perpignan

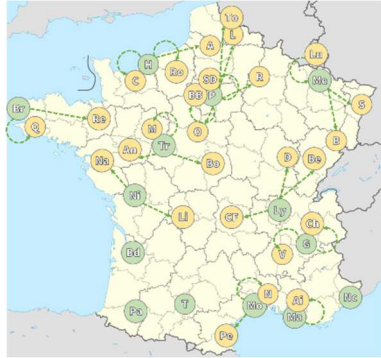
*10.3 Appendix 3 – Maps of the Logistics Networks over Five Years*





2021

2022



2023

Légende des icônes :

- A – Amiens
- Ai – Aix-en-Provence
- An – Angers
- B – Belfort
- Be – Besançon
- BB – Boulogne-Billancourt
- Bd – Bordeaux
- Bo – Bourges
- Br – Brest
- C – Caen
- Ch – Chambéry
- CF – Clermont-Ferrand
- D – Dijon
- G – Grenoble
- H – Le Havre
- L – Lille
- Li – Limoges
- Lu – Luxembourg
- Ly – Lyon
- M – Le Mans
- Ma – Marseille
- Me – Metz
- Mo – Montpellier
- Na – Nantes
- Nc – Nice
- N – Nîmes
- Ni – Niort
- O – Orléans
- P – Paris
- Pa – Pau
- Pe – Perpignan
- Q – Quimper
- R – Reims
- Re – Rennes
- Ro – Rouen
- SD – Saint-Denis
- S – Strasbourg
- T – Toulouse
- To – Tourcoing
- Tr – Tours