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Analysis and modelisation of the logistic network of Banco Alimentare

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CONTENTS

ABSTRACT

Banco Alimentare helps nearly one million and a half indigents by donating food subsidised by the European Union and collecting surplus food that would otherwise be disposed of. It is a *back-line* organisation, also known as *food bank*: food collected is donated to charities, which provide indigents with either hot meals or a box of items.

Much has been analysed in the thesis "The implications of logistics management for the food banking system: the case of Banco Alimentare Onlus" written by Valentina de Micheli: the main additions of this work are a detailed study on productivity and a new investigation on the matrices of flows.

The first has been performed starting from the data collected from a survey sent to each regional division of *Banco Alimentare*. Results have been further detailed by computing the productivity of each activity normally performed inside a warehouse. These have been then used in the last part of the work.

The latter regard matrices of flows. The analysis has been produced directly from data extracted from *SAP*. Differently from Valentina's work, it was preferred to analyse flows based on their commodity-related flows and on the macro-geographical area. The analysis allowed to understand the direction and the entity of flows; moreover, thanks to two additional pieces of research, it was possible to emphasize the importance of two inbound channels, *AGEA* and *Siticibo*, in terms of quantity and variety of flows received respectively.

The last part of the thesis is about the optimal logistic configuration for *Banco Alimentare*. After having implemented the principles of network design, an R code has been written. It receives as input data regarding annual inbound and outbound flows, a list of donors, charities and several other parameters to compute the number and position of all facilities in both echelons of the new network of *Banco Alimentare*. Different scenarios have been created to see how much total cost varies in

relation to different inputs. Total costs are computed for each configuration found.

Independently from the final configuration, network design principles suggest adopting a logistic chain with two echelons with transit points. Centralisation should help *Banco Alimentare* increasing food variety and levelling quantities of food available in different parts of Italy. Nowadays this problem cannot be ignored since an indigent in the North receives on average nearly twice as much the quantity of an assisted person living in the South.

The importance of the subject of this thesis lies in the fact that resources that *Banco Alimentare* can free from optimisation could be better employed for other purposes, such as improving the promising project *Siticibo*, hosting more educational events (both for an external public or for its employees and volunteers), or to extend its support to an increasing number of indigents. Resources available are limited and strongly depend on the donations and the work of volunteers: their use must be contemplated, to make the most avoiding any kind of loss.

SOMMARIO

Banco Alimentare aiuta in Italia circa un milione e cinquecentomila persone in estrema povertà fornendo cibo sussidiato dall'Unione Europea e raccogliendo surplus che altrimenti andrebbe sprecato. L'azienda è un'organizzazione _back-line_, anche detta _food bank_: il cibo raccolto viene donato a strutture caritative, che a loro volta preparano pasti caldi o lo cedono agli indigenti.

Molto è stato analizzato nella tesi di Valentina de Micheli nella sua tesi "The implications of logistics management for the food banking system: the case of Banco Alimentare Onlus": le principali aggiunte a questa vasto lavoro sono state un approfondimento sulla produttività ed una nuova analisi sulle matrici dei flussi.

La prima è stata svolta a partire dai dati di un sondaggio inviato a ciascuna divisione regionale del Banco. I risultati ottenuti sono stati ulteriormente dettagliati andando a calcolare la produttività delle attività normalmente svolte all'interno di un magazzino. Questi sono poi stati utilizzati nell'ultima parte del lavoro svolto.
La seconda aggiunta riguarda le matrici dei flussi. L'analisi è stata svolta a partire dai dati direttamente estrapolati da _SAP_. Differentemente dal lavoro di Valentina, si è preferito analizzare i flussi per categoria merceologica e per macroarea geografica. L'analisi ha permesso di capire la direzione e l'entità dei flussi merceologici; inoltre, mediante due analisi aggiuntive, è stato possibile evidenziare l'importanza dei canali _AGEA_ e _Siticibo_, rispettivamente in termini di quantità di flusso ricevuto e categorie merceologiche recuperate.

L'ultima parte riguarda invece la ricerca della rete logistica ottimale per _Banco Alimentare_. Dopo aver applicato i principi per la progettazione di reti logistiche, è stato scritto un modello in R che, ricevuti in input i dati riguardanti entrate ed uscite annuali, donatori, riceventi e svariati parametri, calcola il numero e la posizione di ogni struttura nel primo e nel secondo livello della nuova rete distributiva di _Banco Alimentare_. Sono stati creati

diversi scenari per vedere come i risultati del modello variano in relazione ai dati inseriti. Vengono inoltre calcolati i costi totali per ciascuna configurazione.

Indipendentemente dalla configurazione finale, i principi per la progettazione di reti logistiche suggeriscono l'adozione di una rete logistica a due livelli dotata di transit point. La centralizzazione dovrebbe aiutare *Banco Alimentare* ad aumentare la varietà di prodotti disponibili ed a livellare la quantità di prodotto donabile in diverse zone d'Italia. Attualmente questo problema sussiste e non è trascurabile, dato che una persona bisognosa riceve in media il doppio al Nord rispetto al Sud.

L'importanza di questo argomento di tesi è legata al fatto che le risorse che *Banco Alimentare* è in grado di liberare potrebbero essere impiegate per altri scopi, come potenziare il promettente progetto *Siticibo*, fare più eventi di formazione per il pubblico o per il proprio staff, oppure semplicemente per estendere il proprio sostegno ad una più larga porzione di indigenti. Le risorse di cui dispone sono limitate e dipendono fortemente dalle donazioni e dal lavoro dei tantissimi volontari: il loro utilizzo deve quindi essere ponderato, in modo da poter fare più possibile evitando ogni tipo di spreco.

EXECUTIVE SUMMARY

Banco Alimentare is an Italian food bank based in Milan but with warehouses and activities widespread on the whole national territory. It was founded to recover scraps and leftovers of industrial activities in Lombardy but then grew quickly into what, thirty years later is a reference organisation in its sector in Italy and Europe.

The role of a food bank consists of handling donated food and giving it to charities. *Banco Alimentare* receives food from several channels: the most important one is the *AGEA* channel, which flows are fully sustained by the European Union; *industry* is a channel that brings lots of products, but its concentration towards North is a cause for delivered food imbalance between northern and southern Italy; *Large-scale retailers* typically donate lower quantities compared to factories but the variety of food categories is wide, hence their importance; last but not least, *Giornata Nazionale Colletta Alimentare* is a one-day event organised by *Banco Alimentare* to collect food donated from people in supermarkets. Just as for charities, suppliers are distributed on the whole national territory, with a higher concentration in the North.

The purpose of this work is continuing the thesis *The implications of logistics management for the food banking system: the case of Banco Alimentare Onlus* (De Micheli, 2019 [9]), that is an analysis of the existing logistic network of *Banco Alimentare* and its modelisation together with the proposal of a new network configuration. This work will add pieces of research that were not conducted and a model in R to compute the location and number of facilities on the proposed optimising network.

A more detailed explanation of what has been proposed by the above-mentioned thesis has been produced. The most important parts were an analysis on productivity at a regional level, a research on the matrices of flows, the analysis of the as-is costs and proposal of four network configurations, all with thirty transit points but different central warehouses. Transportation costs and warehousing costs have been calculated for every scenario.
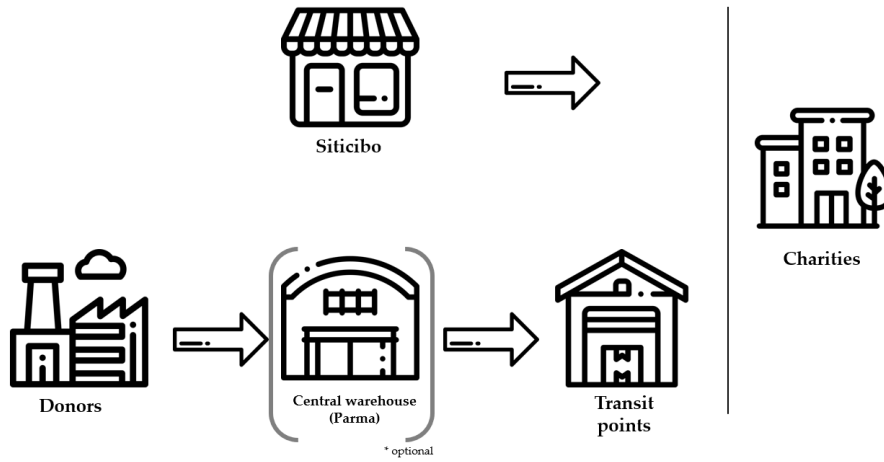
Figure 1: Representation of the actual network of *Banco Alimentare*.

As concerns this work, the analysis on productivity has been continued with a higher level of detail: after collecting the results of a survey provided to the Regional Directors of *Banco Alimentare*, it was possible to make a list of all warehouses of the network and to compute the value of productivity for each warehouse. The formula for productivity is the one reported below.

$$Productivity\left[\frac{t}{y*FTE}\right] = \frac{F_{in}\left[\frac{t}{y}\right]}{FTE} \qquad (1)$$

Since the value of productivity depends on both *FTE* and inbound flow F_{in}, an ABC analysis has been conducted on both results.

As far as regards F_{in}, the warehouse in Muggiò (Lombardy) accounts nearly twice as much as the second biggest warehouse in Fisciano, Campania. The first class represents nearly 30% of warehouses but accounts for 90% of overall flows; the last one, which groups half of the facilities, accounts for 3% on annual inbound flows. Figure 2 shows all inbound flows in descending order. The value of *FTE* has been computed according to formula 2.

$$FTE = FTE\ FT\ Employees + FTE\ PT\ Employees + FTE\ Volunteers \qquad (2)$$

Again, an ABC analysis has been performed on the value of *FTE* computed according to the data provided by each Director. Bigger warehouses are those who have more employees and volunteers and account for 73% of the total level of *FTE*; class C contains nearly 8% of total labour force. The shape of the plot of *FTE* in descending order has a shape similar to the one of figure
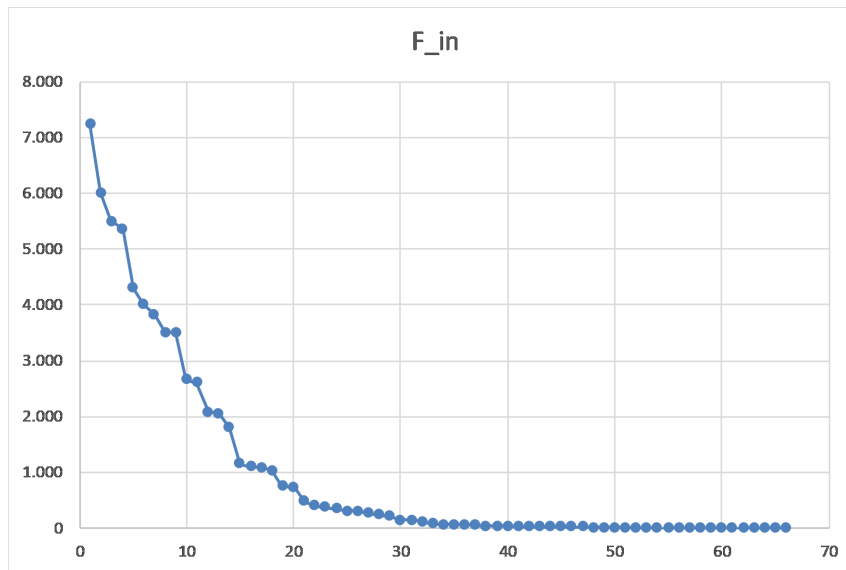
Figure 2: Inbound flows in descending order.

2.

Computation of productivity according to formula 1 followed. Figure 3 summarises the results found.

Linear regression has been applied to F_{in} against *FTE*. After cleaning data from outliers, the regression model fits the data, but a polynomial regression of grade two performs even better. It was possible to obtain a new regression curve, which has been reported in formula 3. Given arbitrary values of F_{in} inside equation 3, it was possible to plot F_{in} against *FTE*.

$$F_{in} = -1.1886FTE + 330.62FTE - 187.57 \tag{3}$$

This analysis shows that productivity reaches its maximum with an inbound flow around 4,000 $\frac{tonnes}{year}$ and 13 *FTE*.

In chapter 6.2, productivity has been assessed as regards logistic activities performed inside warehouses too. The aim of the research is finding throughput capacities to feed the final model: these data would be used to compute the number of employees per activity according to the quantity of flow managed. Moreover, a visit has been made to two warehouses, Parma and Moncalieri. Unfortunately, the analysis conducted after collecting data directly from a dozen of warehouses of the network has led to unreliable results. The facilities examined work in different conditions and handle different types of flows.
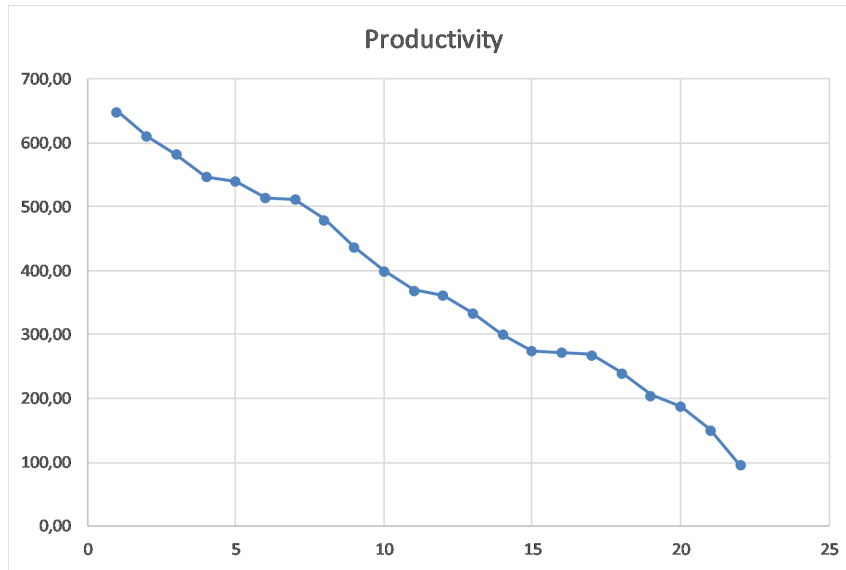
Figure 3: Productivity in descending order.

Activity	Value	Unit of m.
Delivery organisation	4	$\frac{FTE}{CW}$
Unloading and stocking	25	$\frac{Pallet}{hour*person}$
Pallet retrieval	25	$\frac{Pallet}{hour*person}$
Order preparation	*Variable*	$\frac{FTE}{Facility}$
Loading	33	$\frac{Pallet}{hour*person}$

Table 1: List of values of throughput capacities according to *DHL*, assumptions and computations made.

Regression helped to understand that data had to be refused. An external expert from *DHL* has been interviewed to provide esteems about throughput capacities of the activities previously highlighted. Computation for picking and order preparation depends on the time required to perform a single-command cycle, hence calculation of the number of workers depends on the size of the facility too. Values found have been collected into table 1.

The analysis of the matrices of the flows was conducted differently with respect to the one of the previous thesis [9]. In this case, flows have been analysed according to product groups and macro areas, instead of analysing inbound and outbound flows for each region without distinguishing between different types of food handles. Data has been taken from *SAP* and flows related to *Siticibo* have been included.

Results (please refer to table 2) show the differences between North, Centre, South and Islands in terms of food collection and redistribution for each food category. If on one hand it is true that most of the indigents live in the North, it is also true that quantities collected from factories, *Siticibo* and *Large-scale retailers* are much higher: since many products may be close to their expiry date, redistribution of these goods happens in the same macro area from where they originate. In this way, despite the higher number of indigents, assisted people in the North receive on average nearly twice as much as their similar in the South and Islands. Moreover, the variety of food received is worse in terms of nutritional content and food availability.

Analysis has been repeated excluding flows from *AGEA*. Results have become even worse, given the importance the program has for *Banco Alimentare*. If indigents living in the northernmost part of Italy would still receive nearly a half of their subside, those who live in the South and Islands would experience a drop in donations of 85% and 75% respectively.

Another research has been conducted focusing on food donated through *Siticibo*. The program actually accounts for 9.6% of the total inbound flows, which is roughly comparable to the quantities handled with the National Collection Day. Its importance lies in the variety of food handled: in fact, *Siticibo* is an important channel to enrich the food donated in terms of product categories and value density. However, since the program is more developed in northern and central Italy, most of the quantities collected are redistributed in these areas.

As regards the actual network of *Banco Alimentare*, it can be pictured with two echelons and several warehouses on the entire Italian territory. However, only 4,6% of flows pass through the central warehouse located in Parma: the network is *de facto* a one echelon network for most of the flows.

According to the lectures of Logistics Management held by Professors Alessandro Perego and Riccardo Mangiaracina (Melacini and Perego, 2017 [4]), the actual shape of the network should be the one represented in figure 1, with two echelons, where the second is constituted by transit points only.

Due to the high computational capacity required and lack of part of data, precise and optimising mixed-integer programming could not be implemented. The problem has been addressed in two subsequent steps: the first one applies k-means clustering to the charities to find the position and number of transit points;

	North	Centre	South	Island
Fruit and vegetables	10,5	7,5	4,1	2,2
Seasonings	6,6	6,4	5,7	5,2
Milk and derivates	12,0	9,2	8,1	6,4
Beverage	7,0	5,9	1,2	3,4
Cheese	0,8	1,1	0,0	0,3
Meat	0,8	0,3	0,0	0,1
Fish	0,7	0,6	0,3	0,3
Cereals, flour and pasta	13,2	12,2	10,2	11,7
Beans	2,3	2,1	2,1	0,1
Snacks and sugar	7,1	7,6	4,7	5,0
Infant food	1,0	0,4	0,1	0,1
Total [$\frac{kg}{pers*year}$]	61,8	53,3	36,5	34,7

Table 2: Total amount of kilograms of food that an indigent would receive on average in different parts of the country.
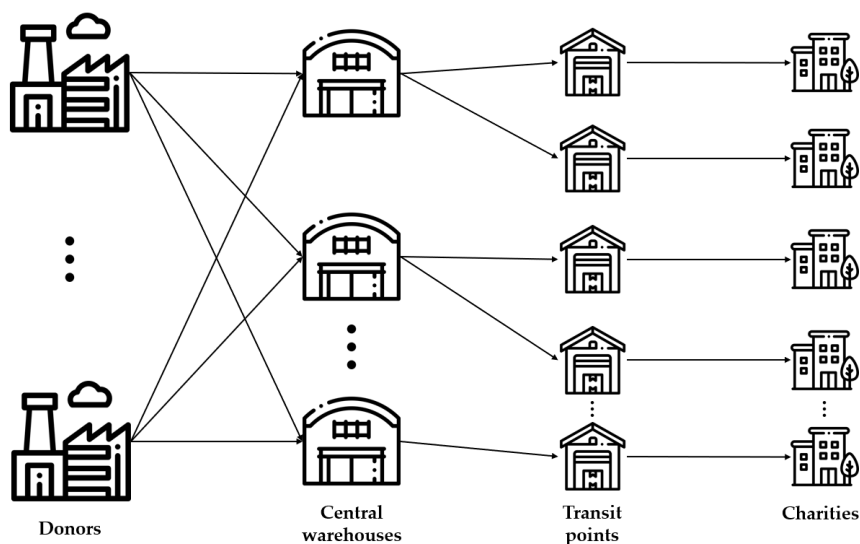

Figure 4: The new logistic channel of *Banco Alimentare* should be constituted by two echelons, where the second one consists of transit points.

the second one applies a centre-of-gravity approach to do something similar to the previous step but to compute the number and position of central warehouses according to the origin or destination of flows and their entity.

For each configuration transportation and warehousing costs have been computed: only the least costly solution has been selected amid all others. Moreover, the number of transit points is based also on the.

The best solution has two central warehouses in northern and southern Italy and 27 transit points, with a total expected cost of 7,277,537 €per year. All cost voices have been analysed and explained in a dedicated section 8.4.6 on page 90.

Transportation costs include *AGEA* products, which are currently shipped until the last echelon. What could happen is that the *FEAD* program, responsible for these products, decides not to renew the contract with *Banco Alimentare* according which transportation is covered until destination, which in the to-be case would be central warehouses. There could be savings up to 373,000 €per year if **Banco Alimentare** would be able to reformulate the agreement with its supplier.

Given the unbalance in terms of available quantity in different parts of the country, it is necessary to include an exchange of goods between central warehouses. It has been organised a transportation in full truckload every two weeks: this should help reducing inequalities.

Since the implementation of this project would require several years in the making, a mid-term solution has been proposed. It consists of adding the two central warehouses to the network and transforming the actual warehouses into transit points. In a second moment, it would be necessary to change the location and number of transit points to complete the transition from mid-term to to-be scenario. As regards costs, the total expenditure for this scenario has been estimated being around 8,633,367 €per year.

To conclude, some remarks about the work, data used and possible future developments have been produced. One of the biggest concerns is about factory donations directed to central warehouses. The risk is rejecting small donations due to unbearable transportation costs; a possible solution might be shipping these small or negligible quantities to transit points.

Another comment has been provided on data reliability. Unfortunately, several instances extracted from *SAP* did not prove

to be reliable enough and had to be corrected (if possible) or deleted.

The annexes contain each table related to the analysis of the matrices of flows and the code used by the model.

The aim of this work is proposing an improvement for the actual network of *Banco Alimentare*.

Centralisation has many advantages and allows the organisation to save money in transportation costs, which directly impact on expenditures. It is also possible to prepare orders in advance since each charity has a pre-allocated quantity of food depending on the number of accredited indigents. Furthermore, this configuration should improve the service level and the unbalance between different warehouses in different parts of the country.

INTRODUCTION ON BANCO ALIMENTARE

95 kilograms per capita: this is the average quantity of food surplus generated by an Italian citizen every year. It may seem little quantity in an entire year, but it is not. It means buying nearly 3 hectograms of unwanted food every day. It means that in a family of five people there is an average purchase of 500 kilograms of unnecessary food.

Nowadays nearly 800 million people around the world do not have "sufficient, safe and nutritious food that meets their dietary needs [. . .] for an active and healthy life", to cite the definition of the *Food and Agriculture Organisation* [11]. Meanwhile, in Europe 88 million tonnes of perfectly safe food are disposed of. This quantity of food is worth 143 billion €, which is roughly like the annual GDP of Hungary, just to provide the reader with an idea of the size of the problem.

Other researches suggest an annual *per capita* waste that is twice or three times bigger than the figures reported in the first part of this introduction.

It is clear that to make the Food Supply Chain more sustainable and ethical it is necessary to stop this paradox of food insecurity and waste [12]. There is still much to do to improve ourselves and to cease food hunger and denutrition, and this field of studies is still relatively new and unexplored, but trends let hope for improvement grow.

Many not-for-profit organisations have been founded to fight food waste and more and more companies are collaborating with them. New laws have been declared to help associations, foster food donation and prevent its disposal. Even consumers' attention towards food security, sustainability and other ethical aspects seem to become more and more important.

Since 2015, the European Union is trying to fight against the issue of food surplus, i.e. food that cannot be sold to its primary customers any more for various reasons. Different governments decided to solve the problem *ad hoc* laws, Italy promulgated law *Gadda* in September 2016.

Several are the innovations introduced by it, but the most im-

portant point is its objective: fostering donations through administrative simplifications and fiscal incentives by defining at the same time a safe standard to handle food. Everyone across the supply chain is satisfied and a collaborative and supportive environment is created between different actors.

Why and how are food surplus and waste generated? It is a problem that regards all actors of the Food Supply Chain (Garrone et al., 2015 [12]).
On the production side, food surplus generation is mainly an issue related to the expiration of the internal sell-by date[1] (67% of the total quantity of surplus food generated), non-compliance with aesthetical standards (12%), issues during the packaging process (6%) and refusals or returns due to unsold products (15%).
In the retail stage of the supply chain, 49% of flows are still related to the reach of the sell-by date, 28% to returns or refusals and the remaining part to non-conformities.

Managing surplus food follows a hierarchy of steps that precede disposing of wasted food (refer to figure 5): *prevention* means doing everything possible to avoid the creation of unnecessary food, like improving demand forecasts and marketing actions; *redistribution* means recovering all surplus food and direct it to secondary channels; *recycling and recovery* include transforming food into energy, using it to feed animals or to produce other materials; *disposal* means incinerating food or putting it into landfills to destroy it. The first two are related to *waste prevention*, the last ones to *waste management*; preventing is the best option while destroying without recovering anything from food is the worst one.

Recovery is undoubtedly the part on which this thesis is focused on: however, even this activity can be performed in different ways.
When a *commercial logic* is applied, surplus food is destinated to

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[1] The internal sell-by date is like an expiry date for the sales department of a company. The concept is simple: products flow from the beginning to the end of the supply chain going through transformations and getting nearer and nearer consumers. Products must arrive in the last echelon of the supply chain with a residual shelf-life that is sufficient to sell them. That is why there is a sell-by date: if products pass it without having arrived at the next actor along the supply chain, they residual shelf-life when arriving at the point of sale would not be the promised one.
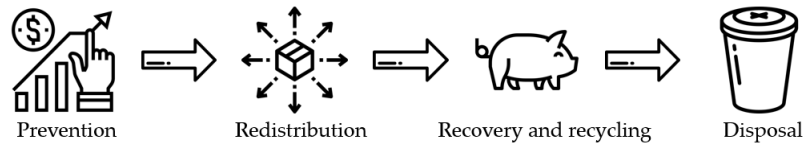
Figure 5: Hierarchy in surplus food management.

secondary markets (such as outlets or discounts); sometimes it can be used to sponsor events or for other kinds of actions.
When a *social-responsibility logic* is chosen, usually food is donated to not-for-profit organisations.

Nearly 90% of surplus food has a high or medium recoverability. But what makes some food to be said more or less recoverable? It is a matter of the point of the supply chain in which it is and the conditions at which it needs to be kept.
Food that does not need to go through different production steps is more recoverable than items that need to be processed more; fresh or cold foods need more attention in the way they are handled with respect to canned or dry food.

In Italy, there are nearly 15,000 NPOs dedicated to food recovery and redistribution. They can be divided into two categories: front-line organisations, that is companies dealing with people in need for this kind of support and back-line organisations, namely companies dealing with donors on one side and front-line associations on the other side.
The latter are also known as Food Banks: *Banco Alimentare* belongs to this kind of organisations. With the aim of providing food to other NPOs, *Banco Alimentare* assists nearly 1.5 million people in Italy. Its activities were mostly related to *macro logistics* activities, with significant shipments of food on long-distance, but in the latest years, a program called *Siticibo* is witnessing a steep increment in handled flows.

Today only 9% of food surplus in Italy is donated (Garrone et al., 2015 [12]): figures are expected to grow in the following years, hoping that more and more people in need could be helped in a better and better way. This work aims at providing a suggestion to improve the logistic network of *Banco Alimentare* to decrease costs maintaining at least the actual level of service. Saving money means freeing resources for new projects, im-

proving the existing ones or expanding the network: it means directly reaching a higher number of indigents with more food or ensuring better equity between quantities received by people in different parts of the country.

Figure 6: Logo of *Banco Alimentare*.

THE PURPOSE OF THE THESIS

The purpose of the thesis is continuing the assessment of the logistic network of *Banco Alimentare* made by Valentina de Micheli. Many considerations, hypothesis and examinations have been made in the thesis "The implications of logistics management for the food banking system: the case of Banco Alimentare Onlus [9]": considering it a starting point for the work described in the following pages, this document will deeper investigate on several aspects and inspect topics that were not mentioned in the above-mentioned work.

However, before entering in the details of these topics, a summary of Valentina's thesis is proposed.

5.1 SYNOPSIS OF THE PREVIOUS THESIS

This part will provide a summary of the thesis "The implications of logistics management for the food banking system: the case of Banco Alimentare Onlus". Much work has been done in understanding the product managed by *Banco Alimentare*, how its flows are directed and which productivity *OBAs* have, as well as in collecting many other details. In the end, the author proposes several network configurations and computes a total cost for each one of them.

Starting from the left part of the supply chain, those that will be called "donors" fall into one of the following descriptions.

- *FEAD* program [18] (which sometimes has been called *AGEA*[1]) is a European program aimed at fighting hunger. Each semester some products are bought through tenders: this food is then distributed through the logistic network of *Banco Alimentare*. Transportation to the final destination (i.e. *Banco Alimentare*'s warehouse) is charged to the program.

- *Fruit and vegetable markets* provide food according to a similar mechanism to the one explained above. Products are financed by the European Union.

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[1] Agenzia per le Erogazioni in Agricoltura.

- *Factories* provide surplus food to *Banco Alimentare* according to their stock surplus or other production unexpected events. Donations cannot be predicted and transportation cost is usually organised and paid by *Banco Alimentare*, even if exceptions can happen.

- *Large-scale retailers*[2] are donors too. Usually, the donated quantity is lower compared to factories, but their variety is higher, as explained in chapter 7. They are involved in the program *Siticibo*[3], which collects food from supermarkets, canteens and restaurants to directly donate it to charities.

- *The national collection day*, also known as *GNCA*[4] is a one-day event responsible for collecting nearly 9% of the overall volumes handled yearly. Its importance lies also in the fact that several critical food categories (such as infancy food) are mostly recovered on this occasion.

As concerns the right part of the supply chain, charities are widespread on the entire national territory and each one of them is recorded with address and number of accredited indigents per structure. An important finding of the required service level has been reported in the second survey [13] delivered by Valentina de Micheli. Nearly 29% of associations seem to be available to travel 20 kilometres to receive a shipment, while 62% of them can travel a distance which is less than 50 kilometres. At the moment, both these limits are not satisfied. Moreover, most of the charities need an increase in volume (more than 78%).

Regarding the matrices of the flows[5], most of the flows (but not all of them) originate from the North and are directed to the South. This is due to the higher industrial concentration in the northern part of the country; if part of the flows were not directed towards South, there would be a disparity in terms of quantity of food available in different parts of the country. In addition to this, regardless of where they are produced, *FEAD* products must be equally distributed among all indigents, according to the rules of the program.

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[2] In Italian it is usually referred to as *GDO*, Grande Distribuzione Organizzata. For its semplicity and since this acronym is widely used in *Banco Alimentare*, *GDO* has been used in this document too.
[3] *Siticibo* has been described in section 7.5 on page 57.
[4] Giornata Nazionale della Colletta Alimentare.
[5] This topic will be assessed in different terms in chapter 7 on page 44.

For the model, Valentina decided to compute the costs related to a two-echelon network with 2, 3, 6, 7 central warehouses and a fixed number of 30 transit points. The configuration with 2 central warehouses turns out to be the most convenient one, but with the recommendation of sharing costs and savings between *Banco Alimentare* and *FEAD* program, the inbound channel to which the highest level of inbound flows are associated.

PRODUCTIVITY

6.1 PRODUCTIVITY OF WAREHOUSES AND OBAS

The productivity of *OBAs* has already been computed by Valentina de Micheli in her thesis[1]. In the case of Lombardy and Piedmont, it was possible to recover data directly from balance sheets; for smaller *OBAs*, this was not possible and several surveys have been sent to collect the needed data. Indeed, data on *SAP* do not seem to be reliable enough: this was emphasised both by Valentina and Vittore Mescia, head of the Operations Department in *Banco Alimentare*.
Productivity has been computed according to formula 4,

$$Productivity\left[\frac{t}{y * FTE}\right] = \frac{F_{in}\left[\frac{t}{y}\right]}{FTE} \tag{4}$$

where F_{in} represents the yearly inbound flows in tonnes and *FTE* takes into account both employees and volunteers of the logistic department. In her thesis, Valentina considered volunteers depending on the entity of inbound flows, so that those warehouses with a more consistent level of voluntary workforce are not too much penalised in the computation.

Size	Flows	Coefficient
Large	more than 5,000	0.3
Small	less than 5,000	0.7

Table 3: Summarisation of how logistic volunteers have been taken into account according to the computations and assumptions in *The implications of logistics management for the food banking system: the case of Banco Alimentare Onlus*.

The analysis presented here is a continuation of this work with a higher level of detail. Nowadays, *Banco Alimentare* has no clear information about the flows moved in both terms of entity and direction. A survey has been provided to *OBAs* to collect

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[1] See chapter 5.10 of [9]

data about the number and location of warehouses controlled by each local organisation, the typology of warehouse, the value of inbound flow F_{in}, as well as the number of employees and volunteers working during opening time. Data received had been cleaned and checked (whenever possible): however, some information could not be recovered and results could not be computed[2]. Some of the provided information could be the result of an estimate made by those who replied to the survey: the accuracy of the results might be influenced by this.

Outcomes show how productivity is affected by the entity of its numerator and denominator.

The impact of F_{in}

As regards F_{in}, productivity is positively impacted by its value. The following table summarises the main warehouses in terms of inbound flows.

Region	Warehouse	Fin [t/y]
Lombardia	Muggiò	14.154
Campania	Fisciano	7.233
Catania	Catania	6.000
Emilia Romagna	Imola Zello	5.500
Piemonte	Moncalieri	5.353
Veneto	Verona	4.300
Calabria	Cosenza	4.000
Lazio	Aprilia	3.830
Emilia Romagna	Parma Fontevivo	3.500
Palermo	Palermo	3.500

Table 4: List of the ten biggest warehouses of the network in terms of tonnes of goods managed per year.

Almost every *OBA* was able to provide data about inbound flows, except for some *GNCA* warehouses and Daunia. *GNCA* is an extraordinary event that employs many resources. Due to its nature, it is difficult to keep track of all details that would normally be recorded. This regards information about F_{in} but also data about the operating time of each facility, the number of people employed and much more information. Daunia is a

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[2] Unluckily, there is no information about Trentino-Alto-Adige and Tuscany since they never replied to the survey.

different case: according to Filippo Varacca, responsible for the Parma - Fontevivo warehouse (buffer stock), Daunia is facing a troubled period due to the lack of a volunteer manager, at the moment this reasearch was carried out. Without this role, volunteers have no clear objective in their work and motivation is low. The above-mentioned problem might be caused by this. Image 7 represents the inbound flows in descending order.
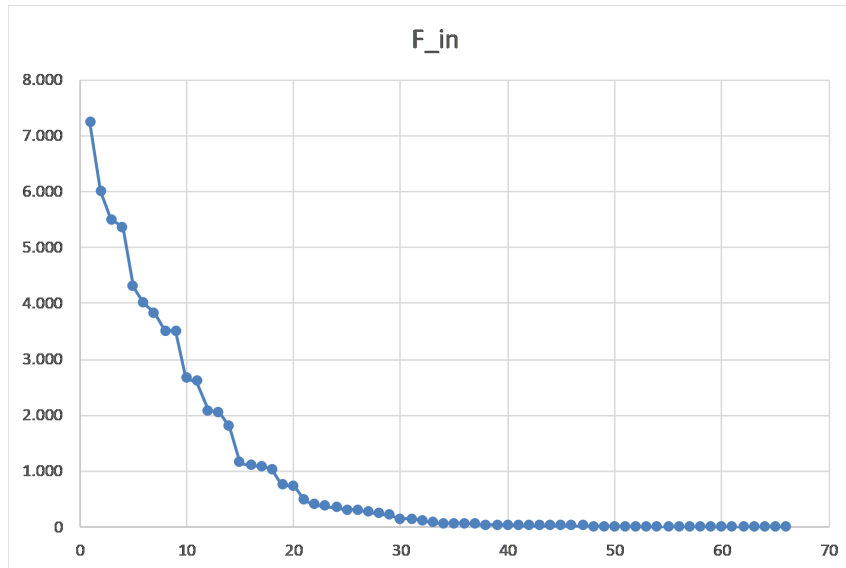

Figure 7: Inbound flows in descending order.

As you can notice, the first warehouse (Muggiò, Lombardy) is meaningfully bigger than the remaining ones. By applying the tangent method[3] to divide them into three classes, you can find the results displayed in table 5. At first glance, you can notice that Class A is wide, due to the very long tail of class C.

Class A, despite representing 30% of the total number of warehouses, accounts for nearly 90% of overall flows managed: Muggiò, the most relevant warehouse in terms of inbound flows accounts for more than 18% of total annual F_{in}. Class B has a number of warehouses similar to the one constituting class A, but its importance is much lower. Class C, as anticipated, contains nearly half of the warehouses under examination; however,

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[3] The tangent method is an approach used to perform ABC analyses. In finding class A, you need to compute the average of all values and label as "A" those who are higher or equal than the computed mean; to find all items of class B, you need to repeat the previous step for all values excluded those labelled as "A"; values belonging to class C are those who were excluded in the last iteration.

	Number of warehouses	% of flows
Class A	15	88%
Class B	12	10%
Class C	25	3%
Total	52	100%

Table 5: ABC analysis results

these facilities manage just 3% of overall flows. As regards their location, each class seems to be well-distributed through the country. Northern Italy hosts nearly a half of the total number of warehouses, Central Italy nearly half of the North, Southern and Insular Italy have a sensibly smaller number of facilities with respect to the Centre. This could be explained by of density of population in these areas, which follows the same pattern.

The impact of FTE

As for *FTE*, its impact on productivity is negative, being at the denominator of the formula for productivity. Its computation is the sum of three pieces of data recovered from the survey, as reported in formula 5.

$$FTE = FTE\,FT\,Employees + FTE\,PT\,Employees + FTE\,Volunteers \tag{5}$$

These three factors[4] refer to logistic employees and volunteers only. This data was even more difficult to provide for many *OBAs*, especially in the case of *GNCA* warehouses: it is generally much easier to quantify the collected amount of food rather than the number of people involved in the activities. This was just to say that unfortunately many *GNCA* warehouses were mentioned in the Excel files received but in most of the cases little or no information has been recorded about them.

Computation for *FTE* followed this logic: every person working in those warehouses had to be converted in *FTE*. The case of full-time employees was easy since each operator already works full-time. Part-timers are supposed to work four hours a day (i.e. each part-time operator accounts for half *FTE*) and exceptions have been taken into account.
The critical part is constituted by the last part of the formula,

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4 FT means full-time and PT part-time.

which translates volunteers into *FTE*. This conversion was based on two types of data provided by the *OBAs*: the average number of logistic volunteers working during opening times and the weekly duration of the activities for each warehouse[5]. Following formula 6, *FTE* for logistic volunteers was estimated.

$$FTE\ Log.\ Volunteers =$$

$$\frac{Weekly\ Opening\ Time\left[\frac{h}{week}\right]}{40\left[\frac{h}{week}\right]} * ANVW \quad (6)$$

where ANVW stands for "Average number of volunteers in the warehouse. Table 6 and graph 8 condense the results of the main warehouses in terms of *FTE*.

Region	Warehouse	FTE
Lombardia	Muggiò	52
Piemonte	Moncalieri	26
Lombardia	Siticibo ristorazione (transito)	22
Campania	Fisciano	20
Veneto	Verona	16
Umbria	Perugia	14
Calabria	Cosenza	12
Liguria	Bolzaneto	12
Catania	Catania	9
Emilia Romagna	Imola Zello	9

Table 6: List of the ten biggest warehouses of the network in terms of *FTE*.

As you can notice from graph 8, *FTE* tends to be extremely high for a few warehouses and pretty low for the majority of them.

An ABC analysis was performed using the tangent method. Differently from the previous case, the number of warehouses belonging to each class seems to be more homogeneous, even if their relative importance in terms of *FTE* is significant.
Class A accounts for 73% of total *FTE*, class B for 19% and class C for 8%. Muggiò (Lombardy), with more than 50 *FTE*, is 17.5% of the overall value of *FTE* of the network.

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[5] In some cases, one of these two items was estimated on the basis of the data provided by each *OBA*.
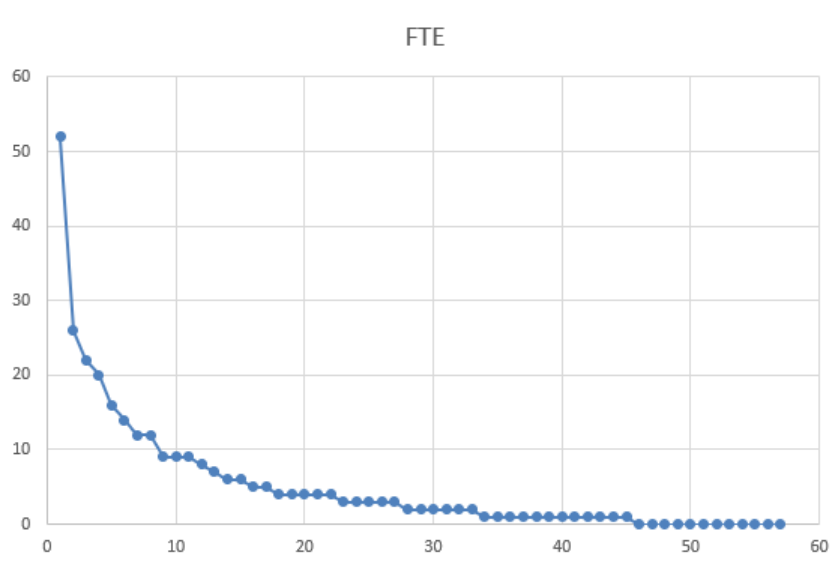
Figure 8: FTE in descending order

Results of productivity

Table 7 collects some of the results of the computation of productivity in descending order. Since for several of the warehouses

Region	Warehouse	Productivity	Fin [t/y]	FTE
Catania	Catania	667	6.000	9
Puglia	Taranto	650	2.600	4
Emilia Romagna	Imola Zello	611	5.500	9
Emilia Romagna	Parma	583	3.500	6
Lazio	Aprilia	547	3.830	7
Marche	San Benedetto	540	1.080	2
Alessandria	Novi Ligure	515	1.030	2
Sardegna	Muros	513	2.050	4
Catania	Siracusa	480	480	1
Palermo	Palermo	438	3.500	8

Table 7: The ten highest results of productivity in descending order.

at least one between *FTE* and F_{in} is missing, the computation of productivity could be performed on half of the warehouses. Results show a homogeneous decrease in the descending order, as it can be noticed from the graph in figure 9.

It is interesting to assess an aspect mentioned by Filippo Varacca[6] during the visit to the warehouse in Parma. According

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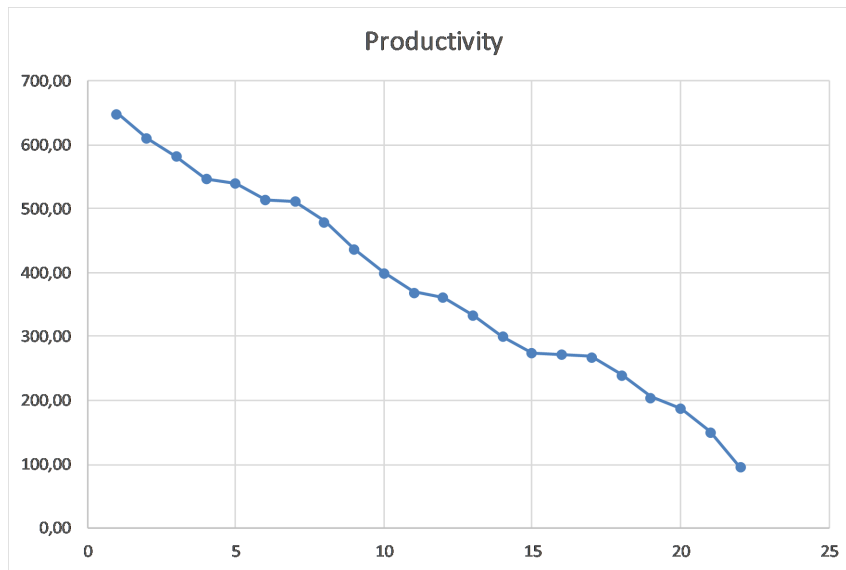[6] Responsible for the buffer warehouse in Parma Fontevivo.

Figure 9: Productivity in descending order

to him, inbound quantity and people do not increase proportionally, because of the increase in complexity generated by the growth of the organisation. To simplify its thoughts, he said: "if one person carries ten, to get twenty you need three people". The hypothesis behind this statement is that smaller warehouses are leaner in organisational terms and are more concentrated on the "traditional" warehousing activities, which can move a lot of quantity with few people; these activities concern moving pallet loads with forklift trucks and pallet jacks and preparing orders mostly.

On the other hand, bigger warehouses have increased their F_{in} progressively through the collection of smaller quantities of food, which employ a higher quantity of resources. These activities are conducted along with the "traditional" ones.

Here is a couple of examples of "less traditional" warehouse activities: "bananas boxes" and white products.

"Bananas boxes" is a colloquial way to refer to cartons in which donors put loose products. Not all warehouses can handle these boxes, since they need to be opened, loose products need to be sorted, checked, some of them removed and put in the garbage, and put in mono-product pallets. These activities are resource-intensive, and only a selected number of warehouses have enough workforce to do this.

White products are unlabelled items donated to *Banco Alimentare*. An example is typically the one of tomato puree. Pallets of white

products need to be opened, labelled, reassembled into pallet loads and put in stock. Again, this activity is labour-intensive and not all warehouse can perform it.

To verify the truthfulness of the statement above, F_{in} was plotted against *FTE* and linear regression was performed. Graph 10 shows the data plotted with the regression line. According
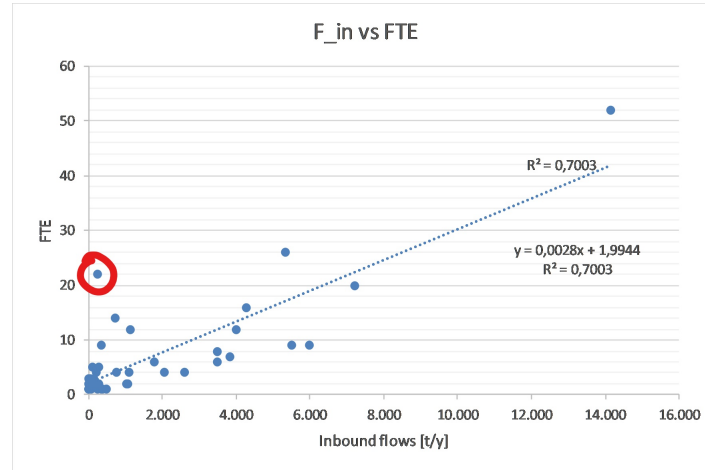

Figure 10: Plot with the regression line of inbound flows against *FTE*.

to the value of R^2, this model can explain 70.03% of the cases analysed. However, by considering the warehouse "Lombardia Siticibo Ristorazione" and the warehouse in Perugia as outliers (see the red circles in image 10), R^2 improves up to 81.38%. A slightly better result could be found by applying polynomial regression with grade 2 (see figure 11.). In this case, the model can explain 70.42% of instances, which can improve up to 82.38% by not including the same outliers of the previous analysis. This makes it good enough to prove the above-mentioned statement of Filippo Varacca, that is the non-linearity between *FTE* and F_{in}. The regression curve found in the previous computation is represented by formula 7.

$$F_{in} = -1.1886FTE + 330.62FTE - 187.57 \qquad (7)$$

A simulation of productivity can be obtained from formula 7 since it is possible to plot F_{in} with arbitrary values of *FTE*. Results can be seen in graph 12.
Productivity reaches its maximum with 13 *FTE* [7], which corre-

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[7] This result varies accordingly to the values used for regression. Graph 12 is extremely nervous: after having added two warehouses, the new maximum computed is nearly 1,000 tonnes smaller! However, its shape has not changed.
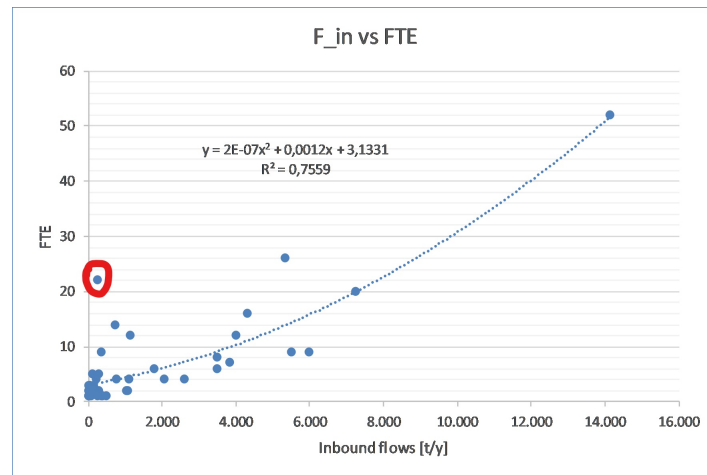
Figure 11: Plot with the regression curve of inbound flows against *FTE*.

sponds to nearly 3,910 $\frac{tonnes}{year}$ of F_{in}. In reality, productivity in warehouses can be much higher, due to higher values of F_{in} and lower *FTE*; a bigger sample and more homogeneous operating conditions between different warehouses could have improved the results in terms of precision.

Last but not least, the projection in figure 12 strongly depends on the regression line: in this case, being equation 7 a parabola, the plot of *FTE* against F_{in} reaches a maximum and then it declines, when in theory productivity should go to saturation without decreasing, unless increasing the number of workers becomes an obstacle to everyday activities (Varian, 2002 [16] and [10]) . However, you can still refer to the projection to see how productivity tends to vary in relation to F_{in} and *FTE*, given the non-linearity between these values.

To conclude, this analysis of productivity has led to results that have to be read carefully. *Banco Alimentare*'s network is constituted by warehouses of different kinds, with different sizes and dissimilar availability of workforce. Productivity can tell how much tonnes an *FTE* has moved in a year, according to the formula used, but this assessment should consider F_{in} and *FTE* too. It is necessary to keep in mind that if F_{in} grows, *FTE* will increase even faster, while productivity will slowly start decreasing its growth.
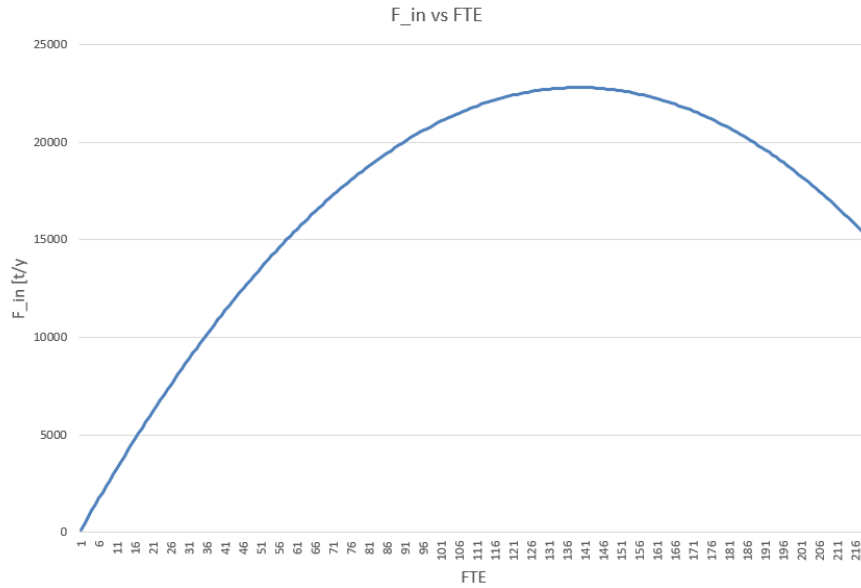
Figure 12: Projection of *FTE* according to F_{in} computed with the regression function.

6.2 PRODUCTIVITY OF ACTIVITIES INSIDE A WAREHOUSE

A more detailed study has been developed to investigate the productivity of each activity inside the warehouses of *Banco Alimentare*. The results found in this section will be directly implemented in the model to find the necessary number of workers for each activity in each facility of the network.

The starting point is defining the activities to measure. To do this, an official document [14] of *Banco Alimentare* has been used. This document, called "Gestione prodotti: Analisi processi generali", drafts the main activities of personnel depending on the main source of donation.

A list of the main activities has been outlined:

DELIVERY ORGANISATION This activity consists in keeping in touch with donors and organising transports towards the main warehouse of the *OBA*. In addition to this, personnel is in charge of recovering goods from factories and organising expeditions between the main warehouse in Parma and the *OBAs*[8].

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[8] Large mono-product loads are usually directed to Parma because it is difficult to make warehouses accept substantial quantities of the same product, due to limited available storage capacity. These aspects are coordinated by

UNLOADING AND STOCKING Once arrived at destination, items are unloaded from the truck by professional forklift drivers, who are usually devoted to this kind of work only.

QUALITY AND QUANTITY CHECK Items are checked before putting them into stock. Usually, it is very difficult to inspect items before loading the truck if the shipment is not associated with *AGEA*[9]: this leaves the possibility of acquiring damaged pallets that have to be disposed of. This activity is necessary to detect them and to eliminate them.

PICKING AND ORDER PREPARATION Each warehouse follows its own rules to perform this activity. Sometimes pallets are recovered from stock and placed in a picking area, where cartons are picked to compose an order only when the charity arrives[10]; in other warehouses orders are prepared before charities' arrival, just like in Moncalieri [2].

ADMINISTRATIVE ACTIVITIES Items have to be registered on *SAP* before putting them in stock. A document has to be prepared when items are left to charities too.

LOADING Once an order has been prepared, items are loaded onto the mean of transport of the charity. Some warehouses, due to workforce limitation, help with forklifts only in case of lorries, leaving charity volunteers alone in this activity in case of vans or cars.

A survey has been provided to a series of warehouses to collect data. The control group is diverse in terms of size and location. Table 8 summarises the warehouses included in the survey.

Unfortunately, some Directors (i.e. the addressee of this survey) were not able to reply to the survey. This was not uncommon since data requested by the survey are not recorded and required several experts in warehouse activities to give esteem. Moreover, the request came in an unfortunate event, since

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Filippo Varacca, which works as a single reference point of *Banco Alimentare* towards large companies widespread on the Italian territory. He is in charge of deciding how to allocate big donations among different warehouses according to the quantity donated, its location and what *OBAs* need.

[9] This problem was emphasised by Vilma Soncin, Director of the Regional Food bank of Piedmont, during the visit to the main warehouse of Moncalieri.

[10] In Parma, this activity is carried out in this way, according to what Filippo Varacca said in an interview in December [1].

Warehouse	OBA	Size class	Included
Foggia	Daunia	C	Yes
Moncalieri	Piedmont	A	Yes
Muggiò	Lombardy	A	Yes
Fisciano	Campania	A	Yes
Pasian di Prato	Friuli-Venezia-Giulia	C	Yes
Aprilia	Lazio	A	Yes
Pescara	Abruzzo	B	Yes
Florence	Tuscany	B	No
Palermo	Sicily	A	Yes
Verona	Veneto	A	No
Trento	Trentino-Alto-Adige	C	No
Imola	Emilia Romagna	A	Yes
Novi Ligure	Alessandria	B	Yes
Bolzaneto	Liguria	B	Yes

Table 8: List of the warehouses that were asked to take part in the survey and their main attributes. The last column indicates whether they have been included or not.

OBAs were asked to provide the headquarters in Milan some important documents regarding the *FEAD* program, and some regional divisions were in difficulty.

Directors were asked to say how many people were working for each of the activities listed above on page . Since scraps are detected before putting into stock, *OBAs* were asked to provide the annual inbound quantity of food managed in $\frac{tonnes}{year}$ as well as the overall quantity of damaged food to be disposed of. Therefore the quantity managed before quality checks needs to include annual scraps.
However, refuses strongly depend on the type of flows managed (flows related to the *FEAD* program are almost perfect since in case of defects the entire lot can be refused) and on the warehouse, since many of them do not record them in *SAP*. For those who do not appear on the system, an esteem of wasted material has been made on based on the expertise of the personnel inside each *OBA*.

Conversion of the number of employees and volunteers into *FTE* has been made according to the description produced by each Director.
Computation of productivity follows formula mentioned on

page 26. In any case, numbers have been checked and cleaned before using them.
Results have been summarised in figure 13, according to the numbers collected in table 9.
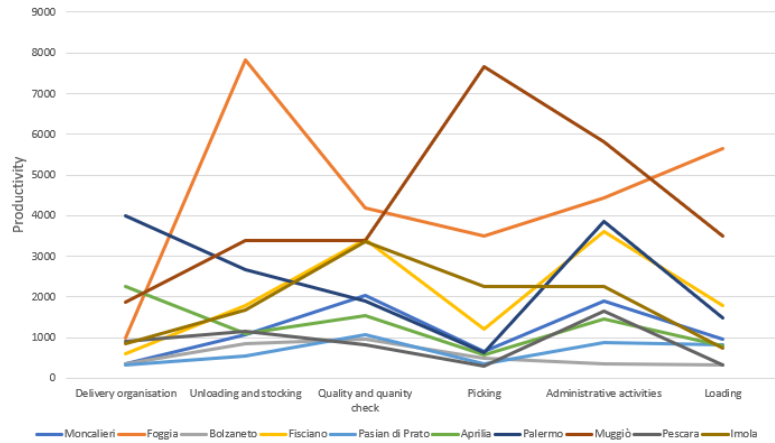

Figure 13: Plot of the evolution of productivity for each activity inside different warehouses of the network. Each colour represents a single warehouse.

The results presented in figure 13 and in table 9 are too diverse to be considered reliable.

To prove it, regression has been applied, which means finding an equation that can explain the behaviour of F_{in} with FTE. Figure 14 is the plot of F_{in} against FTE the dotted line represents the regression line together with the result of the R^2 index.
 At first glance, dots do not seem to have the awaited trend of productivity, as mentioned on page 35: the value of coefficient R^2 is around 0.01, which means that the regression line is able to explain 1% of the data with its equation.
By removing six entries with value of F_{in} above 10,000 $\frac{tonnes}{year}$, the value of R^2 seems to improve up to 0.0759, which is still too low to consider the regression line valid.
A polynomial regression of grade two has been applied either, with R^2 equal to 0.0791. Still, data do not seem to respect the theoretical trend of productivity and had to be rejected.

At this point, it is clear that data cannot be trusted and another solution needs to be found. Research has been conducted about productivity in warehouse activities and some results have been found.

Warehouse	Del. org.	Unload and stock	Check	Picking	Adm. act.	Load
Moncalieri	354.77	1.073.18	2.044.14	657.89	1,907.87	953.93
Foggia	998.65	7,829.44	4,194.34	3,499.41	4,445.97	5,650.08
Bolzaneto	367.38	857.22	964.38	498.9	365.35	340.16
Fisciano	595.21	1,800.5	3,429.52	1,200.33	3,601	1,800.5
Pasian di Prato	336.43	535.23	1,070.45	362.03	891.15	827.5
Aprilia	2,256.67	1,091.93	1,538.64	582.76	1,469.57	786.05
Palermo	3,991	2,660.67	1,900.48	643.14	3,858.83	1,498.57
Muggiò	1,882.11	3,387.8	3,387.8	7,662.73	5,813.10	3,512.08
Pescara	894.41	1,157.47	819.88	307.45	1,639.75	333.51
Imola	853.80	1,686.25	3,372.5	2,248.33	749.44	133.33

Table 9: Recap of the values of productivity per activity for the selected warehouses in $\frac{tonnes}{FTE}$.
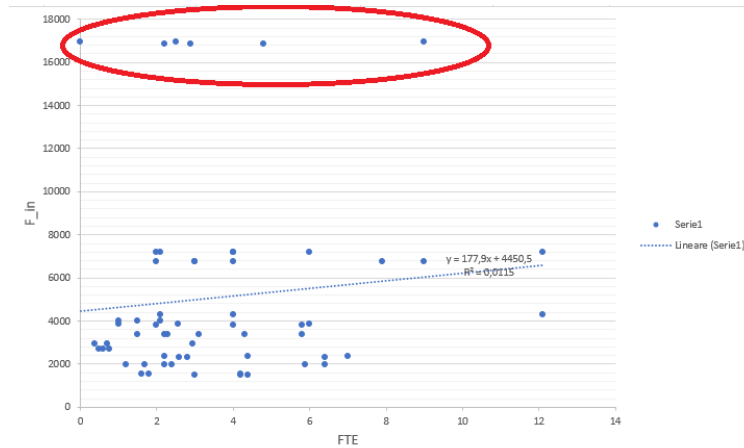
Figure 14: Plot of F_{in} against *FTE* and of their regression line. The circled values are those who were considered to be outliers.

A Management Engineer working for *DHL Logistics Italy* provided some esteems of throughput capacity of personnel inside Italian warehouses of *DHL* network. These values have been collected in table 10.

One advantage of referring to these values lies in the fact that *DHL* is a world leader in logistics: these values could be considered as targets that *Banco Alimentare* should tend to.

The activity of keeping in contact with donors, looking for possible donation opportunities and organising transports occupies three to five people in the warehouses that received the survey. Since the quantity they can bring to their warehouse depends more on the density of factories in the area where the warehouse is located rather than on the number of people working on this activity, a fixed number of four operators have been considered for each facility.

Administrative activities have been computed on the basis of other data provided by *Banco Alimentare*. Apparently, through-

Activity	Value	Unit of m.
Unloading and stocking	25	$\frac{Pallet}{hour*person}$
Pallet retrieval	25	$\frac{Pallet}{hour*person}$
Order preparation	1	$\frac{Pallet}{hour*person}$
Loading	33	$\frac{Pallet}{hour*person}$

Table 10: List of values of throughput capacity according to *DHL*.

put capacity for this activity seems to be equal to 105 $\frac{Pallets}{hour*person}$. This value is a simple conversion of nearly 2,500 $\frac{tonnes}{FTE}$, a result that has been found according to what Directors have esteemed.

Order preparation consists of picking several cartons to build a pallet to be shipped to customers. In this case, since boxes are retrieved directly from the storage area of the warehouse, composing a pallet is time-consuming. In the case of *Banco Alimentare*, you can imagine introducing a picking area where dedicated personnel picks a selected number of cartons from a mono-product pallet and puts them on another pallet that will be sent to a charity. In this sense, the throughput capacity of 1 $\frac{Pallet}{hour*person}$ esteemed by *DHL* cannot be considered suitable for the case[11].

The computation followed to get the throughput capacity of order preparation will be explained in the following subsection.

Computation of the throughput capacity of order preparation

The computation of throughput capacity for the activity of pallet preparation has to be explained in detail, hence the creation of this subsection.

The value provided by *DHL* was one pallet per hour and it did not seem to fit the case of *Banco Alimentare*. An estimation has been made to simulate its value.

Let us consider the data listed in table 11 and let us suppose the warehouse configuration in figure 15: each central warehouse will have a section dedicated to the store mono-product pallets and another one dedicated to the order preparation.

Pallets will be retrieved and placed in the green area, while operators will pick several cartons with a chart to fulfil an order. Once the pallets in the blue area are ready, they will be wrapped in plastic and loaded on a truck ready to be sent to the transit points.

The duration of the path of the picker depends on the length of U_{reale}: here is the list of computations made to find the necessary

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[11] The expert in *DHL* said that this throughput capacity refers to the composition of a pallet load considering the time needed to retrieve boxes directly from the storage area.
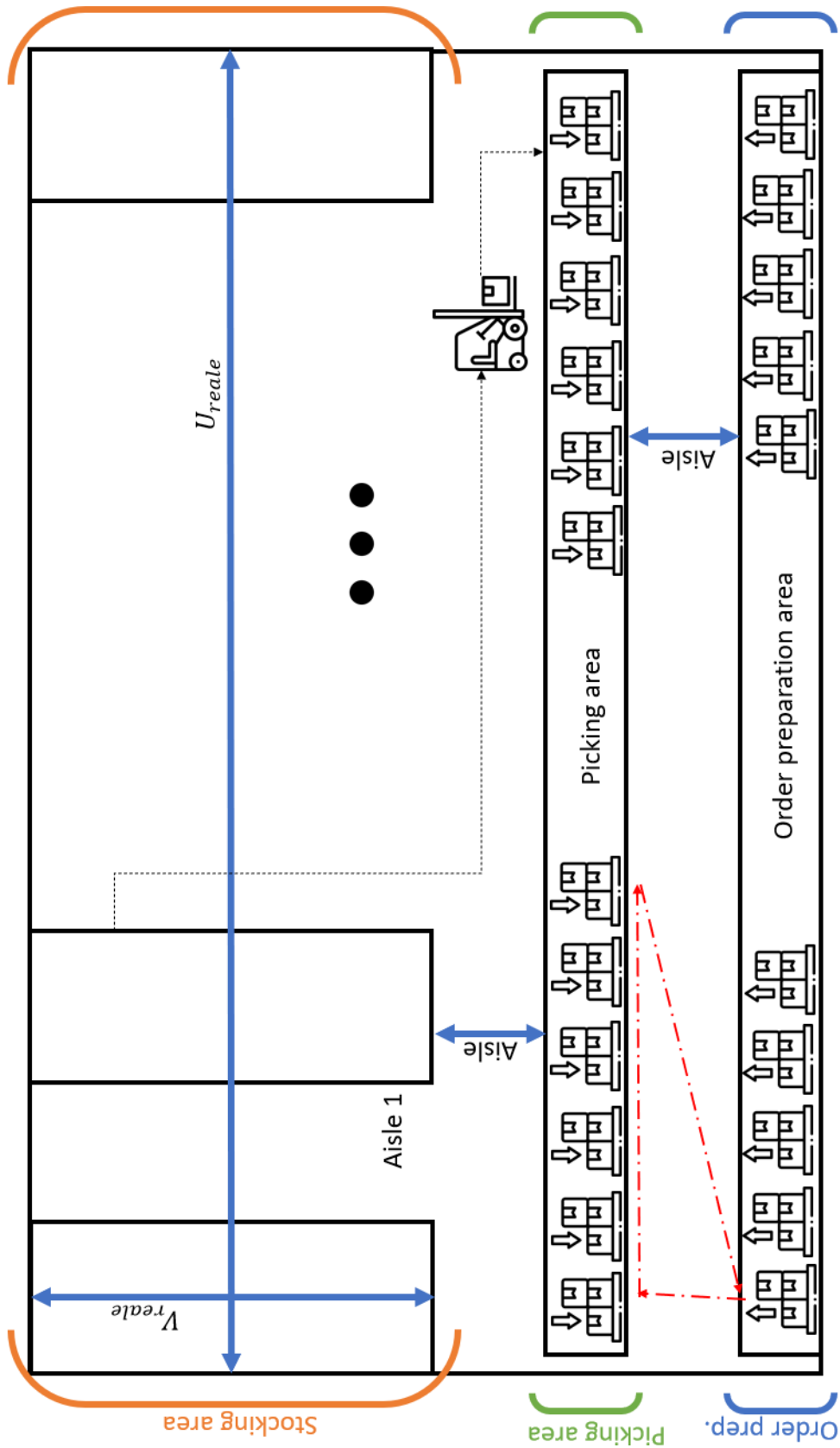
Figure 15: Configuration of a central warehouse.

time to complete a pallet.

$$T_{SC} = Fixed\ time + Variable\ time \tag{8}$$

where

$$Variable\ time = Number\ of\ trips * \frac{Path[m]}{Speed[\frac{m}{s}]} \tag{9}$$

Number of trips has been estimated being equal to 8 and it represents the number of trips that the picker needs to perform with a chart to complete a pallet. It is the division of the number of cartons per pallet and the capacity of five cartons per chart. The shape of the path is a triangle, where one cathetus is the aisle (5 metres) and the other one is half of U_{reale} (it has been represented in red in the lower left corner of figure 15).
The result states the number of minutes necessary to complete a pallet: you can get the number of pallets per hour, hence the number of people necessary to prepare all orders for transit points.

Name	Value	Unit of m.
Pallet jack retrieval	30	Seconds
Pallet wrap-up	1.5	Minutes
Dimensions of a carton	25 x 30 x 40	Centimetres
Cartons in a manual cart	5	Cartons
Number of cartons in a pallet	40	$\frac{cartons}{pallet}$
Operator speed	0.8	$\frac{metres}{second}$

Table 11: Data used to estimate the throughput capacity of the pallet preparation activity.

MATRICES OF THE FLOWS

This chapter is a continuation of section 5.8 of *The implications of logistics management for the food banking system: the case of Banco Alimentare Onlus*, describing and analysing the so-called "matrices of flows". These tools represent a way to display inbound flows depending on their area of origin and destination; in fact, these matrices have been used to assess the position of donors and suppliers as well as to understand where goods are directed. Flows have been divided according to their channel[1] and commented. After doing this, it was possible to plot each *OBA* on a graph according to its levels of non-local inbound and outbound flows, identifying the regions that share and donate the most as well as the ones that appear to be more in need of being supplied.

The available data used to continue the analysis are the same used for the above-mentioned research: different Excel files related to the year 2018 have been selected, merged, and cleaned. These files show the same data that could be found on *SAP*, with the advantage of having been corrected[2]. All information has been processed using RStudio (using the R language); eventually, several matrices of flows have been printed. To keep this chapter readable, just some of them will be presented and described here, while all of them can be found on page .

Data completeness was not always true and led to difficulties in the analysis. Many lines analysed were incorrect and therefore revised, many of them were incomplete and had to be eliminated. More than 600 lines related to flows received by Tuscany had to be excluded because there was no information about the area of origin of such products. Nearly 2,000 records related to Veneto were incomplete and not usable; therefore, this

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[1] i.e. *AGEA*, *Industry*, *GNCA*, *Siticibo*, *Fruit and vegetable markets* and *Distributors*

[2] This was confirmed by the Operations Department in *Banco Alimentare*, especially by Roberto Spinelli, responsible for the system: as a matter of fact, correcting a mistake on *SAP* is too complex and people prefer correcting a copy of the data on an Excel file.

OBA had to be excluded by the analysis[3]. There is no or little information about Sardinia because this *OBA* is not uploading information on *SAP* but using a program on its own instead. Aosta Valley had similar reasons to be neglected. Data regarding Apulia, Marche, Trentino and Daunia were limited to some inbound channels only (for example, Apulia uploaded records of *AGEA* and *Fruit and vegetable market* only).

Moreover, in her analysis Valentina decided to exclude *Siticibo* since the purpose of the analysis was understanding there flows originate and where they are sent to. *Siticibo* is local for local; therefore it was not meaningful to include this channel into this research[4].
For the purpose of this research, excluding this channel is wrong for two reasons. First of all, by following this rule above, all flows from all other channels originating and sent to the same region should have been excluded, and this was not the case. Second of all, considering food collected from *Siticibo* is important since it is still food that people receive in donation, no matter where it comes from.

To sum up, data of *Banco Alimentare* is partially incomplete and sometimes incorrect. The situation changes according to the *OBA* registering records and it strongly depends on the organisation of each *OBA*. If there is lack of personnel and there is no one fully dedicated to recording data on *SAP*, people might underestimate how valuable recording data is and information might be loaded with mistakes due to the urgency of performing other activities. Having people totally devoted to this will imply better advantages related to the learning curve and, more importantly, it will help *Banco Alimentare* ensure data completeness and correctness.

To conduct the analysis, food has been divided into eleven categories, which have been recapped in table 12. These classes have been obtained by aggregating the 140 food codes in terms of nutritional similarity or raw material origin. They represent the main food categories, not the complete variety of food offered by *Banco Alimentare*, having excluded a few codes. This is a good compromise between an excessive number of classes and a poor representation of food items.

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[3] Veneto started implementing *SAP* for its transactions in 2018.
[4] See section 5.8 on page 47 of [9].

Another important detail is the way the Italian territory has been divided. Regions have been aggregated to make tables easy to be read as well as to cope with the problem of missing or excluded data. The division follows the following rule:

NORTH Aosta Valley, Piedmont, Lombardy, Emilia - Romagna, Liguria, Veneto, Trentino - South Tyrol and Friuli-Venezia-Giulia;

CENTRE Tuscany, Umbria, Marche, Abruzzo and Lazio;

SOUTH Campania, Molise, Apulia, Basilicata and Calabria;

ISLANDS Sicily and Sardinia.

OBAs have been divided according to the same principle. As regards the inbound flows, the category "Abroad" had to be introduced, since some food categories are produced in foreign countries.

Food categories
Fruits and vegetables
Beverages
Infant food
Cheese
Milk and derivatives
Seasonings
Fish
Beans
Cereals, pasta and flour
Sugar and snacks
Meat

Table 12: List of the food categories created to develop the analysis

By working with RStudio on 2018 flows data, different matrices have been produced. Considering a certain food category, flows have been aggregated according to the area of origin and destination as mentioned above (meaning that flows from Lombardy, for example, are considered flows from the North since this region belongs to northern Italy.). From this table, which shows data in $\frac{kg}{y}$, two other tables have been derived: the first one presents each flow from origin i and destination j as a percentage of the total flows from origin i; the second one displays each flow as a percentage with respect to the overall yearly quantity collected. Finally, a table showing the percentage of flows from area i on the total of flows has been produced.

These matrices show flows under different perspectives. It is useful to understand the area of origin of the most important flows, as well as to understand how these quantities are sent to the rest of the country. For this purpose, the second and the last

type of matrix are the most useful, while the third one can be considered as a more complete version of the fourth one.

As already mentioned, data are not complete and some regions and *OBAs* are underrepresented. If it is true that regions with data issues are distributed across the country and not concentrated in one area, it is also necessary to specify that the goodness of the following analysis is based on the data available.

7.1 ANALYSIS OF THE MATRICES OF FLOWS

The analysis of the matrices of the flows shows different results for the different categories taken in exam. Due to this comments have been provided considering not only the location of suppliers and industries but also value density [$\frac{€}{kg}$], distribution of indigents and other logistic difficulties related to the features of each food class.

As regards value density, table 13 was drawn to summarise the main differences between them. As it can be noticed, some cate-

Food class	Value density $\frac{€}{kg}$
Fruits and vegetables	[1;3]
Beverage	[0;1]
Milk and derivates	[0;3]
Cereals, pasta and flour	[1;2]
Snacks and sugar	[1;5]
Seasonings	[0;5]
Beans	[3;5]
Cheese	[8;10+]
Meat	[8;10+]
Fish	[9;10+]
Infant food	[10;10+]

Table 13: Value density range in $\frac{€}{kg}$ for the food categories analysed.

gories have a low value-density (under 3 € per kilogram), some have a high one (above 7 € per kilogram), and some others are in the middle: in this last case, being categories an aggregation of different foods which are somehow related from a nutritional point of view, value density becomes broader. Together with other perspectives, this will help analyse food categories.

According to 2018 data about the associations to which is do-

nated, the number of assisted people (and their percentage) is the one summarised in table 14. In general terms, it can be

Area	Number of indigents	%
North	553,191	42.26%
Centre	195,533	14.94%
South	319,985	24.44%
Islands	240,349	18.36%
Total	1,309,058	

Table 14: Number of people assisted thanks to *Banco Alimentare* and their percentage on total

noticed that at least 25% of what is originated in a certain area stays in the same area to avoid unnecessary transportation costs: on average, the percentage is close to 65%. Nearly 80% of the inbound flows analysed come from northern Italy, less than 8% from central Italy and 13% from the south, as proof of the distribution of factories across the country. Marginal volumes originate from islands and foreign countries.

Nearly 80% of the overall quantity of *fruits and vegetables* comes from northern Italy. Most of what is collected is redistributed in the same area (almost 80%), and the rest is almost given to the Centre. South produces more than 20% of the total flows and donates almost a third of it to Northern Italy, while nearly a half stays in southern regions. The entire amount of flows from foreign producers, even if marginal, is donated to the North.
As regards *seasonings*, this variegated category aggregates oil, pasta dressings and other kinds of seasonings. This category is produced 50% in the North and 50% in the South. Northern Italy uniformly supplies the rest of the country (there is an important *AGEA* supplier in Cremona). The situation is similar in the South. Islands keep 100% of collected flows. *Milk and derivates* does not include cheese, which is represented by a dedicated class. Milk and other milk-related items such as yoghurt may be close to expiry date: most of these products are not transported too far and stay in the same area of origin. Almost all production is concentrated in northern Italy, which keeps almost 50% of production. Centre, South and Islands are uniformly supplied by the North. These areas, however, tend to hold more than 70% of the items collected.

Beverage is the class with the lowest value density. Indeed, these items tend to stay in the area of origin despite production is concentrated in northern (85%) and insular Italy (11%). The North keeps more than 70% of what collected and donates 20% to the Centre. Insular Italy behaves similarly by supplying to the South nearly 20% of product.

As concerns *cheese*, its value density is much higher than milk and derivates and its expiry date is longer too. Production is concentrated in northern and central Italy. While the Centre holds its product within its geographical boundaries (such as the Islands), the North supplies Centre and Islands mostly. The entire foreign production is donated to northern *OBAs*.

Meat mostly originates from northern Italy. Each area of origin tends to keep more than 85% of meat collected, while the remaining 15% is shared with the closest macro-area. An exception is the North, where 95% of product is generated; more than 10% is sent to the Islands too. Meat can be either frozen or fresh; in both cases, its expiry date is generally close. Transporting these items is also more expensive than other long-term items. Similarly to meat, fish is almost entirely collected in northern Italy. Central Italy donates 40% of its collection to the North and the Islands, while the latter keep everything they are given. Northern Italy keeps almost 60% of its product and donates 17% to Centre, 14% to South and the rest to the Islands. Apart from fresh fish, this category seems to be easier to move with respect to meat.

As for *cereals, pasta and flour*, the North produces 75% of flows and the South the remaining part. The first delivers products the remaining part to all other regions, while the latter supplies Islands only. In central and insular Italy, products tend to be kept in the same area.

Production of *beans* the only one in which the North is not the most important area of origin, since it accounts for 32% of flows, while the South accounts for the remaining 68%. Central and insular Italy hold most of their production, while North and South supply the entire country. There is an important *AGEA* manufacturer in Campania.

Snacks and sugar are mostly produced in northern (75%) and central Italy (24%). Both areas donate their flows to every part of the country.

Infant food is high in value density and high in importance. Nearly 90% of this class is produced in northern Italy, which keeps nearly 80% of its product. The remaining part comes from

the Centre, which shares its products with South and North.

In general, it can be said that production is mostly concentrated in the northern part of the country where, among other things, the majority of indigents live. Transportation of food is subject to the collection in each area too since sometimes transporting donated food from north to south is too costly.
It would be interesting to see, according to the available data, which categories of food people get across the country and in which quantity.

7.2 FOOD VARIETY ACROSS THE COUNTRY

Flows received in each area of destination have been aggregated; then, a percentage has been computed according to formula 10.

$$\%Flow_{i,j} = \frac{\sum Flow_{i,j}}{Total\ Flow_i} \tag{10}$$

where i indicates the area of destination and j stands for the food class. In other words, this calculation computes the weight of flows related to a certain food class against the total flows received. This calculation has been performed on the four areas of destination.
Results have been summarised in figures 16, 17, 18 and 19.
These simple graphs represent how food variety can be different across Italy.

North and Centre have similar graphs. *Cereals* account for one-fifth of what people receive, followed by *milk and derivates* (approximately 18%), *fruits and vegetables* (15%) and *sugar and snacks* (12-13%).
South sees an increase of *cereals* (nearly 30%), *milk and derivates* (23%), *seasonings* (15%) and *sugar and snacks* (13%). *Fruits and vegetables* account for 11%.
Isles receive 34% *cereals*, 18% *milk and derivates*, 15% *seasonings*, 14% *snacks and sugar* and 6% *fruits and vegetables*.
Beverage, which represents nearly 10% in each region, counts less than 4% in the South, which is mostly supplied by the Islands, where production is limited.

The fact that most of the production is concentrated towards north, the distribution of indigents, the quantity collected in
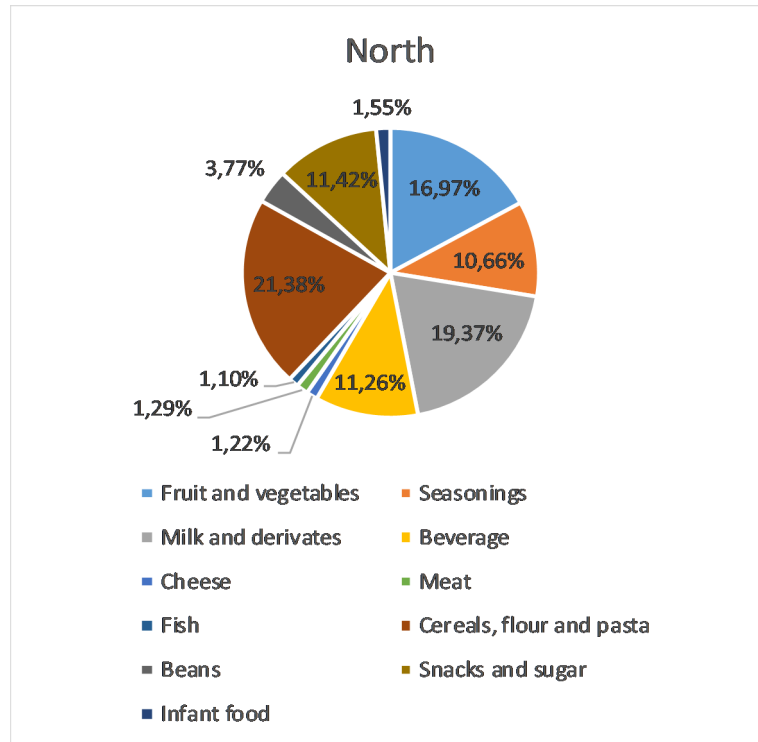
Figure 16: This graph represents the variety of food received in northern Italy in percentage terms.
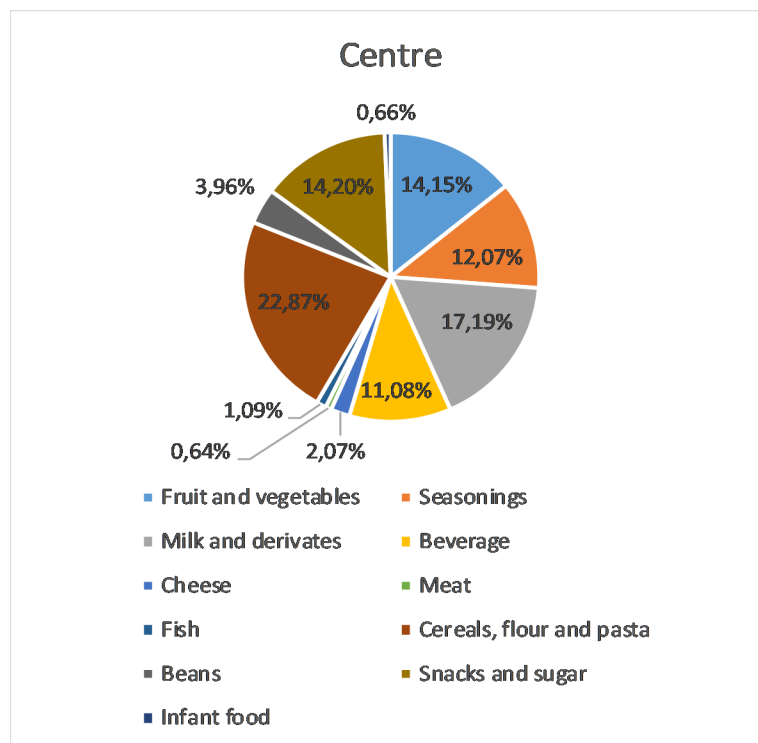

Figure 17: This graph represents the variety of food received in central Italy in percentage terms.
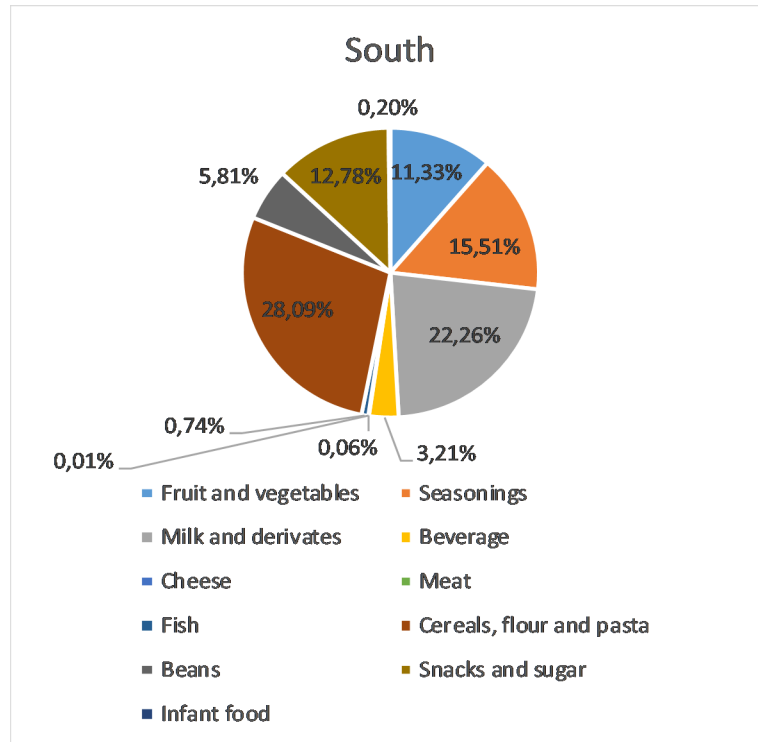
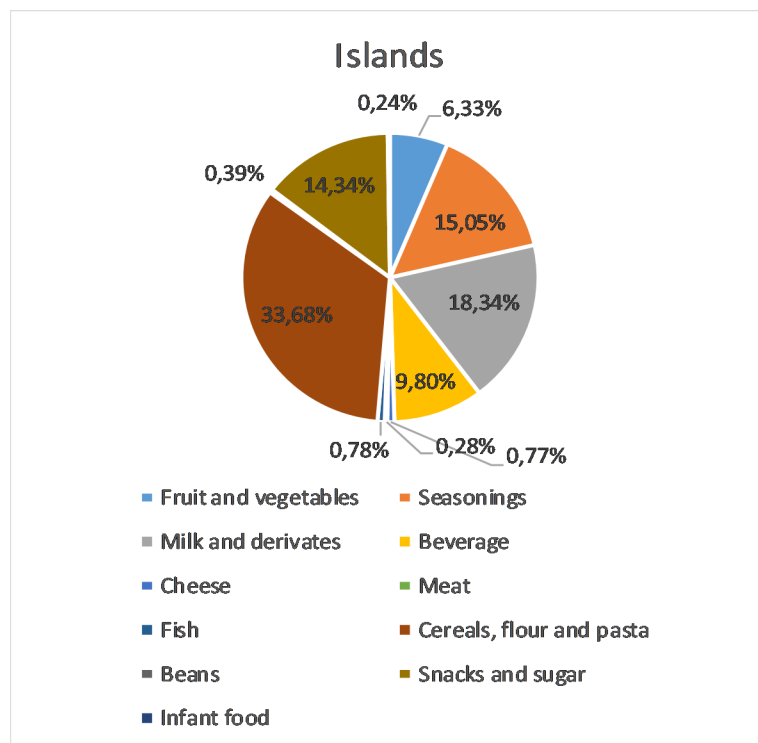Figure 18: This graph represents the variety of food received in southern Italy in percentage terms.

Figure 19: This graph represents the variety of food received in insular Italy in percentage terms.

each area (not from factories working with *AGEA*[5]), the costs related to the movement of goods as well as their features (e.g. freshness, expiry date) have a huge impact on the availability and variety of food available in each *OBA*, and this can be proved by the graphs above. The more the distance from the North, the more the percentage values change.

Beside this relative analysis about which categories indigents receive the most (on average) in different parts of the country, a quantitative one about how much indigents receive was performed.

7.3 FOOD QUANTITY ACROSS THE COUNTRY

After examining how the variety of food changes across the country, it is necessary to assess the quantity of food received. To do this, a sum was made on the number of assisted people for each *OBA*; these outcomes were later on aggregated according to the division of the Italian territory mentioned on page 46. Quantity $F_{i,j}$ where i stands for the area of origin and j for the food category was then divided by the total number of assisted people in area i. In this way, it is possible to make a comparison of the quantity of food available for each person in need in different parts of Italy.

Northern and central Italy are similar, despite having a difference of almost ten kilos per person of food donated. The main differences are in *fruits and vegetables* and *milk and derivates*.

Assisted people in the South receive nearly half with respect to people in the North. For each one of the categories, the available quantity is substantially lower compared to corresponding parts of other areas, except for the Islands. *Cheese*, *fish*, *meat* and *infant*

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[5] According to the *AGEA* tenders characteristics, products must be redistributed across the country depending on the number of indigents in each region. This means that even if the supplier is in the North, even the islands, the most distant macroarea with respect to northern Italy, will receive a quantity of goods proportional to the number of assisted people they have. Transportation is not up to *Banco Alimentare* since it is included in the tender. Conversely, products received from other channels such as *Siticibo*, *Fruit and vegetable markets*, industries and *GNCA* depend on what people or organisations *in loco* decide to donate. Unfortunately, quantities collected are low in southern and insular regions. Since transportation costs for these items are sustained by *Banco Alimentare* and expiry date may be close, possibilities of receiving what is needed are limited for the most remote parts of the country.
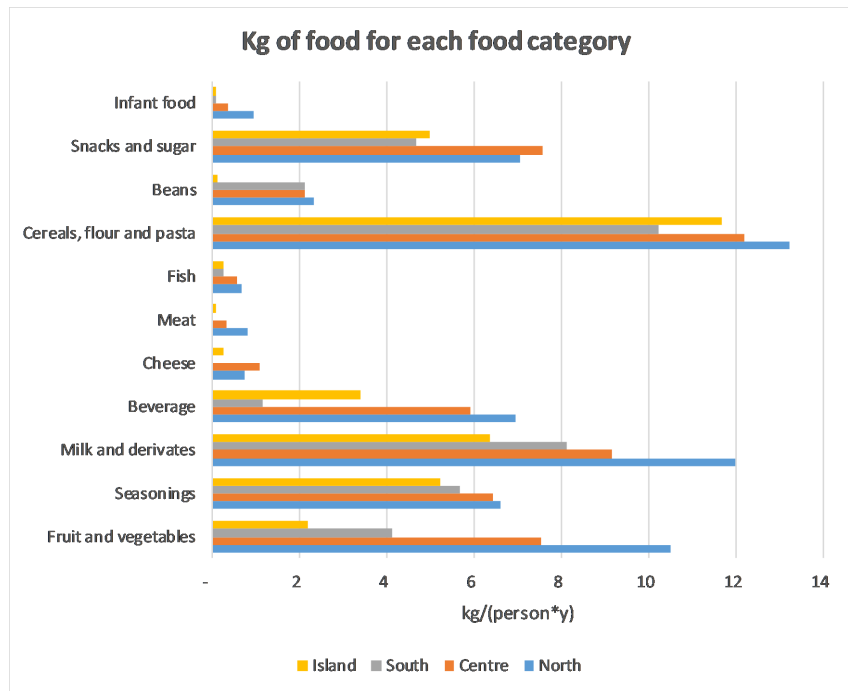
Figure 20: This graph shows the quantity in *kg* of food received by an indigent for each category in each macro-area of Italy.

food are almost nonexistent.

The situation is even worse in the islands. In this case even beans are close to 0 $\frac{kg}{person*year}$. All other classes are significantly lower with respect to the same categories in the North or Centre. In studying a new network for *Banco Alimentare*, you need to consider this aspect and to address it as much as possible, to reduce inequalities between indigents in different parts of the country.

7.4 MATRICES OF FLOWS - EXCLUSION OF THE *fead* PROGRAM

FEAD program has a central role in *Banco Alimentare*'s flows. These products are bought through tenders using founds of the European Union; this mechanism always includes transportation until the warehouse indicated by *Banco Alimentare*. The execution of the initiative is controlled by *AGEA*, which stands for "Agenzia per le Erogazioni in Agricoltura". It has been estimated that *FEAD* accounts for 60% of total redistributed volumes managed by *Banco Alimentare*[6]. In her thesis, Valentina

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[6] See section 5.2, page 21 of [9]

	North	Centre	South	Island
Fruit and vegetables	10,5	7,5	4,1	2,2
Seasonings	6,6	6,4	5,7	5,2
Milk and derivates	12,0	9,2	8,1	6,4
Beverage	7,0	5,9	1,2	3,4
Cheese	0,8	1,1	0,0	0,3
Meat	0,8	0,3	0,0	0,1
Fish	0,7	0,6	0,3	0,3
Cereals, flour and pasta	13,2	12,2	10,2	11,7
Beans	2,3	2,1	2,1	0,1
Snacks and sugar	7,1	7,6	4,7	5,0
Infant food	1,0	0,4	0,1	0,1
Total [$\frac{kg}{pers*year}$]	61,8	53,3	36,5	34,7

Table 15: Total amount of kilograms of food that an indigent would receive on average in different parts of the country.

reveals the possibility of seeing this percentage growing due to a decision of the EU of allocating more funds for this.

In this section, the importance of the *FEAD* program will be shown and proved with numbers. To do this, all passages previously described in this chapter have been repeated; the only difference lies in the input database since all lines related to *AGEA* or *Fruit and vegetable market*[7] have been deleted.

Among all matrices produced, the most impressive is the one obtained by confronting table 15 with table 16, where the latter is just the same table but with data filtered just like described above. This evaluation has been made in percentage and listed in table 17. Collected volumes would steeply fall in all areas, even if not to the same extent.
Northern Italy would lose more than 50% of quantity for many categories; the most impacted would be *Milk and derivates* and *Seasonings*. This part of the country receives considerable amounts of donations from industries, *Siticibo* and the National Collection Day; nevertheless, quantities derived from *FEAD* are considerable and food per capita would be nearly halved without considering them.

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7 The EU buys surplus of fruits and vegetables for *Banco Alimentare*. Transportation costs up to the warehouse designated by *Banco Alimentare* are always included.

	North	Centre	South	Island
Fruit and vegetables	6,6	3,0	0,0	0,6
Seasonings	2,6	1,3	1,1	0,7
Milk and derivates	3,0	1,0	0,2	0,6
Beverage	7,0	5,9	1,2	3,4
Cheese	0,7	1,1	0,0	0,3
Meat	0,8	0,3	0,0	0,1
Fish	0,4	0,2	0,0	0,0
Cereals, flour and pasta	6,2	3,4	0,9	1,6
Beans	1,0	0,9	1,3	0,1
Snacks and sugar	3,3	2,3	0,8	1,2
Infant food	1,0	0,4	0,1	0,1
Total [$\frac{kg}{pers*year}$]	32,6	19,8	5,5	8,7

Table 16: Total amount of kilograms of food that an indigent would receive on average in different parts of the country by excluding *AGEA*.

	North	Centre	South	Island
Fruit and vegetables	-37,52%	-60,66%	-99,84%	-74,76%
Seasonings	-60,66%	-79,54%	-80,14%	-86,75%
Milk and derivates	-74,72%	-88,83%	-97,51%	-89,97%
Beverage	0,00%	0,00%	0,00%	0,00%
Cheese	-5,39%	0,00%	-6,12%	0,00%
Meat	-0,32%	-24,11%	0,00%	0,00%
Fish	-37,83%	-71,40%	-93,39%	-85,59%
Cereals, flour and pasta	-53,00%	-71,96%	-91,65%	-86,36%
Beans	-55,21%	-56,54%	-40,79%	0,00%
Snacks and sugar	-53,12%	-69,08%	-82,85%	-76,11%
Infant food	0,00%	0,00%	0,00%	0,00%
Total [$\frac{kg}{pers*year}$]	-47,28%	-62,90%	-84,85%	-74,95%

Table 17: How much would quantities listed in table 15 change if there were not *AGEA*? This table shows the variation in percentage for each area of destination.

Central Italy would see a decrease in its per capita donated food of more than 62%. Apart from *Milk and derivates* and *Seasonings*, even *Fruits and vegetables*, *Fish*, *Cereals, pasta and flour* and *Sugar and snacks* would be substantially redimensioned. Islands would lose 74% of flows; southern Italy would be the most impacted area, losing 85% of donated items. The highest percentual changes concern the above-mentioned categories.

7.5 THE IMPACT OF SITICIBO

After having described the variety and quantity of food received on average by indigents in different parts of the country, a clarification needs to be made. The analysis made takes into consideration the flows related to *Siticibo* because food recovered is still food donated to people. Still, does everyone benefit from it? Unfortunately, the answer is no.

To explain the why of this, you need to represent *Siticibo* at a higher level of detail.
Siticibo is the application of law 155/2003; it is a program to recover fresh or cooked food from canteens, restaurants, hotels, shops and, since 2009, from mass retail channels. Food is redistributed to charities which will donate food to people in need [19].
Items collected through this channel are close to expiry date (some days), low in volume, high in value and they must be redistributed within 10 kilometres from their origin (Casali et al., 2017 [7]). Even if the first two features seem to be discouraging (indeed, collecting few quantities close to expiry date or with particularly strict sanitary rules to be followed such as for cooked food), the value of food recovered is enough to justify these activities. According to research conducted by professors Paola Garrone, Marco Melacini and Alessandro Perego [12], for each euro spent to collect food, there are at least three euros of benefits for the society. This ratio grows up to 1:10 as you go up into the supply chain (because recoverability is much easier).

How to cope with freshness and expiry date? The solution adopted consists in letting charities recover food directly from the donors without passing through the network of *Banco Alimentare*. Food is directly recovered to cut on transportation costs, handling costs (including the number of volunteers needed to

manage these flows) and, most of all, to make the lead time as short as possible. To keep the recovery under control and most of all to make sure sanitary standards are met, a selected number of associations is qualified by *Banco Alimentare* to pick these items. This opportunity is open to any kind of charity: the limited number of authorised associations is mainly explained by the need for volunteers willing and available to take part in this project.

This clarification is needed because the analysis in sections 7.2 and 7.3 represent average values of the overall quantities received : since flows of *Siticibo* are reserved to a certain number of associations, not everyone can receive those products. This means that quantities in sections 7.2 and 7.3 are slightly overestimated for most of the indigents and considerably underestimated for few people.

The steps mentioned in those previous sections have been repeated on flows related to *Siticibo* only. According to the data available, the impact of *Siticibo* is negligible compared to the total amount of flows collected: it has a weight close to 7% with respect to them. As mentioned by Valentina de Micheli as well as by many people inside the Operations Department, in the following years volumes could grow much more thanks to broader adoption of this program: today a selected number of points of sale and charities take part to it. However, the actual strength of *Siticibo* lies in the categories of food it can recover. *Fruits and vegetables*, *Meat* and *Cheese* are the most impacted categories by *Siticibo*, with a percentage of flows recovered through this channel higher than 25%. The most important areas of retrieval are the North (78%) and the Centre (21%), even if the second is much more marginal. The rest of the country has much smaller importance, mainly due to difficulties with the main players (with some of them it is difficult to have a unique agreement at corporate level, some players dismissed their activities in the South such as Carrefour) and the absence of leftovers in small shops, that are much more diffused.

According to an estimation made, this extra flow of products regards 185,000 people, which represent almost 12% of indigents. With respect to the numbers summarised in table 15, these indigents seem to receive nearly 25 kilograms of food per year more. Nearly half of it is constituted by *Fruits and vegetables* and

one fifth by *Cereals, pasta and flour*. In the South *Sugar and snacks* accounts for 41%; in the northern and insular parts of Italy, *Milk and derivates* represents 10% of extra flows, while in the Centre and Isles *Cheese* is nearly 10%. All data have been summarised in tables 18 and 19.

	North	North %	Centre	Centre %
Fruit and vegetables	13,5	50%	13,6	54%
Seasonings	0,2	1%	0,2	1%
Milk and derivates	3,1	11%	1,2	5%
Beverage	0,4	2%	0,7	3%
Cheese	1,1	4%	2,6	10%
Meat	1,0	4%	1,1	5%
Fish	0,1	0%	0,1	0%
Cereals, flour and pasta	6,9	26%	4,4	18%
Beans	-	0%	0,0	0%
Snacks and sugar	0,6	2%	1,0	4%
Infant food	0,0	0%	0,0	0%
Total [kg/pers*y]	26,9	100%	25,0	100%

Table 18: Summarisation of the kilograms of food retrieved through *Siticibo* and donated to indigents in 2018 for North and Centre.

	South	South %	Island	Island %
Fruit and vegetables	0,0	39%	4,4	48%
Seasonings	-	0%	0,0	0%
Milk and derivates	-	0%	1,4	16%
Beverage	-	0%	0,1	1%
Cheese	-	0%	0,9	10%
Meat	-	0%	0,5	5%
Fish	-	0%	0,0	0%
Cereals, flour and pasta	0,0	20%	1,6	17%
Beans	-	0%	-	0%
Snacks and sugar	0,0	41%	0,2	2%
Infant food	-	0%	0,0	0%
Total [kg/pers*y]	0,1	100%	9,2	100%

Table 19: Summarisation of the kilograms of food retrieved through *Siticibo* and donated to indigents in 2018 for South and Islands.

THE MODEL

This chapter is dedicated to the description of the model used to analyse and optimise the current distribution network of *Banco Alimentare*. Each of the following sections is focused on a specific part of the work, such as the methodology applied, the data used, the steps followed in the model as well as the several assumptions made to obtain the output. Before going through this explanation, a description of the actual network as well as a qualitative analysis of the problem was necessary to reduce its complexity.

8.1 THE ACTUAL NETWORK

The current distribution network of *Banco Alimentare* is a two-echelon network with one central warehouse in Parma - Fontevivo and nearly 40 warehouses located all over the peninsula. Their role depends on the decisions taken by each *OBA*: some of them are considered central warehouses, some other transit points or secondary warehouses. There are even some temporary facilities used to store for a short period (usually one or two months, but it can be even less) food recovered during the National Collection Day.
For example, in Piedmont there is one major warehouse in Moncalieri serving and preparing orders for secondary facilities in the rest of the region (i.e. Novara, Biella, Cuneo and Asti); in Campania, there is only one warehouse in Fisciano.

Fact is that almost all flows are directed to the second level of warehouses bypassing the first echelon, which is used only to temporarily store pallets when other warehouses are full, or to divide mono-product full-truckload shipments into several mixed-pallet ones, which are much easily accepted by *OBA*s.
This behaviour has been confirmed by Filippo Varacca during an interview in Parma in December. Data seem to confirm what Filippo witnesses: only 4.6% of flows[1] passes through the first-

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[1] Excluding flows related to *Siticibo* as well as other rows of the dataframe "Flussi.csv" that were incomplete or incorrect.
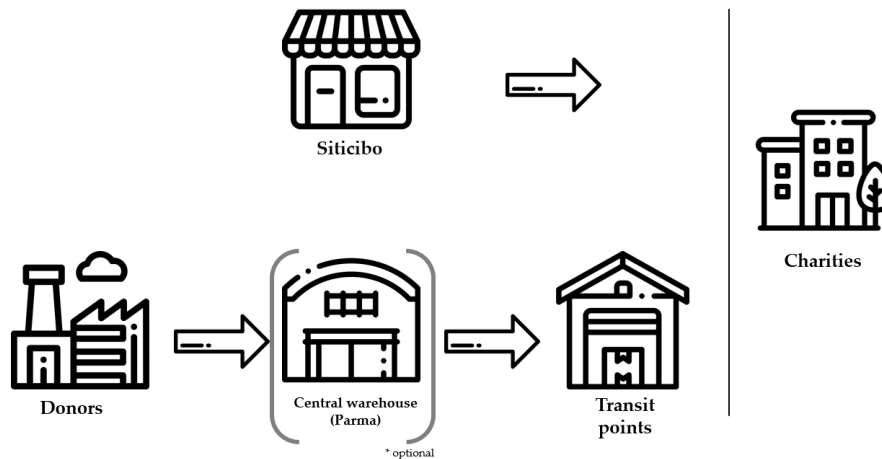
Figure 21: Representation of the actual network of *Banco Alimentare*.

echelon warehouse of Parma.

A representation of the actual network is the one proposed in figure 21. To sum up, if the existing logistic network of *Banco Alimentare* is a two-level network, *de facto* it is used as a one-echelon logistic chain.

Is this the best configuration *Banco Alimentare* can aim at? If not, which network should the company adopt to optimise its costs given a target service level? These are the questions the following section will try to reply to.

8.2 THE STARTING POINT

Let's suppose the actual distribution system adopted by *Banco Alimentare* did not exist and someone had to create one from scratch. On one side there is a wide and variegated amount of donors (e.g. factories, canteens, supermarkets, *AGEA* in the number of nearly 19,000 single points of origin) and on the other one 11,400 different charities to deliver the food to. Which kind of network configuration would be more appropriate, given the characteristics describing *Banco Alimentare*? In other words, how many levels should the logistic channel have and how wide each echelon should be? And which kind of facilities should each level be made of?

In designing a distribution network, some high-level considerations need to be made first. The following methodology to network design was explained in 2018 by Professors Alessandro

```
> length(unique(donatori$ï..Codice.donatore))
[1] 18920
> length(unique(elenco_sc$ï..Struttura))
[1] 11433
>
```

Figure 22: Unfiltered RStudio output of the number of donors and charities of *Banco Alimentare*.

Perego and Riccardo Mangiaracina [4], and it is used to understand which qualities the logistic channel should have according to the case analysed.

First of all, it is needed to have a clear picture of the case of *Banco Alimentare*: it is an Italian not-for-profit organisation, operating in Italy only: its suppliers and its customers are exclusively Italian, except for few suppliers located in Europe. There is a high and variegated number of donors, while suppliers seem to be much more similar to each other and their number is much lower than suppliers. The service level required for most of the caritative structures is one order per month (55%), while about 27% of them would prefer to receive food twice a month [13]. Despite the need to satisfy its associated organisations, *Banco Alimentare*'s ability to provide the required service level strongly depends on its limited resources, which are not always equally widespread in the peninsula.

In a second moment, it is possible to use the design principles, which can be considered as simple guidelines to connect the nature of the problem with its solution. Its application to *Banco Alimentare*'s case can be found in the following lines, and the information considered can be found in table 20.

Let us consider to employ direct shipment. Adding an e-chelon to the network would be positively impactful for different reasons: reduction of the number of transactions between suppliers and customers (thus decreasing transportation costs), reduction of order cycle time (many items are perishable) and improvement of order mix and completeness. Since at least one of the three last motivations holds, at least one echelon is needed in this network.
Decreasing transportation costs is crucial for *Banco Alimentare*, since:

- there are too many points of origin and destination;

Points of origin	Number	18,920 (2019)
	Location	Italy, few of them Europe
	Focus	Medium - high
Products	Range	150 categories
	Value density	Low
Points of destination	Obsolescence	Medium (on average)
	Number	11,433 (2019)
	Location	Italy only
	Order size	Cartons or pallets
Service level	Order cycle time	Short

Table 20: Summarisation of the main data needed to apply the network design methodology.

- products have low value-density (an estimation of $10\frac{€}{kg}$ has been made);

- sometimes products need to have a short cycle time due to perishability;

- one order consists of several products from different suppliers;

- most of all, transportation is expensive for the company because it represents a cash flow expenditure for a not-for-profit company with limited resources.

Once ensured the first echelon is necessary, it is essential to decide the optimal number of warehouses in it. This decision takes into account two perspectives, represented in figure 23:

- by increasing the number of warehouses, transportation costs will improve (up to the point they will rise again, due to truck underuse);

- by increasing the number of warehouses, warehousing costs will increase due to the higher number of facilities, personnel, handling equipment to maintain;

Thus, there is a trade-off between warehousing and transportation costs. However, since product range is not so high, its average value is low and its obsolescence is medium[2], inventory

---

[2] *Banco Alimentare* handles food with both long and short obsolescence. The food with the shortest life span is handled with the *Siticibo* program, in
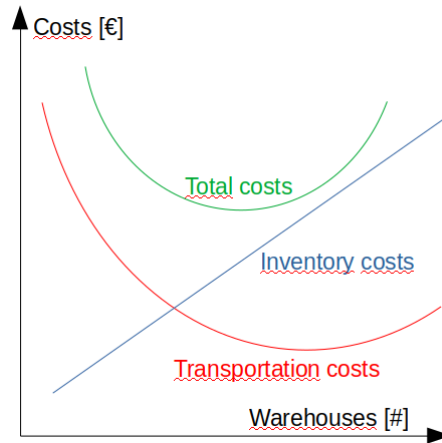
Figure 23: In evaluating the number of facilities to have in the first echelon of the distribution network, you should consider the impact of either inventory and transportation costs.

	< 20 **kilometres**	< 50 **kilometres**
Actual value	22%	43%
Requested value	29%	62%

Table 21: Summarisation of the actual service level and the requested one in terms of distance of each charity with respect to its assigned warehouse of *Banco Alimentare*.

costs should be much less important than transportation costs, meaning that in figure 23 the minimum of the total cost curve should lie towards the right. However, according to the computation made by Valentina de Micheli[3], warehousing costs are much higher, meaning that reducing them is still important.

Service level represents a constraint to the minimum number of warehouses to be adopted. This has been taken into consideration according to the findings of Valentina in her service level survey to associations[4]. 29% of charities can to travel up to 20 kilometres, while 62% of them requires the route to be less than 50 kilometres.

---

which *Banco Alimentare*'s facilities are not involved, hence it was excluded from the analysis; the biggest flows come from industry and *AGEA*, and obsolescence can be considered shorter in the first case. On average it can be assumed that the due date is medium.

[3] See chapter 6.3 of [9]
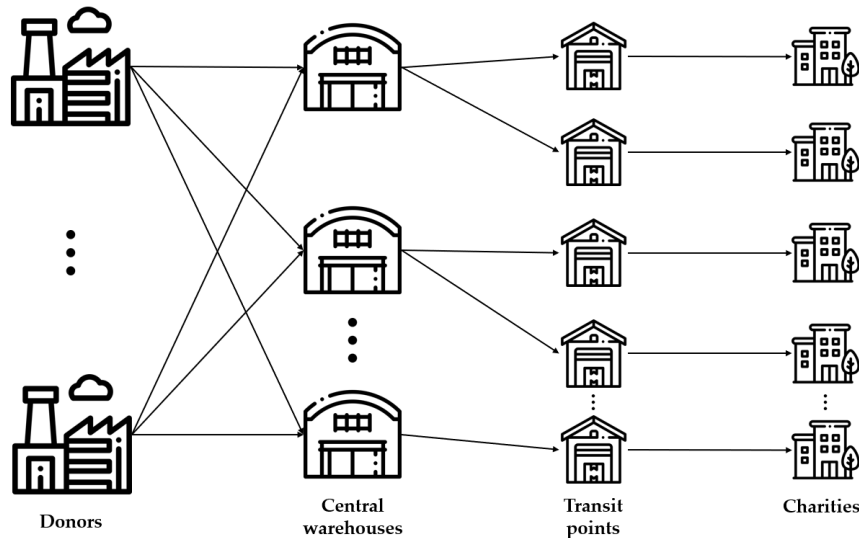[4] See chapter 5.5 of [9]

Figure 24: The new logistic channel of *Banco Alimentare* should be constituted by two echelons, where the second one consists of transit points.

After all of this, you can assess the necessity of a second level for the distribution network. It is recommended to add an echelon if increasing the service level is important and/or if you still want to reduce transportation costs. In the case of *Banco Alimentare*, both motivations hold, even if the second one is much more important; thus, a second echelon should be created.

But which kind of warehouses should be considered? Simple transit points represent a better choice compared to warehouses: stock centralisation will help to cut on warehousing costs and improve product availability. Furthermore, orders are currently prepared according to what associations are allowed to collect: software is in charge of allocating food depending on the number of accredited indigents each charity supports It is then possible to prepare orders in advance. These reasonings are in line with the findings of Valentina de Micheli [9].

To summarise, *Banco Alimentare* should build a two-echelon distribution network, with a second level constituted of transit points only. Figure 24 represents the new logistic channel.
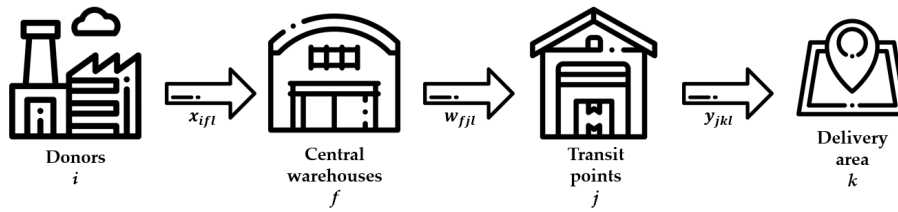
Figure 25: Representation of the problem according to the multi-facility allocation problem.

8.3 HOW THE PROBLEM SHOULD BE ASSESSED

According to theory[5], the creation of this new distribution network represents a location and allocation problem with no fixed number of warehouses, where:

- the number of echelons has already been set;

- the number of warehouses and their geographical position has to be determined;

- the allocation of flows to each warehouse and of each customer to the facilities needs to be computed.

This is a multi-facility allocation problem, where the goal is finding the location and allocation of warehouses by minimising the sum of the considered fixed and variable costs.
The most realistic result would be found with mixed-integer programming. The model represented here is an adaptation of the model explained during the lectures on distribution network design held by Professors Alessandro Perego and Marco Melacini [3], while part of the final comment derives from chapter *Multiple facility location* of Ballou (2004) [6].
 The model variables are:

- x_{ifl} is the quantity of product l produced the donor in plant i and delivered to the central warehouse of *Banco Alimentare* in area f;

- w_{fjl} is the quantity of product l shipped from central warehouse f to transit point j;

- y_{jkl} is the quantity of product l delivered to area k from the transit point in area j;

---

[5] See lectures *Distribution network design: design methodology and models* by Alessandro Perego and Marco Melacini [3].

- $z1_f$ and $z2_f$ are binary variables that assume positive value in case a facility is activated in the corresponding area f or j.

Refer to image 25 for a simple schematisation of the network. The following represent the model parameters:

- a_i represents the average annual donation in kilograms from supplier i[6];

- $costocw_f$ is the annual fixed cost for a central warehouse in area f;

- $costotp_j$ is the annual fixed cost for a transit point in area j;

- $lab1_{fl}$ labour required in facility f to handle one unit of product l;

- $lab2_{jl}$ labour required in facility j to handle one unit of product l;

- $cap1_{Mf}$ and $cap1_{mj}$ represent the minimum and maximum capability of managing flows in warehouse f;

- $cap2_{Mj}$ and $cap2_{mj}$ represent the minimum and maximum capability of managing flows in transit point j;

- $V1_f$ is the unitary cost of material flow passing through warehouse f;

- $V2_j$ is the unitary cost of material flow passing through transit point j;

- $c1_{ifl}$ represents the unitary transportation costs of product l from donor's plant i to central warehouse f;

- $c2_{fjl}$ represents the unitary transportation costs of product l from central warehouse f to transit point j;

- $c3_{jkl}$ represents the unitary transportation costs of product l from transit point j to delivery area k;

- t_{jkl} is the average delivery time of product l to the delivery area k from central warehouse j;

- T_l is the maximum allowed delivery time for product category l.

---

[6] The index i refers to a specific plant location: some companies may have more than one plant in different areas.

The objective function 11 to minimise is the sum of fixed costs of central warehouses, variable costs of central warehouses, fixed costs of transit points, variable costs of transit points, transportation costs from suppliers to central warehouses, transportation costs from central warehouses to the transit points and last-mile delivery costs inside each area of delivery.

$$
\min \left(\sum_f costocw_f \, z1_f + \sum_j costotp_j \, z2_j + \sum_f V1_f \sum_{j,l} lab1_{fl} \, w_{fjl} + \right.
$$
$$
\left. + \sum_j V2_j \sum_{k,l} lab2_{jl} \, y_{jkl} + \sum_{ifl} c1_{ifl} \, x_{ifl} + \sum_{fjl} c2_{fjl} \, w_{fjl} + \sum_{jkl} c3_{jkl} \, y_{jkl} \right)
$$

$$(11)$$

This is subject to different constraints:

- inbound and outbound flows in each central warehouse in area f must coincide;

$$
\sum_i x_{ifl} = \sum_f w_{fjl} \qquad \forall j, l \tag{12}
$$

- inbound and outbound flows in each transit point in area j must coincide;

$$
\sum_f w_{fjl} = \sum_k y_{jkl} \qquad \forall j, l \tag{13}
$$

- the shipped quantity of item l in area k needs to meet the ordered quantity;

$$
\sum_j y_{jkl} = d_{kl} \qquad \forall k, l \tag{14}
$$

- the quantity of flow handled by each central warehouse needs to respect the minimum and maximum values of flows passing through the warehouse;

$$
lab1_{mf} \, z1_f \leq \sum_j lab1_{fl} \, w_{fjl} \leq lab1_{Mf} \, z1_f \tag{15}
$$

- the quantity of flow handled by each transit point needs to respect the minimum and maximum values of flows passing through the warehouse;

$$
lab2_{mj} \, z2_j \leq \sum_k lab2_{jl} \, y_{jkl} \leq lab2_{Mj} \, z2_j \tag{16}
$$

- delivery times to charities must be respected;

$$\frac{\sum_{j,k} t_{jkl}\, y_{jkl}}{\sum_k d_{kl}} \leq T_l \qquad (17)$$

- positivity condition for x_{ijl} and y_{ikl}; imposing that $z1_f$ and $z2_j$ are binary.

$$x_{ijl} \geq 0 \quad w_{fjl} \geq 0 \quad y_{jkl} \geq 0 \quad \forall f,j,k,l$$
$$z1_f = 0,1 \quad z2_j = 0,1 \quad \forall f,j \quad (18)$$

The advantage of this model is that you can find an optimal solution for your case if you have all information necessary to model the final distribution network.
The disadvantages are mainly two: first of all, it is cumbersome from a computational point of view. Huge computational resources are required and the solution might be found after a long time.
Other details could have been included, such as the willingness and possibility of charities to travel to the transit points or other warehousing costs: all these additions would have worsened the computational time and effort in finding the optimal solution.
Secondly, there is another issue: the optimal solution can be found only if you can include all information needed. There is a large number of parameters to collect as well as a rich objective function to build, meaning that all this information must be available and accurate. This is why this method is usually applied only to compare a few alternatives, using design principles to exclude *a priori* those scenarios that make no sense or that are sub-optimal.

Limited time, limited computational resources and limited data forced to make some simplifications to find a reference distribution network *Banco Alimentare* can tend to on the long term. The results of the model explained in the following pages cannot be considered optimal, but according to the calculation and the assumptions made, this solution is going to be close to the optimal one.

8.4 THE MODEL

8.4.1 *The objective of the analysis*

The objective of the analysis is finding an optimal distribution network for *Banco Alimentare*. The impossibility to find an optimal solution has already been explained in section 8.3.
By exploiting distribution design practices and general knowledge of *Banco Alimentare* and its activities, the distribution network should have a shape like the one represented in figure 24 on page 65: it should consist of two echelons of facilities, where the last one is composed of transit points only.

The objective of the model is to compute how many central warehouses and transit points should the network have and where to locate them according to the input data.

8.4.2 *Data used*

Several sources of data have been used to build the model and its cost function. Most of them come from Excel files which are the output of several queries on *SAP*.
Other information comes from the Administrative and Legal Department of *Banco Alimentare* and is shown on its balance sheet.
Last but not least, some reasonable esteem has been made, such as for fuel consumption and cost or for the hourly cost of a truck driver. Some of this data comes from interviews to Regional Directors, experts from the Operations Department of the company or the expertise of workers of different *OBA*s; however, all estimations have been validated by the Operations Department. In any case, all parameters can be modified in the initial part of the model before running all computations. In this way, the R file can be adapted to different situations and even used for a what-if scenario analysis by running the code multiple times under different coefficients, just like it has been described in section 8.4.7 on page 95.

The results presented at the end and the conclusions of this work strongly depend on the assumptions made as well as the reliability of the data found, hence their importance. The latter has been cleaned as much as possible, but its solidity

mostly lies on what has been reported on *SAP*. Unfortunately, several instances and matrices showed errors, inconsistencies or repetitions. In some cases, there is no data because some *OBAs* are not using *SAP* and several others are just partially using it.

Figure 26: Import of several .csv files containing data of different kinds.

Data from SAP

This part will describe the main files used in the model. These .csv files regard inbound flows (i.e. from donors to the warehouses of the network), outbound flows (i.e. from the warehouses to the charities), a detailed list of all accredited not-for-profit organisations with related addresses, a list of all warehouses of *Banco Alimentare* and their current address and a list of the codes used to identify them.

All these files have been extracted from *SAP* as .xsls files and then converted into a .csv one using Excel. The following is a description of the .csv files. A snapshot of the head of each document has been attached to ease their recognition for the end-user.

- **Codici Magazzini.csv** This file allows the code to recognise each warehouse from two codes. It is made of three columns called "Divisione", "Magazzini" and "Nome": the combination of the first two columns allows the code to uniquely identify each warehouse. See figure 27.

Divisione	Magazzini	Nome
10	M001	Parma
10	M002	Parma per Alessandria
10	M003	Parma per Pasian di Prato
10	M004	Parma per Aprilia
10	M005	Parma per Bolzaneto

Figure 27: Head of the database "Codici magazzini.csv".

- **Elenco donatori** This file is a list of all donors of *Banco Alimentare*. Its columns are: "Codice donatore", "Regione", "Via", "Numero civico", "Località", "CAP", "Provincia", "Regione". See figure 28.

onatore	Ragione Sociale	Via	Numero	Localita	CAP	Provincia	Regione
201595	DOLCIFICIO GI&SSE Srl	Via Crevalcore, 3		San Giovanni in Persiceto	40017	BO	Emilia Rom
214187	PAM - Torino (Orbassano)	Corso Orbassanc		Torino	10137	TO	Piemonte
219293	RIALTO Srl DeAmicis (Cinise	Via De Amicis 72		Cinisello Balsamo	20092	MI	Lombardia
216051	U A L Torino s.a s.	VIA MIL	28	Grugliasco	10095	TO	Piemonte
217026	"IL CAPPERO"	ZALEUC	7	Reggio Calabria	89125	RC	Calabria

Figure 28: Head of the database "Elenco donatori.csv".

- **Elenco entrate** This large file contains each transaction between donors and warehouses. It is constituted by the columns: "Mese", "Data di reg.", "Riferimento / N. DDT", "Data documento", "Fornitore", "Rag. Sociale Fornit.", "Donatore Prodotto", "Rag. Donatore", "Prov. prod.", "Materiale", "Codice", "UM acquisizione", "Qtà in UM acq.", "Unità misura base", "Quantità", "Data scadenza / TMC", "Divisione Magaz.", "Camp. AGEA", "Gruppo merci", "OBA" and "Errori". Its 512,300 rows make it the biggest dataframe to be handled by the model[7]. please refer to figure 29 to see how the database is composed.

Data doc	Fornitore	Rag. Soc	Don	Rag. Dc	Prov.	Materi	Codice	UM a	Qtà in	Unità	Quantit	Data sc	Divisic	Maga	Camp.	Grup	OBA
43089	200654	OLEIFICIC	###	OLEIFIC	AGEA	olio di	H0130	COL	2376	L	28512	43803	210	M001	F16	H01	Piemonte
43090	201622	KI GROUI	###	KI GROI	IND	biscott	E0430	COL	1	KG	150	43131	210	M001		E04	Piemonte
43090	201622	KI GROUI	###	KI GROI	IND	second	J07102	COL	17	KG	17	43130	210	M001		J05	Piemonte
43090	201622	KI GROUI	###	KI GROI	IND	bevanc	L02300	COL	54	L	648	43122	210	M001		L01	Piemonte

Figure 29: Head of the database "Elenco entrate.csv".

- **Elenco SC** This is a list of all accredited charities. Its columns are "Struttura", "Vecchio Co", "Nome 1", "Via", "CAP", "Localita", "Rg", "Rit", "NumAs", "Fr", "DistKM", "CS", "Materiale", "D", "Banc", "strutture attive". Its structure is the one represented in figure 30.

- **Indirizzario magazzini** This is a list of all current warehouses of *Banco Alimentare* according to the data collected in the survey to Regional Food Banks for productivity. Its

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7 Make sure your device can support such an amount of data and the following computation. R stores all inputs in the RAM: a 4GB memory might not be enough for this case. Consider an 8GB RAM as the minimum to have a good computation time.

ruttura	Vecchio Co	Nome 1	Via	CAP	Località	Rg	Rit	NumAs	Fr	DistKM	CS	Materiale	D	Banc	strutture
100003	PL0410	Lombardia	Via Papa G	20053	Muggio	MB	0	0	?	0	10			BA04	non attiva
100020		40001 Ass.ne Cena dell'Amicizia	Via Val di E	20161	Milano	MI	12	87	SI	0	8	I01300B		BA04	attiva
100021		40002 Cooperazione Internazionale Onlus	Via De Le	20151	Milano	MI	12	282	SI	0	8		Em	BA04	attiva
100022		40004 Coop. Soc.le Il Sentiero	V.lo Stalle	23807	Merate	LC	12	16	SI	0	8	L03300B	Ila	BA04	attiva

Figure 30: Head of the database "Elenco SC.csv".

values are: "Nome magazzino", "Regione", "Indirizzo".
Its appearance is the one showed in figure 31.

Nome magazzino	Regione	Indirizzo
Pescara	Abruzzo	Via Celestino V 4, Pescara
Novi Ligure	Alessandria	Piazzale Leoni di Liguria, Novi Ligure
Cosenza	Calabria	loc. Pianette 3, Montalto Uffugo
Reggio Calabria	Calabria	Via Nazionale traversa Marra, Reggio di Calabria
Vibo	Calabria	Vibo Valentia

Figure 31: Head of the database "Indirizzario magazzini.csv".

- **Uscite** This .csv is a list of what *Banco Alimentare* has consigned to charities in 2019 all over the country. This document has been created manually from several *SAP* queries since each request on the platform is focused on a regional bank. Its columns are "Codice SC", "Prodotti AGEA", "Prodotti ortofrutta", "Altri prodotti" and "Totale prodotti". Some clarifications have to be made:

  - Sardinia and Trentino Alto Adige do not use *SAP*: an estimation of the quantity received has been made based on the average kilograms per person donated to other associations;

  - Aosta Valley does not use *SAP* such as Trentino and Sardinia. Since it was not possible to find the charities accredited to this *OBA* and there was no address to plot them on a map, it was impossible to include them into the code. However, this exclusion regards only 2,000 indigents on a total of 1,200,000;

  - Apulia records on *SAP* flows associated with *AGEA* and the *Fruit and vegetable market*;

  - Veneto started implementing *SAP* in 2018 and its full transition is yet to be completed. The flows recorded regard the warehouse of Verona only, while the one in Padua has been included following the same procedure of Sardinia and Trentino Alto Adige.

Its head is the one showed in figure 32.

Codice SC	Prodotti AGEA	Prodotti ortofrutta	Altri prodotto	Totale prodotti
105260	3320	0	1319	4639
105264	0	0	1955	1955
105265	0	0	696	696
105266	3421	0	1425	4846
105268	0	355	3233	3588

Figure 32: Head of the database "Uscite.csv".

Data from the Administrative and Legal Department or Regional Food Banks

Other data has been obtained directly from the Administrative and Legal Department and from surveys to regional banks. These data regard the cost of personnel[8], the number of workers, and maintenance costs. Table 22 summarises the costs collected. Regarding the data collected from *OBAs*, data provided by the Director of Emilia-Romagna were the most reliable and complete, that is why they have been used directly to feed the model.

Estimations made and other values

Other data has been estimated, taken from external sources or from Valentina De Micheli's work[9]. See table 23 for specific values.

8.4.3 *Step 0: Data cleaning and preparation*

Before going through the computation of the number and location of both kind of facilities, data had to be cleaned and prepared. Data cleaning is crucial to prevent errors in the following phases as long as to ensure a solid result at the end of the model. Furthermore, preparation of data helps the programmer reducing the complexity of the inputs by screening unuseful resources and joining all necessary information into

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[8] Note that both volunteers and employees have been considered as paid personnel. However, the model offers the possibility to change the salary of both categories of workers.

[9] See all estimations in section 6.2 of her thesis [9].

Parameter	Value	Unit of measurement	Source
Number of refrigerated cells per facility	2	$\frac{cells}{facility}$	Operations Department
Maintenance cost of a truck	12,900[a]	$\frac{€}{year}$	OBA Emilia-Romagna
Maintenance cost of a pallet jack	500	$\frac{€}{year}$	OBA Emilia-Romagna
Maintenance cost of a forklift	2,500	$\frac{€}{year}$	OBA Emilia-Romagna
Maintenance cost of a refrigerated cell	1,200	$\frac{€}{year}$	OBA Emilia-Romagna
Salary of an employee	30,000	$\frac{€}{year}$	Administrative Department
Salary of a volunteer	30,000	$\frac{€}{year}$	Administrative Department

Table 22: Recap of the data collected from the Administrative Department of *Banco Alimentare* and the regional banks.

[a] This value is the average between the MOT cost of a van ($1,600\,\frac{€}{year}$) and an articulated lorry ($11,300\,\frac{€}{year}$).

Parameter	Value	Unit of measurement	Source
Capacity of an articulated lorry	20,000	tonnes	euroimpex.lv [8]
Capacity of a van	2,200	tonnes	fiatprofesional.com [15]
Time to load and empty a lorry	2	hours	DHL informer
Driver cost	30	$\frac{€}{hour}$	External specialist
Mean of transport cost	300	$\frac{€}{day}$	External specialist
Average speed	50	$\frac{km}{hour}$	Assumption
Consumption	5	$\frac{km}{litre}$	Assumption
Petrol cost	1,5	$\frac{€}{litre}$	Average value including VAT
Pallet loads per trailer	33	$\frac{pl}{trailer}$	Operations Department
Offices of a central warehouse	10%	Percentage of the total area	Assumption according to the actual data
Warehousing area of a transit point	600	squared meters	Assumption
Forklift trucks per transit point	2	units	Assumption
Pallet jack per transit point	4	units	Assumption
Means of transport per transit point	1	units	Assumption
Cells per facility	2	units	Operations Department
Space cost	40	$\frac{€}{squaremetre}$	De Micheli, 2019 [9]
Energy cost	7	$\frac{€}{squaremetre}$	De Micheli, 2019 [9]
Other utilities cost	215	$\frac{€}{FTE}$	De Micheli, 2019 [9]

Table 23: Costs from personal estimations or external sources.

new databases.

One of the preliminary steps performed regards the *.csv* file called "Elenco donatori". This file consists of all donors of *Banco Alimentare* and their information, such as their address. All these addresses have been converted into coordinates using the package *ggmap*, which works with a Google Maps API key[10]. A similar operation was performed for "Elenco SC" and "Elenco magazzini". Since this operation requires time, it is possible to save the results and to reuse them for following computations.

The database "Flussi" (which derives from Entrate.csv) has been cleaned from several unuseful columns as well as from those rows referred to *Siticibo* by filtering all those product flows labelled as "SGDO" and "SRIS"[11]. This is because *Siticibo*'s flows are not physically passing through *Banco Alimentare*'s facilities: it is then necessary to remove all those lines. Each flow has then been assigned a coordinate of departure by joining flows and donors on the donor code, which is unique for each donor.
The database of the outbound flows "Uscite" is ready to be used. It is also efficient because each line belongs to a single charity: this aggregated dataset is then better than a huge file containing each collection made by each charity during the year.

8.4.4 *Step 1: Clustering of the charities*
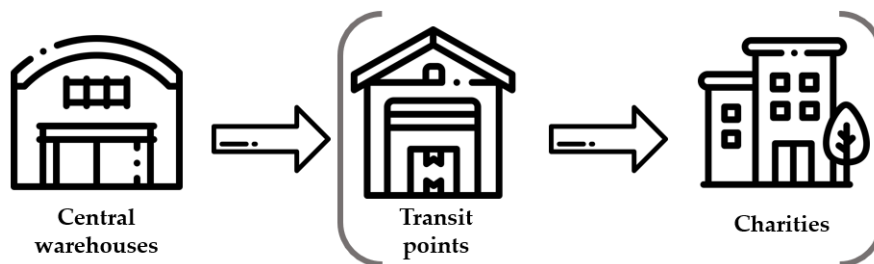
Figure 33: Part of the supply chain of *Banco Alimentare* taken into consideration in this part of the model.

---

[10] Google offers a 300$ credit to each new account. However, the credit offered is not barely enough to cover all computations required to find the final solution. It is recommended subscribing for a paid account, even if costly, to avoid interruptions and other issues.

[11] Respectively "Siticibo GDO" and "Siticibo Ristorazione

To tackle the issue of limited computational resources, the location problem has been divided into two parts: the location of transit points and subsequently location of the central warehouses. This allows dealing with the problem of the service level in a simple way that will be explained in detail further on in this section.
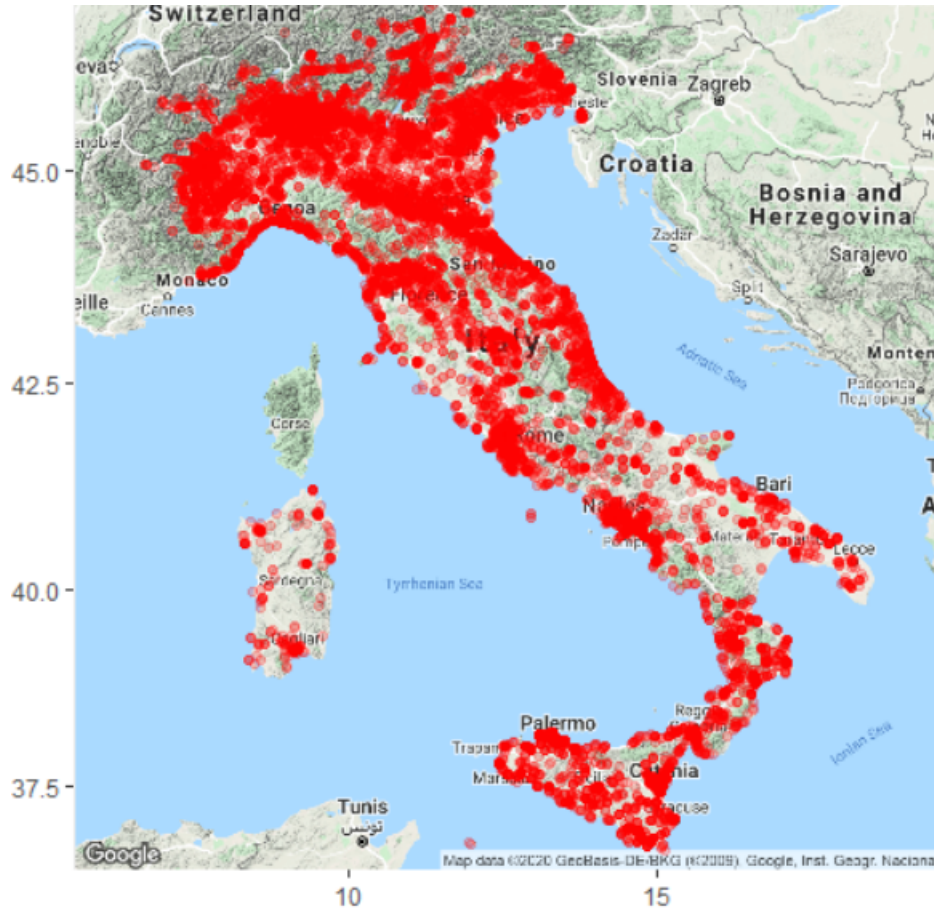

Figure 34: Plot of the position of each charity accredited to *Banco Alimentare* on the Italian territory according to the file "Elenco SC".

The code iterates a series of computations from a minimum value of k transit points to a maximum predefined one. Both parameters can be modified in the input data. At the end of all iterations, the most economic one respecting the requested service levels will be taken as part of the final result.
To simplify the location of k transit points, k-means clustering was applied to the set of charities on the basis of their position. This methodology was chosen against the one of centre of gravity for two reasons:

- it is simpler and more efficient since results are found within seconds instead of several minutes for each iteration;

- it is based on distance only. This might represent an issue because the code is not taking in consideration flows, the number of indigents per association, etc. etc. Truth is that in this way all charities are considered equally important, and their size (thus the weight of their flows) will not affect the distance they have to travel to get their donation.

The following description enters into the details of the code. The default values for the number k of transit points belong to the interval $[15; 40]$. These numbers have been arbitrarily chosen: the author reputed the interval sufficiently wide to find the correct number of transit points in it. However, modifications can be made according to the user's needs.

Given a number k of transit points, the code will start applying the k-means clustering, which computes the clusters' k centroids (with coordinates) and will assign each charity to a cluster. The assigned cluster will be saved in both data frames "elenco_sc" and "uscite".
Distances between each charity and its reference centroid (i.e. its transit point) are computed using a package called *geosphere*: one of its functions allows the computation of Euclidean distances on the surface of a sphere receiving coordinates as input. This distance is converted in kilometres and increased by 5% to simulate the real path between points of origin and destination. Each distance is used to calculate the time needed to cover it: to do this, average speed was estimated to be equal to 50 $\frac{km}{hour}$.

The next step consists in checking if the required service level has been respected. To do this, the code counts how many distances are less or equal than 20 kilometres and how many are less or equal than 50 kilometres. Then a percentage of distances less than 20 kilometres is computed, and if the predetermined threshold is not respected, the code will write it in the results table. The same will be repeated for the 50 kilometres distance.

At this point, **transportation costs** will be computed following formula 19:

$$Transportation\ costs\left[\frac{€}{year}\right] = Number\ of\ FTL\ transports*$$
$$* (Avg\ cost\ of\ fuel + Avg\ cost\ of\ truck\ and\ driver) \quad (19)$$

where:

- the number of full-truckload trips is computed as the sum of the number of trips per year for each transit point i; this is computed as total outbound flow for each cluster divided by the weight carried by a van[12];

$$Number\ of\ FTL\ transports_i\left[\frac{trips}{transit\ point_i * year}\right] =$$
$$\frac{\sum Outbound\ flows\ cluster_i\left[\frac{kilograms}{transit\ point*year}\right]}{Weight\ carried\ by\ a\ van\left[\frac{kilograms}{trip}\right]} \quad (20)$$

- the average cost of fuel per trip is the ratio between petrol cost and fuel consumption multiplied by the average distance, which has been previously computed as Euclidean distance increased by 5%;

$$Avg\ cost\ of\ fuel\left[\frac{€}{trip}\right] =$$
$$\frac{Petrol\ cost\left[\frac{€}{litre}\right]}{Fuel\ consumption\left[\frac{km}{litre}\right]} * Avg\ distance\left[\frac{km}{trip}\right] \quad (21)$$

- the average cost of truck and driver per trip is the multiplication of their hourly cost for the average duration of a trip.

$$Avg\ cost\ of\ truck\ and\ driver\left[\frac{€}{trip}\right] = \frac{Avg\ distance[km]}{Avg\ speed[\frac{km}{h}]} *$$
$$* \left(Driver\ cost\left[\frac{€}{hour}\right] + Truck\ cost\left[\frac{€}{h}\right]\right) \quad (22)$$

---

[12] It refers to a Fiat Ducato [15], which can carry up to 2,200 kilograms when fully loaded. This choice was due to the fact it is the most popular mean of transport of charities, even if some use cars or lorries.

Warehouse costs are computed with formula 23,

$$Warehousing\,costs\left[\frac{€}{year}\right] = Space\left[\frac{€}{year}\right] + Personnel\left[\frac{€}{year}\right] +$$

$$+ Energy\left[\frac{€}{year}\right] + Utilities\left[\frac{€}{year}\right] + Maintenance\left[\frac{€}{year}\right] \quad (23)$$

where:

- Space costs are simply computed as the multiplication of the space occupied by a transit point (see table 23 on page 76) for the number of transit points k of the iteration;

$$Space\,costs\left[\frac{€}{year}\right] = \#Transit\,points*$$

$$* Transit\,point\,area\left[\frac{m^2}{facility}\right] * Unitary\,space\,cost\left[\frac{€}{m^2}\right]$$
$$(24)$$

- Energy cost is computed as the total area of all transit points times a cost per squared metre;

$$Energy\,cost\left[\frac{€}{year}\right] = \#Transit\,points*$$

$$* Area\,of\,a\,transit\,point\left[\frac{m^2}{facility}\right] * Energy\,cost\left[\frac{€}{m^2}\right]$$
$$(25)$$

- Utilities are computed as employees and volunteers converted into FTE multiplied by a unitary cost per FTE;

$$Other\,utility\,cost\left[\frac{€}{year}\right] = Number\,of\,FTE\,in\,transit\,points*$$

$$* Unitary\,utilities\,cost\left[\frac{€}{FTE}\right] \quad (26)$$

- Maintenance is computed as the sum of the maintenance cost of each item times the correspondent number of items to maintain. This calculation is made for refrigerated cells, trucks, forklifts and pallet jacks.

$$Maintenance\,costs\left[\frac{€}{year}\right] =$$

$$\sum Maintenance\,cost_i\left[\frac{€}{year * item_i}\right] * Number\,of\,Items_i$$
$$(27)$$

$$i \in \{Trucks, \ Forklifts, \ Pallet \ jacks, \ Cells\}$$

The computation of the *FTE* in all transit points needs to be more deeply explained. Research has provided data regarding productivity for common warehouse activities: results have been summarised in table 24, even if their full explanation is in section 6.2 on page 35; for the activity of order preparation, please refer to subsection 6.2 on page 41. Some of the values have been collected with an interview to an employee of *DHL*, while the value related to the administrative activities has been computed from several surveys submitted to *OBAs* in January 2019.

The values listed in table 24 will be used to compute the

Activity	Value	Unit of m.	Source
Delivery organisation	4	$\frac{People}{Central warehouse}$	Assumption
Delivery and stocking	25	PL/h	DHL
Picking	25	PL/h	DHL
Order preparation	See 6.2	PL/h	Assumptions
Loading	33	PL/h	DHL
Adm. Activities	105	PL/h	Banco Alimentare

Table 24: Standard productivity values for common warehousing activities and their relative source.

number of *FTE* for both transit points and central warehouses. For each transit point *i* the code computes:

- the inbound flow and outbound flow of a transit point in pallet loads per week (being a transit point, these two quantities coincide);

- the number of *FTE* per activity *j* according to formula 28:

$$FTE \ activity_{i,j} = \left\lceil \frac{Flow_i \left[\frac{pl}{week}\right]}{Productivity_j \left[\frac{pl}{h*person}\right] * 40 \left[\frac{hours}{week}\right]} \right\rceil$$
(28)

$$i \in \{Delivery \ and \ stocking, \ Loading, \ Administrative \ activities\}$$

- The number of *FTE* for each activity is rounded up to the next integer and summed up to compute the number of *FTE* for each transit point;

- The number of volunteers has been deducted as a percentage of the total of *FTE*, according to formula 29. The

number of *FTE* related to employees can be deducted subtracting *FTE* volunteers from the total value of *FTE*.

$$FTE\, volunteers \;\; = \;\; \%FTE\, volunteers * Total\, FTE \quad (29)$$

- The total cost of personnel is computed by multiplying the value of *FTE* for its salary. Both employees and volunteers are paid $30,000\frac{\text{€}}{year}$ to monetise any kind of effort, even if offered and financially costless. End-user is left to decide how to set the salary of volunteers and employees according to its preferences.

Once transportation costs and warehousing costs have been computed, their sum is saved in a table together with the result on the service level double-check, as depicted in figure 35.

At the end of each iteration, the number of transit points k is increased by one: if this value becomes bigger than its predefined maximum, the while cycle is interrupted and the best number of transit points can be found minimising total costs subject to the respect of both thresholds on service level. As you can see from figure 35, the number k that minimises costs seems to be 17, while the number k that minimises costs under the constraint of service level is 26.

8.4.5 *Step 2: Clustering of transit points*

Once the position and number of transit points have been set, it is time to compute the same for the central warehouses. Before doing this, a preliminary step was necessary.
The quantity delivered to each charity is associated with a transit point since each association has been clusterised. Transit points are facilities that have no stock: their role in a network is receiving goods to deliver them to another mean of transport in a short time, meaning that the quantity they receive equals the quantity they hand out. By summing all quantities delivered to each cluster you get the quantity of food each transit point will distribute. The centroids computed are the coordinates of these facilities.
As concerns inbound flows, they have already been associated with their donors' coordinates. You have then all data required

k	costo_tot	c_trasp_tp_sc	costo_mag	risfascia20	risfascia50
15	3152795	1718355	1434440	Non rispettato	Non rispettat
16	3095047	1597207	1497840	Non rispettato	Non rispettat
17	3035380	1413710	1621670	Non rispettato	Non rispettat
18	3068978	1383908	1685070	Non rispettato	Non rispettat
19	3198614	1389714	1808900	Non rispettato	Non rispettat
20	3274686	1402386	1872300	Non rispettato	Non rispettat
21	3314113	1348198	1965915	Non rispettato	Non rispettat
22	3435654	1345909	2089745	Non rispettato	Non rispettat
23	3462064	1308919	2153145	Non rispettato	Non rispettat
24	3379159	1132399	2246760	Non rispettato	Non rispettat
25	3483950	1113360	2370590	Non rispettato	Non rispettat
26	3576174	1142184	2433990	Ok	Ok
27	3657969	1130364	2527605	Non rispettato	Ok
28	3672668	1051448	2621220	Ok	Ok
29	3822004	1107169	2714835	Non rispettato	Ok
30	3759179	950729	2808450	Ok	Ok
31	3852323	950258	2902065	Ok	Ok
32	3951716	956036	2995680	Ok	Ok

Figure 35: Output of the clustering of charities to get the transit points.

to compute a centre of gravity and to create clusters.

The computation of the clusters and their coordinates has been repeated for a certain number of times, starting from 1 up to a maximum number of 15. At the end of the cycle, the number k_cw is increased by one and if this number is higher than the fixed maximum, the computation is interrupted. The computation of the coordinates of the centroids is a weighted sum of flows and their coordinates and is iterated five times to improve their precision. After this, a double *for* cycle computes the distance between each centroid, which represents the central warehouse, and its point of origin or destination, depending on the line of $flussi\_mix$ considered[13] This distance is computed from each point of origin (or destination) with all centroids. To say it in other words, the code computes the distance between each line of $flussi\_mix$ with all of the k centroids. Since this operation is cumbersome, an Euclidean distance approach has

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[13] Please remember that $flussi\_mix$ consists of lines associated with both inbound and outbound flows.
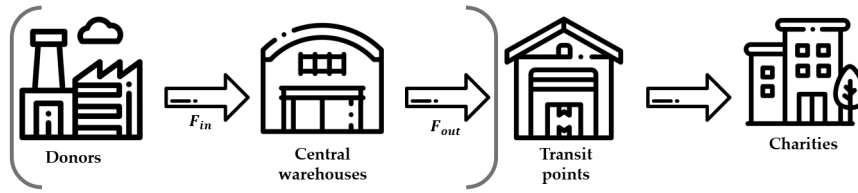
Figure 36: Part of the supply chain of *Banco Alimentare* taken into consideration in this part of the model.

been used, even if using the package *ggmap* to query Google Maps servers would lead to more precise results. The distance has been increased by 5% to simulate the real distance on the road, just like it has been done for the clustering of charities. Another advantage of using *ggmap* lies in the fact that each request can also be translated in time distances; in this case, time distance has been computed by considering an average speed for the mean of transport.

After this, the code looks for the closest centroid for each donor (transit point) and assigns it to each line of *flussi_mix*.

The previous steps are repeated five times to ensure a stable result. After five iterations, the position of each centroid tends to little change and clusters are stationary.

At this point, the costs of this solution can be computed: they have been divided into four categories to make the text more readable.

The first one is represented by **inbound transportation costs**. It computes a full-truckload cost of transportation for all inbound costs. The formula used is 30,

$$
Inbound\ cost\left[\frac{€}{year}\right] = Avg\ FTL\ trips[trips]*
$$
$$
* \left(Avg\ cost\ of\ trip\left[\frac{€}{trip}\right] + Avg\ cost\ of\ truck\ and\ driver\left[\frac{€}{trip}\right]\right)
$$
$$
\tag{30}
$$

where:

- the number of trips required is computed as the sum of all full-truckload trips for each central warehouse, where the reference lorry has a standard capacity of 20,000 kilograms [8];

- the average cost of a trip is the ration between the cost of petrol and the average consumption of a lorry multiplied by the average distance of a trip;

$$Avg\,cost\,of\,trip\left[\frac{€}{trip}\right] = \frac{Petrol\,cost\left[\frac{€}{litre}\right]}{consumption\left[\frac{km}{litre}\right] * Avg\,distance\,per\,trip[km]} \quad (31)$$

- the average cost of truck and driver per trip is given by the average duration of a trip multiplied by the hourly costs of the driver and of the truck.

$$Cost\,of\,truck\,driver\left[\frac{€}{trip}\right] = Avg\,duration\,trip\left[\frac{hours}{trip}\right] *$$
$$\left(Driver\,cost\left[\frac{€}{hour}\right] + Truck\,cost\left[\frac{€}{hour}\right]\right) \quad (32)$$

The computation for the **outbound transportation flows** follows the same logic; in this case, the number of trips is computed as the sum of all full-truckload trips for each transit point in one year, according to the database *uscite*.

An additional transportation cost has been computed: it regards **transportation between central warehouses**. The analysis of flows in chapter 7 revealed an existing unbalance between North and South in terms of product variety and quantity. The higher the number of central warehouses, the higher the inequality of product availability and product variety among different facilities, since donors would be assigned to the closest cluster only. It is then necessary (and more realistic) to think about a solution to this potential issue and to include it in the total costs of this network configuration.

A possible answer could be an exchange of goods between central warehouses to level their stock in terms of quantity and variety. This could be feasible by programming a shipment passing through each warehouse every two weeks, for example[14]. To compute the route, the Dijkstra algorithm (Vercellis, 2008 [17]) has been applied, following these steps:

- the northernmost point in the list of central warehouses is taken as the initial point of the route and it is deleted from the list of *unselected points*;

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[14] Please note that the annual number of expeditions can be modified in the input data.

- the distance between the selected point and all unselected points is computed;

- the point for which the distance from the currently selected point is chosen and it becomes the newly selected point.

It is clear that this procedure is unlikely to compute the optimal minimum path between all central warehouses, but its computational effort is very low and its result tends to the actual length of the path.

Computation of these transportation costs follows formula 30, even if some adaptation has been made.

An example of the output of the Dijkstra algorithm is summarised in table 37.

The sum of the first column, which represents the distance

```
> percorso
         V1         V2        V3
1     0.0000  11.914790  45.98941
2  1014.0583  15.211396  37.66657
3   848.6821  11.748215  44.44345
4   242.1619   9.152832  45.40039
5   110.7137  10.321550  44.93323
6   428.8861  13.618024  42.14782
7   185.2711  14.979151  40.93346
>
```

Figure 37: Example of the results of the application of Dijkstra's algorithm for k=7. V1 is the distance between the selected point and the previous one, V2 and V3 are its coordinates.

between each point and the previous one, gives the total length of the path. The number of transports corresponds to the predefined number of intra-warehouse transports (by default it is 48, i.e one every two weeks). The total length of the path is used to compute the travel time, which in turn is used to compute the costs of driver and truck, as well as the fuel cost.

By combining all these parameters, the result is the cost of transport between central warehouses, which is null in case of one warehouse and growing with a higher number of warehouses: this is in contrast with the other transportation costs, which decrease with a higher number of warehouses.

The next cost category is the one of **warehouse costs**, which is the sum of the same cost voices listed in formula 23, even if the way these components have been computed has changed.

The total area needed by central warehouses is computed according to the following formulas:

- The total area used by a central warehouse is the result of the area that is effectively used by stock, plus the aisles plus the area for order preparation;

$$Area\,central\,warehouse = U_{reale} * V_{reale} + Aisle * U_{reale} * 2 + Second\,aisle * U_{reale} \quad (33)$$

- The total area used by offices corresponds to 10% circa of the warehouse area;

- Computation of U_{reale}, V_{reale} and the real storage capacity SC_{reale} follows the theoretical steps as described during the lectures of Logistics Management [5];

- The required number of pallet locations has been computed as the maximum difference between the cumulative inbound quantity and the cumulative outbound quantity on a monthly basis divided by the average weight of a pallet load;

$$Required\,PL[pl] =$$
$$\left\lceil \frac{Inbound\,cumulative[Kg] - Outbound\,cumulative[Kg]}{Weight\,of\,a\,pallet\left[\frac{Kg}{PL}\right]} \right\rceil \quad (34)$$

- The number of forklifts and pallet jacks have been computed based on the needed throughput capacity;

$$Number\,of\,forklifts =$$
$$\left\lceil \frac{Throughput\,capacity\,required\left[\frac{SCC}{hour}\right]}{Throughput\,capacity\,forklift\left[\frac{SCC}{hour*forklift}\right]} \right\rceil \quad (35)$$

- Forklift throughput capacity has been computed considering a utilisation factor of 70%, while the needed through-

put capacity has been computed as an average hourly quantity of pallet loads received;

$$Throughput\ capacity\ forklift\left[\frac{SCC}{hour * forklift}\right] =$$
$$\left[\frac{Utilisation\ factor * 3600\left[\frac{seconds}{hour}\right]}{Avg\ duration\ of\ a\ single\ command\ cycle\left[\frac{seconds}{cycle}\right]}\right] \quad (36)$$

- Duration of a single command cycle depends on fixed times and variable times, where variable times take into account the vertical path and the horizontal one[15];

$$Single\ command\ time[s] = Fixed\ time+$$
$$\frac{Horizontal\ path[m]}{Speed\left[\frac{metres}{s}\right]} + \frac{Vertical\ path[m]}{Speed\left[\frac{metres}{s}\right]} \quad (37)$$

Differently from forklift trucks and pallet jacks, the total number of trucks and refrigerated cells depends on the number of central warehouses.

Personnel has been computed similarly according to formula 28. Activities performed inside central warehouses are logistic organisation, unloading and stocking, pallet retrieval, order preparation, order loading and administrative activities. For a detailed explanation of this part of the code please refer to section 6.2 on page 35.

Stock-related costs such as inventory cost and obsolescence have not been computed because they are not differential. Independently on the number of facilities adopted, the overall quantity of stock remains the same. Computing safety stock is meaningless because the spirit of *Banco Alimentare* is helping people as much as possible, but with no guarantee of availability in terms of quantity and variety. In other words, people can get only what is available in stock and what the company was able to recover: there is interest in providing as much product variety as possible, but the primary focus of *Banco Alimentare* is not a well-balanced basket of products but providing financial relief to people in need offering them some food they will not be in need to buy. In this sense, computing safety stocks is unuseful.

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[15] Vertical path has not been considered for pallet jacks.

Even computing the cost of scraps is unnecessary, being the overall quantity of wasted food the same among different network configurations. Most of the scraps generate before entering in *Banco Alimentare*'s network. The company is fighting against this problem with donors (*GDO* and factories, mostly) explaining them to donate food that is still good since scraps require the workforce to be disposed of. Shipments coming from *AGEA* and Fruit and vegetable markets may be damaged: in this case, the company has the faculty of refusing the shipment. However, computing the overall quantity of scraps is difficult because data are inaccurate and sometimes unavailable.

After having computed the total costs for a given network, the software computes the inbound and outbound transportation costs of each cluster, selects the most expensive one and assigns each line of $flussi\_mix$ belonging to the selected cluster to a random one. After this, all above-mentioned steps are repeated.
The code then proceeds to save all important databases into the "Risultati" folder in *.csv* format. A final sentence is printed on screen stating how many central warehouses and transit points the network of *Banco Alimentare* should have as well as few aggregated numbers regarding annual costs.

8.4.6 *The results*

This section is focused on commenting on the results of the model in normal conditions, meaning that the input data are those collected directly from *Banco Alimentare* and described in section 8.4.2.
Since part of the model is based on k-means clustering, the position and number of transit points may change, because the initial choice of the cluster for each charity is random. This is why any iteration leads to similar results in terms of costs and location of facilities, but each output can never be exactly replicated anymore.

Let us start from the graphical representation of the clusters: figures 38 plots the 27 clusters of charities and their reference transit point, while figure 39 divides all donors and transit points according to their reference central warehouse.
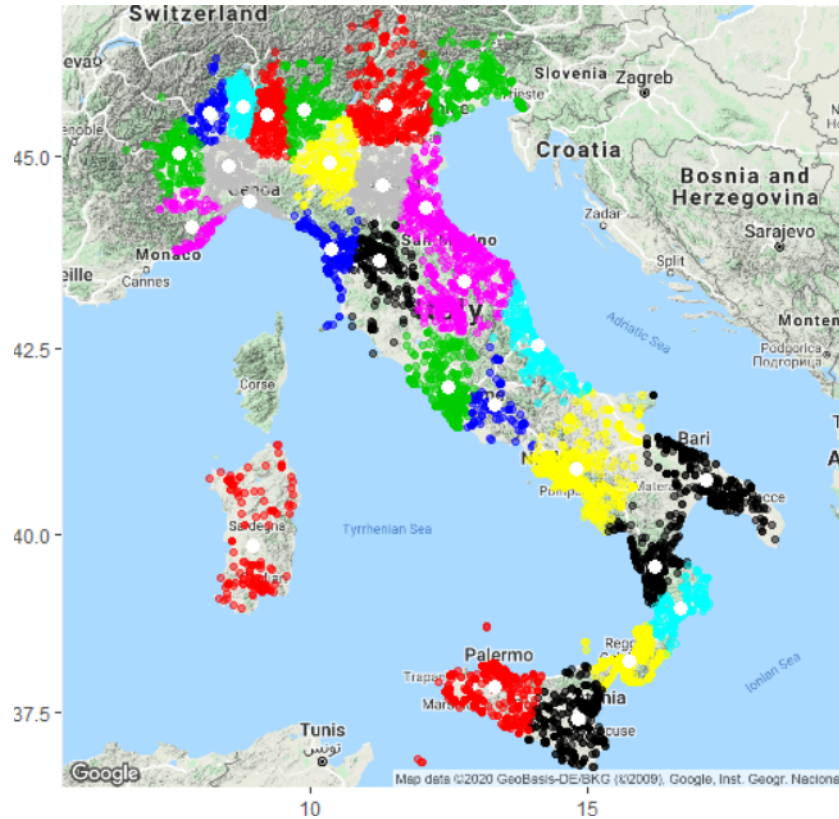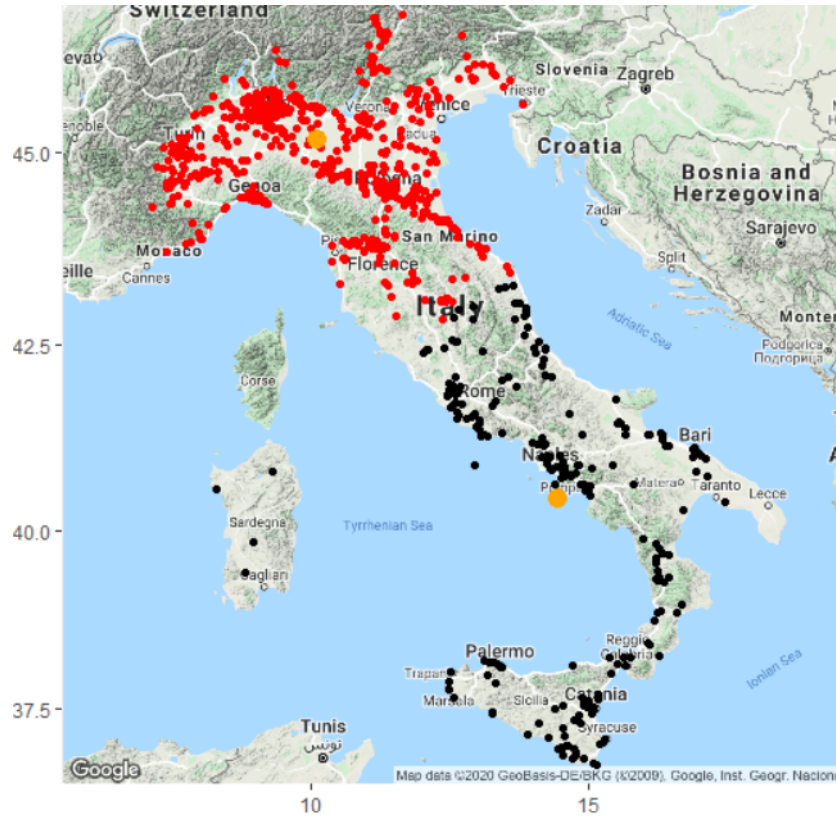 The shape of the areas is influenced by the way distances have

Figure 38: Graphical representation of the result of k-means clustering for k=27. This number and location of warehouses minimises total costs and respects the requirements on service level.

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been computed: due to the high number of requests, using the package *ggmap* and Google APIs was not possible, and a standard Euclidean distance formula has been applied. in future, if there were the opportunity of extensively using this package, it improve the level of accuracy of results.

As regards figure 39, Italy has been divided into two parts, North and South, with central warehouses near Parma and Naples.

The total costs of this configuration are equal to 7,277,537 $\frac{€}{year}$, with 2,425,705 $\frac{€}{year}$ spent in transportation and 4,851,830 $\frac{€}{year}$ spent in warehousing activities. These costs do not include the costs of obsolescence, inventory and ICT since these voices do not vary according to the configuration of the network.

Let us see more in detail how the results are composed. Transportation costs are the sum of the items listed in table 25,

Figure 39: Graphical representation of the result of k-means clustering for $k_{cw} = 2$. This number and location of central warehouses minimises total costs.

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while the graph in figure 40 shows the weight of each cost item with respect to the total of transportation costs.

Looking at costs in terms of accountability, you can notice

Route	Value $\frac{€}{year}$	Accountability
Donor $\to$ CW	745,702	*Banco Alimentare, except for FEAD*
CW $\to$ CW	44868	*Banco Alimentare*
CW $\to$ TP	740,065	*Banco Alimentare*
TP $\to$ SC	895,072	10% *Banco Alimentare*, 90% Charities

Table 25: List of the results of transportation costs

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that the percentage of transportation costs in charge of *Banco Alimentare*, charities and *FEAD* program are the ones listed in figure 41: white represents the percentage of costs attributed to *Banco Alimentare*, green is the part sustained by charities and orange is the one covered by the *FEAD* program.

Transportation costs
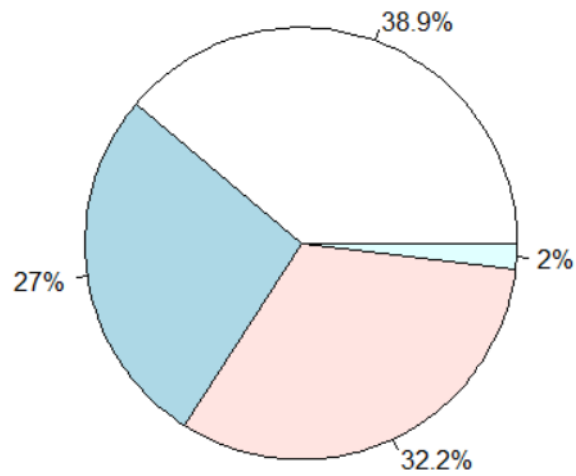
Figure 40: Pie chart representing the weight of each cost item listed in table 25. Light blue represents CW → CW, orange CW → TP, white TP → SC and green Donor → CW
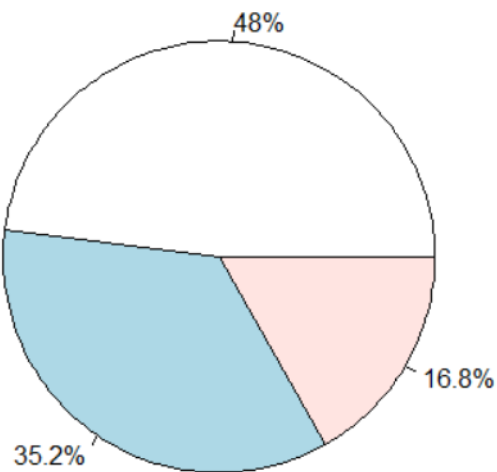
.

Transportation costs

Figure 41: Pie chart representing the amount of cost that can be attributed to each of the above-mentioned actors of *Banco Alimentare*'s supply chain. White represents the percentage of costs attributed to *Banco Alimentare*, green is the part sustained by charities and orange is the one covered by the *FEAD* program.

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Nearly half of transportation costs of the model are sustained by *Banco Alimentare*: this because *FEAD* program covers transportation up to the location designated by *Banco Alimentare*. A solution might be directly shipping *AGEA* products to the transit points, but this would increase complexity and transportation costs of the entire supply chain. Most of all, this choice would frustrate any attempt of centralising stocks and reduce overall costs, given the importance of this kind of flow on inbound quantity.

Whenever possible, *Banco Alimentare* should start bargaining with delegates of the program to share transportation costs, with the common objective of reducing supply chain costs and freeing financial resources that could be reinvested in food subsidies.

The model does not take into account the actor of the supply chain that is going to bear each cost: they need to be manually divided according to the existing agreements between actors.As stated before, transportation costs related to *AGEA* products are fully sustained by *FEAD* until the destination warehouse. If this agreement holds even after *Banco Alimentare* has changed its logistic network, it means that product shipment is covered until the destination central warehouse, and the rest of the transportation costs is left to *Banco Alimentare*. This might sound a little inconvenient, but 2,102 of the 3,363 full-truckload shipments between central warehouse and transit points regard products related to *AGEA* or *Fruit and vegetable market*: they account for nearly 373,000$\frac{€}{year}$ and they would dramatically impact on the overall level of transportation costs of *Banco Alimentare*. Total costs of the solution would decrease by 5% if totally allocated to the *FEAD* program. However, *FEAD* would benefit also from the reduction of the number of destinations, since they would pass from nearly 40 to 2 recipients.

As regards warehousing activities, tables 26 and 27 summarise the main costs voices computed by the model.

The total warehousing costs for both central warehouses and transit points are similar: on the total warehousing costs of the network configuration, 56% of them can be accounted to central warehouses.

Looking at the nature of these costs (please refer to figure 42), the most expensive cost voice is related to maintenance (33.1%), followed by personnel (30.9%), space (30.5%), energy (5.3%) and

Cost	Value $\frac{€}{year}$
Space cost	853,600
Personnel cost	720,000
Energy	149,380
Other utilities	5,160
Maintenance	1,025,100

Table 26: Summarisation of the main warehousing costs of central warehouses according to the configuration computed.

Cost	Value $\frac{€}{year}$
Space cost	624,000
Personnel cost	780,000
Energy	109,200
Other utilities	5,590
Maintenance	579,800

Table 27: Summarisation of the main warehousing costs of transit points according to the configuration computed.

utilities (0.2%).

However, it is useful to remember that the cost of volunteers does not represent a negative cash flow for *Banco Alimentare*: it has been calculated as a way to valorise any kind of resource offered and donated to the company. Even maintenance can be offered sometimes, as the Director of the Regional Food Bank of Daunia emphasised: in this case, savings are much more difficult to be quantified since it is not clear how much it is given for free and with which frequency. Just like donations of food, in most of the cases, there is a lack of predictability.

8.4.7 *Scenario analysis*

How and how much does the output of the model change according to several modifications of the input data? This is the main question of scenario analysis, which consists of high-lighting situations that *Banco Alimentare* might face in the short or long term and observing how the results of the model change.
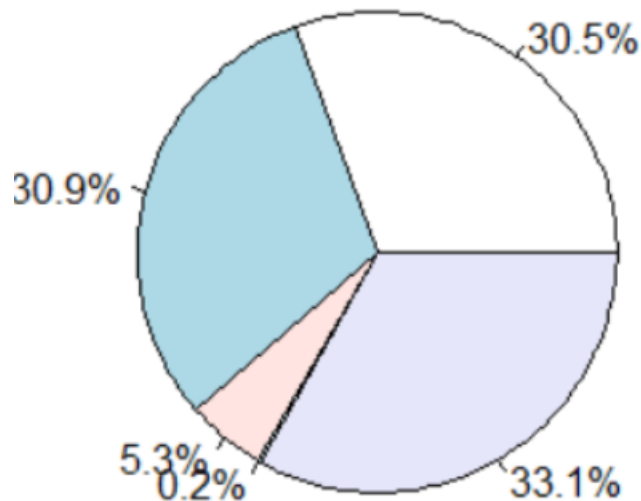
Different scenarios have been listed:

Figure 42: Pie chart that represents the weight of each cost voice inside warehousing costs. Maintenance is purple, personnel is green, space is white, energy is orange and utilities are in light blue

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SCENARIO 1 *Impact on transportation costs* Let us suppose an increment in transportation costs due to a shock of the petrol market or an on-going strike of transporters. Transportation costs increase by 20%; how does the model react to it?

SCENARIO 2 *Impact on service level* Charities get to know the intention of *Banco Alimentare* of improving its distribution network and ask for a higher service level due to financial difficulties. Let us suppose that 40% of charities are willing to travel 20 kilometres maximum and 70% of them 50 kilometres. How much will the second echelon change? Will it have an impact on the first one?

SCENARIO 3 *Increase of handled and demanded quantity* Due to economic recession, an increasing number of indigents asks for the help of *Banco Alimentare*. Let us suppose the European Union is able to increase the funds of the *FEAD* program by 20%, how will the actual network respond to the crisis?

Each one of the above-mentioned scenarios will be assessed separately in one of the following subsections.

Scenario number 1: Impact on transportation costs

This subsection will assess how much will the network configuration change in case of an increase by 20% of transportation costs.

Results seem to show a certain solidity of the system towards this kind of event since the number of transit points has increased by two units only, while the number and location of central warehouses is the same of the to-be scenario.

The overall level of costs has increased, due to the economic shock. Table 28 summarises the main costs of scenario 1 compared to the to-be case, i.e. transportation costs between central warehouses and transit points, transportation costs between transit points and charities and warehouse costs of transit points.

Cost	To-be $\left[\frac{€}{year}\right]$	Scenario 1 $\left[\frac{€}{year}\right]$	Variation
DON→CW	745,702	895,694	20.1%
CW→CW	44,868	54,024	20.4%
CW→TP	740,065	906,245	22.5%
TP→SC	895,072	1,102,565	23.2%
Total Transportation	2,300,767	2,958,528	28.9%

Table 28: Comparison between the main costs of scenario 1 and the to-be one.

Unfortunately, it is not possible to identically replicate the results of the to-be iteration under the condition of a 20% increase of all transportation costs; the position of transit points strongly depends on the first allocation of charities to the k clusters, which are randomly chosen in the initial iteration of k-means clustering.

Despite the increase of transportation costs, the network has not changed: the number of transit points that minimises transportation costs with respect to a minimum service level is still 27, while as regards central warehouses the optimal number is still two. The to-be configuration is solid enough to survive such an economic event.

Scenario number 2: Impact on service level

Changes on the level of service imply changes in the shape of the network since the requirement of accredited charities is based on the distance between their location and their reference transit point. The hypothesis of this scenario is an increase in the distance limitations from 29% to 40% for the 20 kilometres threshold and from 62% to 70% for the 50 kilometres one[16].
How has the network adapted to the new requirements? How many transit points will be necessary to satisfy the charities? Is the number and location of central warehouses changing accordingly?

Results of the simulation indicate an increase of transit points up to 36 units, while central warehouses change neither in terms of units nor in location. Figure 43 shows the new location of transit points: please compare it to figure 38 on page 91 to notice the difference between 27 and 36 transit points.
The shape of the clusters suffers again from the way distance has been computed: again, for a more accurate result please refer to the package *ggmap*.

Table 29 compares to-be costs analysed in chapter 8.4.6 with the costs of this scenario. Since there is no change in the composition of the first echelon, the comparison will be focused on the second one.

Cost	To be $\left[\frac{€}{year}\right]$	Scenario 2 $\left[\frac{€}{year}\right]$	Variation
CW→TP	740,065	827,684	11.8%
TP→SC	895,072	700,896	-21.7%
Warehousing costs	2,098,590	2,905,740	+38.5%

Table 29: Comparison of annual costs of the to-be scenario and the one more demanding higher constraints on service level.

As expected, the number of transit points has increased and reduced the distance between *Banco Alimentare* and charities, causing a drop in transportation costs. Bear in mind that 90% of transportation costs are sustained by caritative associations, meaning that a reduction of transportation expenses would lead to substantial savings.

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[16] The increment is simply an approximation of 10% more of what is required today.
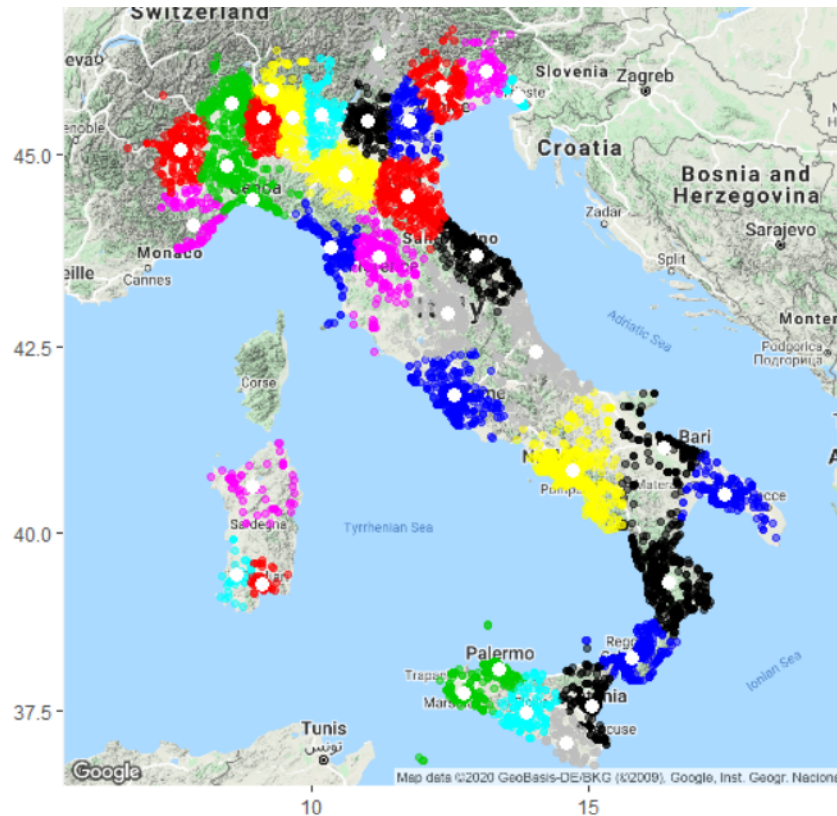
Figure 43: Representation of the second echelon of the network according to scenario number 3.

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Another piece of information worth mentioning is the transportation cost between central warehouses and transit points. This used to be worth 740,065 $\frac{€}{year}$; after the change in the service level, costs rose to 827,684 $\frac{€}{year}$, an increase of 11.8%. This was expected, since the number of destinations, the total number of trips and the total length to travel have increased.
An increment in warehousing costs was inevitable since the number of transit points sees an increment of 9 units. All cost voices related to warehouses grow due to the simple necessity of more people, more space and more equipment.

Figure 44 shows the comparison between the to-be level of cost for both *Banco Alimentare* and charities and the one identified in this scenario. This graph considers only three voices of cost: transportation between central warehouses and transit points, transportation between transit points and charities and warehouse costs. While charities seem to benefit from the increase of the number of transit points lowering their costs by
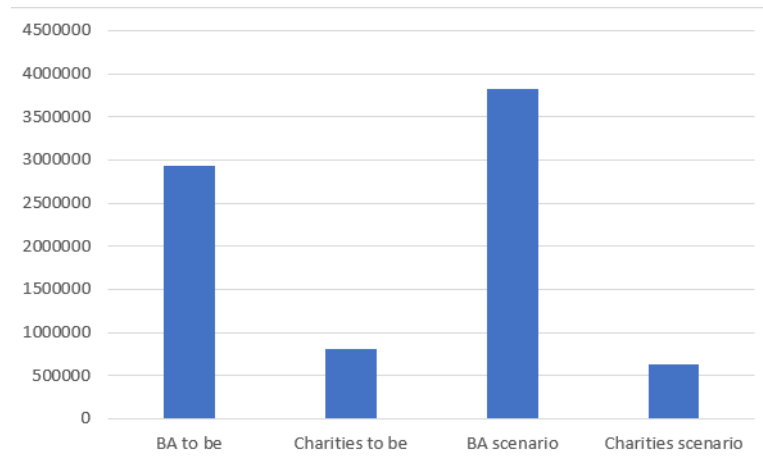
Figure 44: Comparison between the to-be level of cost for both *Banco Alimentare* and charities and the one identified in this scenario.

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21.7%, *Banco Alimentare* would see an increase of 38% of its costs compared to the to-be scenario for these three voices of costs only.

Considering all costs, by incrementing the number of transit points up to 36, *Banco Alimentare*'s total annual expenditure would rise by 11.5%, passing from $7{,}277{,}537 \frac{€}{year}$ to $8{,}114{,}520 \frac{€}{year}$.

Scenario number 3: Increase of handled and demanded quantity

The European Union wants to increase the quantity of food supplied with the *FEAD* program. This possibility is expected to come true in the following years: the suggested network configuration must be able to support an increase of donated quantities. Quantity handled to charities will adapt to the new availability of food in stock.

In setting the model to this new scenario, both inbound and outbound quantities related to the *FEAD* program (i.e. flows coming from *AGEA* and *Fruit and vegetable market*) have been incremented by 20%.

Costs are expected to change according to the increase of inbound and outbound quantities but the actual configuration should remain unchanged with respect to the to-be scenario.

The execution of the code revealed no change in the network configuration since the number of transit points is equal to 27

Cost	To-be $\left[\frac{€}{year}\right]$	Scenario 3 $\left[\frac{€}{year}\right]$	Variation
DON→CW	745,702	840,482	12.7%
CW→CW	44,868	45,070	0.5%
CW→TP	740,065	824,545	11.4%
TP→SC	895,072	999,508	11.7%
Transportation total	2,425,705	2,709,605	11.7%

Table 30: Comparison of transportation costs and total cost of scenario 4 and the to-be case.

and the number and position of the central warehouses is still the one delineated in the to-be scenario.
However, costs have increased up to 8,284,675 $\frac{€}{year}$, which means an increase of 13.8% with respect to the to-be scenario.

Let us see more in detail the reasons for the increment by analysing the components of transportation costs, which have been collected into table 30.
The overall level of costs has risen due to the higher quantity to be transported, hence the higher number of trips required to bring the stock to charities.
Transportation costs regarding exchanges between the two central warehouses are stable since their location has not changed and neither has the frequency of shipment.

The biggest increment is for transportation costs between donors and central warehouses. All parameters involved in formula 19 on page 80 present similar values to those of the base case described in section 8.4.6, except for the number of trips required to bring the inbound quantity towards the two central warehouses. These full-truckload shipments increased by 13%, passing from 3,363 to 3,783.
Nevertheless, transportation costs between central warehouses and transit points as well as last-mile deliveries expenditure have risen due to the agumentation of inbound flows.

Table 31 contains a comparison of these two scenarios in terms of warehouse costs.
The increase in inbound flows implies bigger warehouses, more labour and more handling equipment, which in turn have a negative impact on energy and utilities. Overall warehouse costs are expected to rise nearly by 15%, with an increase of

needed *FTE* of 24%.

Cost	To be $\left[\frac{€}{year}\right]$	Scenario 3 $\left[\frac{€}{year}\right]$	Variation
Space	1,477,600	1,779,440	20.4%
Personnel	1500000	1,860,000	24.0%
Energy	258,580	311,402	20.4%
Utilities	11,060	13,330	20.5%
Maintenance	1,604,900	1,610,900	0.4%
Warehouse total	4,852,140	5,575,072	14.9%

Table 31: Summarisation of warehouse costs for scenario 4 and to-be one.

8.4.8 *Application of the model to the as-is configuration*

Part of the model has been applied to the actual network to compute the total costs of the existing logistic network.

It is important to specify that the model built cannot be used to compute the costs of a logistic solution by simply changing its inputs: it has been coded to get information and to use it to find an optimal solution for a certain case, not to compute the total costs of a solution.

Given the data loaded onto the model (please refer to section 8.4.2 on page 70), it is possible to compute the total cost of the actual network of *Banco Alimentare* using the same cost functions of the to-be case. This chapter describes how this is possible and the main results found.

Computation

Calculation of total costs for the as-is network of *Banco Alimentare* is simpler with respect to computing the same for the to-be scenario since the as-is network can be represented as a one-echelon system[17].

The logistic chain can be represented as in figure 45, where inbound and outbound flows concern quantities passing from donors to warehouses and from warehouses to charities respectively.

Computation of inbound transportation costs followed appro-

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[17] Actually, this is a simplification that does not consider less than 5% of flows passing through Parma.
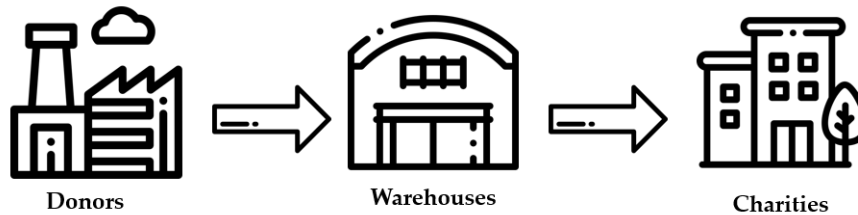
Figure 45: Schematisation of the logistic network of *Banco Alimentare* to compute its total cost.

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ximately the same steps that have been described on page 80. First of all, inbound flows have been aggregated on the basis of their donor. The number of trips has been calculated by dividing the inbound quantity of each donor by the capacity of a truck in full-truckload (i.e. 20,000 kilograms).
All other steps that bring to the solution of equation 19 follow the same steps.

Computation of outbound transportation costs has been computed on the database "Uscite.csv", which is a list of all shipments to charities in the year 2019. All steps described above have been followed, except for the parameter concerning the capacity of the truck. In this case, since most of the charities use vans, the capacity parameter has been set to 2,200 kilograms [15].

Warehouse costs follow formula 23 on page 81. Parameters have been taken from an internal document of *Banco Alimentare* stating the overall number of resources in terms of personnel, squared metres and handling material.

Comment

Results on this particular execution of the code have been summarised into table 32.
Both transportation and warehouse costs of the to-be case are lower in value with respect to the as-is case.
Transportation costs have decreased by 2%, passing from 2,475,122 $\frac{€}{year}$ to 2,425,705 $\frac{€}{year}$. Hovever, cost voices are not fully comparable since the distribution network includes an additional level that is not considered. You can try to compare similar voices by referring to figure 46. On the yellow part, *Banco Alimentare* will be able to save 3% of transportation costs by adding an echelon

Cost	To-be $\left[\frac{€}{year}\right]$	As-is $\left[\frac{€}{year}\right]$
DON→MAG	-	1,399,262
MAG→SC	-	1,075,860
Transportation total	2,425,705	2,475,122
Warehouse total	4,851,830	11,548,158
Total cost	7,277,537	14,023,280

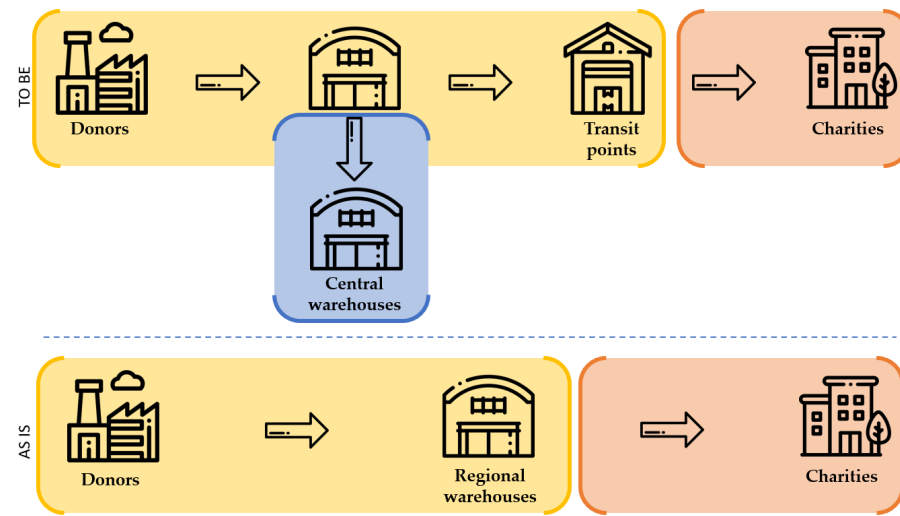Table 32: Summarisation of transportation and warehouse costs of the as-is scenario.

Figure 46: Schema to compare the transportation costs of the to-be and as-is scenarios.

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to its network.

Unfortunately, if you want to include a programmed exchange of stock between the two central warehouses (i.e. the blue area in figure 46), part of this advantage will be consumed by this activity, which was not included in the original network[18].

On the red part, which could be also referred to as last-mile delivery, there could be a potential saving of 20.2%, which affects both *Banco Alimentare* and charities. This could be attributed to to the better location of transit points thanks to clustering.

Warehouse costs show a steep decrease in value. Table 33 collects all main warehouse costs components and their value for both as-is and to-be cases. To analyse the cause of this differ-

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[18] In reality, there could be an exchange between different warehouses, but it is not programmed in advance usually.

Cost	To-be $[\frac{€}{year}]$	As-is $[\frac{€}{year}]$	Variation
Space	1,477,600	1,090,640	-26.2%
Personnel	1,500,000	8,910,000	494%
Energy	258,580	190,862	-26.2%
Utilities	11,060	63,855	477.4%
Maintenance	1,604,900	1,292,800	-19.4%
Warehouse total	4,852,140	11,548,157	138%

Table 33: Summarisation of warehouse total cost components and their variation with respect to the to-be scenario.

ence.

Space, energy and maintenance increase from as-is to to-be scenario, since more facilities need more resources need to be employed and maintained.

The first two depend on squared metres, which cannot but increase due to the addition of 27 transit points. Their size has been set equal to 600 squared metres, but can be changed into the input data.

Maintenance costs depend on the number of refrigerated cells, forklifts, pallet jacks and trucks of *Banco Alimentare*. A computation of throughput capacity made finding a more precise result possible, but the increase of facilities implies an increase in handling equipment units, with a lower level of utilisation.

The most impressive cost is the one related to personnel. Two clarifications need to be made. First of all, the data of *FTE* of the as-is network is not so precise, since it is difficult for each warehouse to say how many volunteers are working and for how long they have been working inside each warehouse. Due to this, conversion of volunteers into *FTE* has been based on the opening time of each warehouse and on the average number of volunteers per day; these pieces of information are esteemed and should be seen as average values.

Secondly, the computation of personnel in the model takes into account logistic-related necessities, without considering all kinds of employees such a company needs for its everyday activities. This means that the value of *FTE* can be an underestimation of the overall number of people needed to make all activities possible.

Last but not least, for *Banco Alimentare* involving more volunteers than necessary is not an issue, but a good thing. Keeping relations between the company and its staff is crucial to make

the company work, grow and improve. In this sense, the larger the network of volunteers, the better for the company.

For a company such as *DHL*, on which most of the data about throughput capacity has been based, efficiency is crucial and directly related to cash flows, since there is no volunteer working in their network. Data received by the external advisor should be carefully treated, since they represent the performances of a company leading in the sector.

The new configuration proposed is the one that, according to theory, fits the needs of *Banco Alimentare*'s activities. This might increase warehouse costs due to a higher number of facilities and a higher number of employees to run everyday activities: however, transportation costs are lower and product variety (and product quantity) should be more levelled once orders will be managed by the two central warehouses. Service level will be respected and this will lower transportation costs of charities.

8.4.9 *The mid-term solution*

The actual distribution network of *Banco Alimentare* will consistently change if the company decides to fully adopt the proposed to-be network. This evolution implies the construction or search for new facilities, hiring or moving employees and volunteers, separating or incorporating Regional Food Banks according to the clusters, re-thinking all the activities performed inside transit points and warehouses[19], finding or moving handling equipment to the new nodes of the network. This important change will need time and resources in its preparation and actuation. This is the reason for which the proposed network has been referred to as "long-term solution", or in other words "the solution to which *Banco Alimentare* should tend in the long term".

One simpler solution consists in keeping the actual facilities while changing what happens inside them. In this way, *Banco Alimentare* can leverage on its existing resources to improve its network. The impact of this "Plan-B" solution is still relevant in terms of effort since the central warehouses still need to be built and the transition of warehouses into transit points still needs to organised and undertaken. However, this might be the

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[19] Valentina De Micheli investigated this aspect in her thesis [9] in chapter 7.3.2.

beginning of a bigger evolution of *Banco Alimentare*'s logistic network.

An estimation of the mid-term distribution network costs has been made by adapting the code of the model to the assumptions of this scenario:

- the transition from as-is to-be will take several years in the making;

- transition from as-is to the mid-term scenario could take a couple of years to build (or buy) the central warehouses and to make them operative: the reorganisation of activities inside transit points and central warehouses will take less than two years, meaning that *FTE*, handling equipment and trucks will be the ones of the to-be scenario (or at least closer to its values with respect to the as-is ones);

- total area required by the network is the sum of the to-be area of the central warehouses and the total area of warehouses in the as-is scenario.

A list summarising all main cost voices for this scenario has been produced and can be found in table 34. In this section, as-is, mid-term and to-be scenarios will be also addressed as phase A, B and C to limit repetitions.

Costs	A As-is	B Mid-term	C To-be	A vs B	B vs C
DON→CW	1,399,262	746,439	745,702	-1%	-17%
CW→TP		877,014	740,065		-16%
CW→CW	0	40,970	44,868	-	10%
TP→SC	1,075,860	1,051,377	895,072	-2.3%	-15%
Transp total	2,475,122	2,715,800	2,425,707	10%	-11%
Whs costs	11,548,158	5,917,567	4,851,830	-49%	-18%
Total costs	14,023,280	8,633,367	7,277,847	-38%	-15.7%

Table 34: Summarisation of all transportation and warehouse costs of the as-is, mid-term and to-be scenarios in $[\frac{€}{year}]$.

The general trend of costs shows that they are expected to decrease both passing from as-is to mid-term and from mid-term to to-be: the best saving is still in the to-be case, with a drop of 15.7% of total costs with respect to the mid-term solution. Transportation costs between donors and central warehouses in

mid-term and to-be cases are similar in value and show a decline with respect to the as-is case due to the addition of the first echelon, which has two destinations only: that is a clear benefit of introducing the first echelon, that is reducing the number of destinations from suppliers to the central warehouses.

Transportation costs are expected to rise between A and B; however, if *Banco Alimentare* were able to negotiate with the *FEAD* program, there would be up to 373,000 € of potential savings per year, as stated in section 8.4.6. The same economies could be achieved in the to-be case.

The difference between intra-central warehouse transportation costs is simply due to their position, which should be the same. The location of transit points does not depend on the position of actual warehouses of the network but has been set according to the future position of transit points. A difference of 4,000 € could be considered negligible.

Significant is the difference in last-mile delivery: for phase A it was equal to $1{,}075{,}860\frac{€}{year}$, in phase B costs have decreased to $1{,}051{,}377\frac{€}{year}$ and in phase C to $895{,}072\frac{€}{year}$. Again, since the code is slightly different from the as-is and mid-term cases, even if last-mile delivery should cost the same, it was unfortunately not possible to obtain the same result. The decreasing trend from the as-is to the to-be scenario is however glaring.

As regards warehouse costs, there is an important drop from as-is to mid-term. The latter has been computed according to the units of trucks, handling equipment and *FTE* of the to-be case, thus the significant variation in value. Most of it can be attributed to personnel costs, due to issues that have already been explained in detail in section 8.4.8. The last reduction in warehouse costs is due to the fact transit points take less space than traditional warehouses.

On the long-term, however, *Banco Alimentare* should achieve a new and lower level of costs due to the advantages of centralisation.

CONCLUSION

The model was built to show an opportunity of revolutionising the logistic network of *Banco Alimentare*. According to its characteristics, a two-echelon network with transit points should be the best configuration to adopt: computations made in the previous sections were able to highlight all opportunities related to what appears to be the best configuration, the one with 27 transit points and 2 central warehouses.
Nevertheless, modelisation and all calculations made are based on assumptions, some simplifications and available data: its correctness lays on these three pillars.
Several are the recommendations and suggestions that could be made for the potential successor of this work.

One of the biggest concerns about the model is about donations: if the biggest ones are conveniently brought to a central warehouse and shared, the smallest ones could be rejected due to senseless transportation costs. *Banco Alimentare* could decide where to direct a donation on the basis of its entity, meaning that if there is a substantial donation, it should be directed towards a central warehouse, while if there is a smaller quantity donated it may be better bringing it to a transit point or directly leaving it to a charity. This procedure has already been used by *Banco Alimentare* to cut on transportation costs, but the model cannot consider it since inbound flows had to be aggregated by donor. Including it in future developments is important not to discourage the donation of quantities that may be small in quantity but frequent.

Secondly, several rows extracted by *SAP* did not seem to be reliable information. Sometimes data were incomplete, redundant or wrong. Unfortunately, the results of this work are strongly based on this data.
Lot of work still needs to be done. Unfortunately, there is only one employee in Milan working on this and checking data consistency. The company needs to invest more time and resources in training people using *SAP* because every minute spent for-

ming employees can be an hour correcting mistakes less.

In the perspective of reducing transportation costs, the Regional Food Bank of Piedmont suggested some charities they organised themselves to collect their order together with a lorry instead of separately and with vans. In this way, they were able to split costs and reducing them.
Unfortunately, what happens is that charities do not know each other even if they live close to each other. But what if *Banco Alimentare* were able to provide a map on which all accredited associations are plotted? This would allow them to find their neighbours, foster supportive behaviours and most of all encouraging nearby charities to aggregate shipments on bigger means of transport, thus reducing costs.

Last but not least, another important pillar of the model regards the contract with *AGEA*. For the moment, the agreement states that transportation costs are included in the final cost and fully beared by the *FEAD* program. Nowadays, warehouses of *Banco Alimentare* directly receive pallets from the *FEAD* program, but what would happen if the first echelon with two central warehouses were implemented? Transportation costs would be covered up to the first echelon, leaving to *Banco Alimentare* the commitment of bringing every pallet including the ones related to *FEAD* to the transit points. Furthermore, *FEAD* would benefit from the new configuration, since shipments can be aggregated and sent to just two locations.
There is an urge to talk with the representatives of the *FEAD* program to split costs and benefits of the new configuration of *Banco Alimentare*, otherwise there would be an unbalance of benefits and costs between these two actors. The final aim of both parties is helping the highest number as possible in the best way as possible, so there should be space for a peaceful and new agreement between these two actors.

ANNEXE - MATRICES OF FLOWS

This part contains the matrices of flows of 2018 divided by geographical area. *OBAs* and regions of origin have been aggregated into different areas: North, Centre, South, Islands. In the case of regions of origins, a fifth channel has been introduced to include foreign products. Flows have been divided into eleven classes, which are displayed in table 12.

From/to	North	Centre	South	Islands
North	60,3%	30,4%	0,1%	9,2%
Centre	5,5%	94,3%	0,2%	0,0%
South	65,0%	5,9%	25,2%	3,9%
Islands	30,7%	0,2%	1,3%	67,8%
Abroad	100,0%	0,0%	0,0%	0,0%

Table 35: Subdivision of the flows related to fruits and vegetables of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	79,2%	13,1%	1,0%	6,6%
Centre	0,5%	99,5%	0,0%	0,0%
South	32,1%	0,0%	67,9%	0,0%
Islands	3,0%	0,0%	1,7%	95,3%
Abroad	100,0%	0,0%	0,0%	0,0%

Table 36: Subdivision of the flows related to beverage of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	81,7%	14,3%	0,1%	3,9%
Centre	22,1%	72,1%	4,7%	1,1%
South	n.d.	n.d.	n.d.	n.d.
Islands	0,0%	0,0%	0,0%	100,0%
Abroad	n.d.	n.d.	n.d.	n.d.

Table 37: Subdivision of the flows related to infant food of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	52,4%	31,1%	0,0%	16,5%
Centre	0,0%	100,0%	0,0%	0,0%
South	44,3%	5,2%	50,5%	0,0%
Islands	0,1%	0,0%	0,0%	99,9%
Abroad	100,0%	0,0%	0,0%	0,0%

Table 38: Subdivision of the flows related to cheese of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	74,3%	4,6%	0,8%	20,3%
Centre	0,6%	99,4%	0,0%	0,0%
South	9,3%	0,0%	90,7%	0,0%
Islands	0,0%	0,0%	0,0%	100,0%
Abroad	n.d.	n.d.	n.d.	n.d.

Table 39: Subdivision of the flows related to milk and derivatives of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	79,5%	12,7%	2,3%	5,4%
Centre	9,0%	89,3%	1,4%	0,3%
South	29,5%	11,0%	45,3%	14,3%
Islands	0,0%	0,0%	0,0%	100,0%
Abroad	n.d.	n.d.	n.d.	n.d.

Table 40: Subdivision of the flows related to seasonings of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	77,7%	13,8%	0,4%	8,2%
Centre	1,0%	97,7%	0,0%	1,3%
South	n.d.	n.d.	n.d.	n.d.
Islands	0,0%	0,0%	0,0%	100,0%
Abroad	n.d.	n.d.	n.d.	n.d.

Table 41: Subdivision of the flows related to fish of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	55,4%	36,4%	0,5%	7,8%
Centre	3,2%	96,5%	0,0%	0,4%
South	44,2%	14,5%	41,2%	0,0%
Islands	0,0%	0,0%	0,0%	100,0%
Abroad	n.d.	n.d.	n.d.	n.d.

Table 42: Subdivision of the flows related to beans of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	71,7%	17,9%	0,5%	9,8%
Centre	1,0%	99,0%	0,0%	0,1%
South	1,4%	0,7%	47,3%	50,6%
Islands	0,0%	0,0%	0,0%	100,0%
Abroad	93,6%	0,0%	6,4%	0,0%

Table 43: Subdivision of the flows related to cereals, pasta and flour of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	69,4%	18,9%	1,6%	10,1%
Centre	1,8%	93,4%	1,7%	3,1%
South	31,6%	0,0%	68,4%	0,0%
Islands	0,8%	0,1%	0,3%	98,8%
Abroad	42,9%	57,1%	0,0%	0,0%

Table 44: Subdivision of the flows related to sugar and snacks of 2018 by area of destination and origin in percentage terms

From/to	North	Centre	South	Islands
North	51,3%	38,0%	0,0%	10,7%
Centre	0,1%	99,9%	0,0%	0,0%
South	0,0%	64,5%	35,5%	0,0%
Islands	0,0%	0,0%	0,0%	100,0%
Abroad	n.d.	n.d.	n.d.	n.d.

Table 45: Subdivision of the flows related to meat of 2018 by area of destination and origin in percentage terms

ANNEXE - THE CODE OF THE MODEL

The following pages have been attached to show the code of the model.

To run the code, make sure all libraries indicated have been previously installed and that your machine has a RAM of 8 gigabytes at least.

```r
1   #caricare (solo dopo averle scaricate!) le seguenti librerie
2   library(tidyr)
3   library(dplyr)
4   library(ggmap)
5   library(rworldmap)
6   library(rgl)
7   library(sp)
8   library(osrm)
9   library(maps)
10  library(RCurl)
11  library(stringr)
12  library(VIM)
13  library(beepr)
14  library (geosphere)
15  library(sendmailR)
16
17  #settare la directory di R in \Directory del modello\Risultati
18  setwd("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
    modello\\Risultati")
19
20  ### DATI
21
22  #importo i database (elenco dei donatori, elenco dei flussi
    annuali, elenco dei magazzini del Banco, elenco dei codici
    identificativi dei magazzini)
23  donatori <-
    read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
    modello\\Dati\\Elenco donatori 2018 Originale.csv")
24  flussi <-
    read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
    modello\\Dati\\Elenco entrate 2018 CSV.csv")
25  indirizzi_magazzini <-
    read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
    modello\\Dati\\Indirizzario Magazzini.csv")
26  codici_magazzini <-
    read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
    modello\\Dati\\Codici Magazzini.csv")
27  uscite <-
    read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
    modello\\Dati\\Uscite Italia.csv")
28  elenco_sc <-
    read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
    modello\\Dati\\Elenco SC.csv")
29
30  #immetto la chiave API di Google
31  register_google(key = "AIzaSyBd8x60sUd9uy2v6F0TdevxNGXGlNn0obU",
    write = TRUE)
32
33  #inserire un'email personale per ricevere notifiche di fine calcolo
34  to <- "<raffaello.barri@gmail.com>"
35
36
37  ## COSTI DI TRASPORTO
38
39  #capacità di un tir in FTL (secondo euroimpex.lv) [kg]
40  ftl <- 20000
41
42  #capacità di un furgone Ducato in FTL (secondo euroimpex.lv) [kg]
43  ftl_tp <- 2200
```

```r
44
45    #tempo di carico e di scarico di un tir [h]
46    tempo_car_scar <- 2
47
48    #costo del guidatore [€/h] (fonte: papà)
49    c_autista <- 30
50
51    #costo del mezzo di trasporto [€/h] (fonte: papà)
52    c_mezzo <- 300/24
53
54    #velocità media del mezzo di trasporto [km/h]
55    vel_media <- 50
56
57    #consumo del mezzo di trasporto [km/l]
58    consumo_kml <- 5
59
60    #costo del carburante [€/l]
61    costo_diesel <- 1.5
62
63    #numero di scambi tra magazzini centrali all'anno secondo il
      percorso trovato con Dijkstra
64    trasporti_annuali_cw_cw <- 24 #di base calcolo due trasporti al
      mese
65
66
67    ##COSTI DI MAGAZZINO
68
69    #dati per il calcolo del personale
70    ricevimento_scarico <- 25 #[pl/(persona*ora)]
71    prelievo <- 25 #[pl/(persona*ora)]
72    carico <- 33 #[pl/(persona*ora)]
73    attività_amministrative <- 105 #[pl/(persona*ora)]
74    org_ritiri_cw <- 4 #[pers/cw]
75
76    #dati per il calcolo della throughput capacity della preparazione
      ordini
77    num_cartoni_pl <- 40
78    num_cartoni_carrello <- 5
79    viaggi_per_pallet <- 8
80    corridoio_pick <- 5 #[m]
81    velocità_operatore <- 0.8 #[m/s]
82    tempi_fissi <- 120 #[s]
83
84    #tir: portata e numero di pallet
85    portata_tir <- 20 #[t]
86    pallet_tir <- 33 #[pl/tir]
87    peso_pl <- ftl/pallet_tir #[kg/pl]
88
89    #area di un ufficio e del magazzino di un magazzino centrale
90    area_magazzino_cw_un <- 5000
91    area_uffici_cw_un <- 500 #gli uffici sono il 10% dell'area
      occupata circa (da dati rete attuale)
92
93    #area di un transit point, numero muletti, transpallet, mezzi,
      celle
94    area_tp_un <- 600 #[m^2]
95    muletti_tp <- 2
96    transpallet_tp <- 4
97    mezzi_tp <- 1
```

```
 98    celle_tp <- 2
 99
100    #numero muletti, transpallet, mezzi della rete nel 2019
101    transpallet_rete <- 117
102    muletti_rete <- 58
103    mezzi_rete <- 77
104
105    #numero di celle per magazzino centrale
106    celle_cw <- 2
107
108    #dimensioni di un modulo di sei pallet
109    W <- 5.3 #[m]
110    D <- 2.8 #[m]
111    H <- 1.5 #[m]
112
113    #altezza massima raggiunta da un muletto ed altezza massima
       dell'edificio (fare rifermento alla figura nella tesi)
114    h_max_muletto <- 4.5 #[m]
115    h_max_edificio <- 8 #[m]
116    corridoio <- 3 #[m]
117
118    #dati del muletto
119    vel_orizz_muletto <- 2 #[m/s]
120    vel_vert_muletto <- 0.3 #[m/s]
121    FU <- 0.7 #fattore di utilizzo
122
123    #dati di un transpallet
124    vel_orizz_transpallet <- 1 #[m/s]
125
126    #tempi per la throughput capacity dei muletti e dei transpallet
127    Tfissi <- 55 #[s]
128
129    #costo della manutenzione dei mezzi, muletti, celle, transpallet
       [€/(un*y)]
130    c_manut_cella <- 1200
131    c_manut_mezzo <- mean(1600+11300)
132    c_manut_transpallet <- 500
133    c_manut_muletto <- 2500
134
135    #costo dello spazio [€/(m^2*y)]
136    c_spazio <- 40
137
138    #costo di stipendiati/volontari nell'anno 2019[€/(y*pers)]
139    c_empl <- 30000
140    c_vol <- 30000
141
142    #calcolo la percentuale di volontari in base al rapporto FTEvol
       del 2019 vs FTEtot 2019
143    FTE_empl_2019 <- 85
144    FTE_vol_2019 <- 1468
145    perc_vol <- FTE_vol_2019/(FTE_empl_2019+FTE_vol_2019)
146
147    #somma dei flussi in un anno (nell'anno 2019 e nel caso attuale)
       [t/y]
148    tot_flussi_2019 <- 91762730
149    tot_flussi <- 91762730
150
151    #costo dell'energia [€/(m^2*y)]
152    c_energia <- 7
```

```
153
154    #costo delle altre utenze [€/(m^2*pers)]
155    c_utenze <- 215
156
157
158    #DATI PER IL CLUSTERING DELLE SC (lo tengo solo per controllare
       che si rispetti questo livello di servizio, non è limitante)
159
160    #percentuale di SC che vogliono un tragitto sotto i 20 km
161    fascia20<- 0.29
162
163    #percentuale di SC che vogliono un tragitto sotto i 50 km
164    fascia50<- 0.62
165
166    #inserisco il numero di cluster k di partenza e massimo per i
       transit point
167    k <- 15
168    k_max <- 40
169
170    #inserisco il numero di cluster k di partenza e massimo per i
       magazzini centrali
171    k_cw <- 1
172    k_cw_max <- 10
173
174    #cartina dell'Italia
175    map <- get_map(location = 'Italy', zoom = 6)
176
177    #CALCOLO DELLE COORDINATE (una tantum)
178
179    ######################################################################
       ###################
180    # i passaggi sottostanti portano alle coordinate di donatori e
       riceventi ed ?          #
181    # sufficiente svolgerli solo una volta. le informazioni sono
       salvate in un file .csv #
182    # che viene poi richiamato nel calcolo delle distanze con
       osrm.                           #
183    ######################################################################
       ######################################################################
       ####
184
185    #sistemo il db donatori
186    donatori <- as.data.frame(donatori)
187    colnames(donatori) <- c('Codice donatore',  'Ragione Sociale',
       'Via',  'Numero civico',    'Localita', 'CAP',  'Provincia',
       'Regione')
188
189    #sistemo l'indirizzo nel db donatori
       (https://stackoverflow.com/questions/6081439/changing-column-names-
       of-a-data-frame)
190    dati_ind <- c('Via', 'Numero civico', 'CAP', 'Localita')
191    donatori$Indirizzo <- apply(donatori[ , dati_ind ] , 1 , paste ,
       collapse = ", ")
192    donatori <- donatori[ , !(names(donatori) %in% dati_ind)]
193    donatori$Indirizzo <- gsub(" ,", "", donatori$Indirizzo)
194
195    #calcolo le coordinate per i fornitori dati con geocode (ggmap);
       unisco le due nuove colonne a donatori
196    donatori$Indirizzo <- paste0(donatori$Indirizzo, ' Italia')
```

```
197  coordinateprovvisorio <- geocode(donatori[, c("Indirizzo")],
     output = "latlon", source = c("google"))
198  donatori <- cbind(donatori, coordinateprovvisorio)
199
200  #scrivo la tabella donatori da parte togliendo le righe non
     trovate; filtro le righe al di fuori dagli estremi geografici
     italiani
201  donatori <- donatori[which(donatori[,c("lat")] < 47.072975),]
202  donatori <- donatori[which(donatori[,c("lat")] > 35.493333),]
203  donatori <- donatori[which(donatori[,c("lon")] < 18.520556),]
204  donatori <- donatori[which(donatori[,c("lon")] > 6.627281),]
205  donatori <- donatori[complete.cases(donatori[,6]),]
206  write.csv2(donatori,
     "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
     modello\\Salvataggi\\Donatori con coordinate.csv")
207
208  #ripeto gli stessi passaggi per calcolare la posizione dei
     magazzini destinatari
209  #indirizzi_magazzini <- as.data.frame(indirizzi_magazzini)
210  colnames(indirizzi_magazzini) <- c('Nome Magazzino',
     'Regione', 'Indirizzo')
211  indirizzi_magazzini$Indirizzo <-
     paste0(indirizzi_magazzini$Indirizzo, ' Italia')
212  indirizzi_magazzini$Indirizzo <-
     as.character(indirizzi_magazzini$Indirizzo)
213  coordinateprovvisorio <- NULL
214  coordinateprovvisorio <- geocode(indirizzi_magazzini[,3], output
     = "latlon", source = c("google"))
215  indirizzi_magazzini <- cbind(indirizzi_magazzini,
     coordinateprovvisorio)
216  rm(coordinateprovvisorio)
217
218  write.csv2(indirizzi_magazzini,
     "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
     modello\\Salvataggi\\Magazzini con coordinate.csv")
219
220  #ripeto gli stessi passaggi per calcolare la posizione delle sc
221  elenco_sc <- as.data.frame(elenco_sc)
222  colnames(elenco_sc) <- c('Struttura', 'Vecchio Co', 'Nome',
     'Via', 'CAP', 'Localita', 'Rg', 'Rit', 'NumAs', 'Fr',
     'DistKM', 'CS', 'Materiale', 'D', 'Banc', 'strutture
     attive')
223  dati_ind <- c('Via', 'CAP', 'Localita')
224  elenco_sc$Indirizzo <- apply(elenco_sc[ , dati_ind] , 1 , paste ,
     collapse = ", ")
225  elenco_sc <- elenco_sc[ , !(names(elenco_sc) %in% dati_ind)]
226  elenco_sc$Indirizzo <- gsub(" ,", "", elenco_sc$Indirizzo)
227  elenco_sc$Indirizzo <- paste0(elenco_sc$Indirizzo, ' Italia')
228  elenco_sc <- elenco_sc[, c('Struttura', 'Nome', 'Banc',
     'Indirizzo')]
229
230  coordinateprovvisorio <- geocode(elenco_sc[,c('Indirizzo')],
     output = "latlon", source = c("google"))
231  elenco_sc <- cbind(elenco_sc, coordinateprovvisorio)
232  rm(coordinateprovvisorio)
233
234  write.csv2(elenco_sc,
     "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
     modello\\Salvataggi\\Elenco SC con coordinate.csv")
```

```
235
236   ###fine parte una
      tantum#################################################
      #################################################
      ####
237   #################################################
      #################################################
      ####################
238
239   #PROVV RIP carico le posizioni dei magazzini
240   indirizzi_magazzini <-
      read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
      modello\\Salvataggi\\Magazzini con coordinate.csv")
241   donatori <-
      read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
      modello\\Salvataggi\\Donatori con coordinate.csv")
242   flussi <-
      read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
      modello\\Dati\\Elenco entrate 2018 CSV.csv")
243   codici_magazzini <-
      read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
      modello\\Dati\\Codici Magazzini.csv")
244   elenco_sc <-
      read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
      modello\\Salvataggi\\Elenco SC con coordinate.csv")
245   uscite <-
      read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
      modello\\Dati\\Uscite Italia.csv")
246
247   #plotto i magazzini ed i donatori su una cartina (salvare
      manualmente le immagini)
248   mappamagazzini <- ggmap(map) + geom_point(aes(x =
      indirizzi_magazzini$lon, y = indirizzi_magazzini$lat), data =
      indirizzi_magazzini[,4:5], alpha = .6, col='red')
249   mappadonatori <- ggmap(map) + geom_point(aes(x = donatori$lon, y
      = donatori$lat), data = donatori[,6:7], alpha = .2, col='red')
250   mappamagazzini
251   mappadonatori
252
253
254   ##FLUSSI
255
256   #tolgo le righe che riguardano Siticibo
257   flussi <- as.data.frame(flussi)
258   flussi <- flussi[-which(flussi$Prov..prod. == "SGDO"),]
259   flussi <- flussi[-which(flussi$Prov..prod. == "SRIS"),]
260   flussi <- flussi[-which(flussi$Prov..prod. == "sGDO"),]
261
262   #rinomino le colonne
263   colnames(flussi) <- c("Mese", "Data registrazione", "Riferimento
      DDT", "Data documento", "Fornitore", "Ragione sociale fornitore",
      "Codice.donatore", "Ragione sociale donatore", "Provenienza",
      "Materiale", "Codice materiale", "UM acquisita", "Qta in UDM
      acquisita", "UDM", "Qta", "TMC", "Divisione", "Magazzino",
      "Campagna AGEA", "Gruppo Merci", "OBA", "Errori")
264   colnames(codici_magazzini) <- c("Divisione", "Codice", "Nome
      magazzino")
265   colnames(donatori) <- c("X", "Codice donatore", "Ragione
      sociale", "Provincia", "Regione", "Indirizzo donatore",
```

```
              "Longitudine donatore", "Latitudine donatore")
266
267    #ora inserisco il nome del magazzino e seleziono le informazioni
       necessarie
268    flussi <- merge(flussi, codici_magazzini, by.x = c("Divisione",
       "Magazzino"), by.y = c("Divisione", "Codice"))
269    flussi <- flussi[c("Codice.donatore", "Ragione sociale donatore",
       "Provenienza", "Codice materiale", "UM acquisita", "UDM", "Qta",
       "OBA", "Nome magazzino")]
270
271    #pulisco il db da informazioni mancanti importanti (quantità e
       codice donatore)
272    flussi_sel <- drop_na(flussi, c("Codice.donatore", "Qta", "Nome
       magazzino"))
273
274    #unisco i database donatori con flussi_sel rispettivamente su
       donatore prodotto
275    flussi_coord <- merge(flussi_sel, donatori, by.x =
       "Codice.donatore", by.y = "Codice donatore")
276    flussi_coord[c("X", "Ragione sociale", "Provincia", "Regione")]
       <- NULL
277    rm(flussi_sel)
278
279    #sistemo il db delle uscite
280    colnames(uscite) <- c('Codice SC', 'Prodotti AGEA',    'Prodotti
       Ortofrutta',  'Altri prodotti',   'Totale')
281
282    #SALVATAGGIO PROVVISIORIO PRE CLUSTERING
283    save.image("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
       modello\\Salvataggi\\Salvataggio pre clustering TP.RData")
284
285
286
287    #CLUSTERING DELLE SC PER TROVARE LE COORDINATE DEI TRANSIT
       POINT#########################################################
       ##
288
289    #carico il salvataggio provvisorio
290    load("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
       modello\\Salvataggi\\Salvataggio pre clustering TP.RData")
291
292    #Questa parte raggruppa le SC sotto k transit point tenendo conto
       dei risultati del secondo questionario
293    #sul livello di servizio. Il 29% delle SC non vorrebbe viaggiare
       per più di 20 chilometri, il 62% è
294    #disposta ad affrontare un viaggio sotto i 50 chilometri. Queste
       percentuali vengono usate per verificare
295    #che il numero di TP soddisfi il livello di servizio richiesto,
       ma non vieta al Banco di dotarsi di una rete
296    #che minimizzi i costi di trasporto delle sc senza tenere conto
       di questo aspetto.
297
298    #rimuovo eventuali coordinate al di fuori del territorio italiano
       (vedi punti estremi d'Italia)
299    elenco_sc <- elenco_sc[which(elenco_sc[, c('lat')] < 47.072975),]
300    elenco_sc <- elenco_sc[which(elenco_sc[, c('lat')] > 35.493333),]
301    elenco_sc <- elenco_sc[which(elenco_sc[, c('lon')] < 18.520556),]
302    elenco_sc <- elenco_sc[which(elenco_sc[, c('lon')] > 6.627281),]
303
```

```
304    #NB: evitare k troppo bassi per evitare centroidi sul mare!
305    RIS <- NULL
306
307    while (k <= k_max) { #iterare una volta per vedere se funziona
       tutto
308
309      #applico il k-means clustering
310      clusters <- kmeans(elenco_sc[, c('lon', 'lat')], k, iter.max =
         15)
311
312      #creo la tabella delle coordinate del centroide
313      coord_centr <- clusters$centers
314
315      #salvo il magazzino di riferimento in una colonna di elenco_sc
         e in uscite
316      elenco_sc$clust <- as.factor(clusters$cluster)
317      uscite$cluster <- elenco_sc[match(uscite$`Codice SC`,
         elenco_sc$Struttura), c("clust")]
318
319      #occorre controllare che gli indirizzi non siano sul mare,
         troppo lontani dalla strada o che siano NA
320      #sostituirli manualmente!
321      #plottarli aiuta
322      #View(coord_centr)
323      ggmap(map) + geom_point(aes(x = lon[], y = lat[]), col = "red",
         size =3, data = as.data.frame(coord_centr))
324
325      #calcolo la distanza tra ciascun centroide e ciascuna sc
326      dist_provv <- NULL
327      tempo_provv <- NULL
328      elenco_provv <-NULL
329      coordinata_centroide_k <- NULL
330      elenco_sc_n <- NULL
331
332      for (o in 1:k) {
333        elenco_provv <- elenco_sc[which(elenco_sc[, c('clust')] == o),]
334        coordinata_centroide_k <- coord_centr[o,]
335        dist_provv <- c()
336        tempo_provv <- c()
337
338        for (p in 1:dim(elenco_provv)[1]) {
339          dist_provv[p] <- distVincentySphere(coordinata_centroide_k,
           elenco_provv[p, c('lon', 'lat')])*1.05/1000 #divido per
           mille per avere chilometri
340          tempo_provv[p] <- dist_provv[p]/vel_media+tempo_car_scar*2
341        }
342
343        elenco_provv$dist <- dist_provv
344        elenco_provv$tempo <- tempo_provv
345        elenco_sc_n <- rbind(elenco_sc_n, elenco_provv)
346      }
347
348      #rispetto il livello di servizio richiesto dalle SC?
349      #controllo la percentuale di SC a cui andrebbe bene il centroide
350      ok_fascia20 <- 0
351      ok_fascia50 <- 0
352
353      dist <- elenco_sc_n$dist
354      dist <- dist[!is.na(dist)]
```

```r
355
356        for (f in 1:length(dist)) {
357          if (dist[f] <= 20) {
358            ok_fascia20 <- ok_fascia20+1
359          }
360          if (dist[f] <= 50) {
361            ok_fascia50 <- ok_fascia50+1
362          }
363        }
364
365        if (ok_fascia20/length(dist) >= fascia20 &&
           ok_fascia50/length(dist) >= fascia50) {
366          risfascia20 <- c("Ok")
367          risfascia50 <- c("Ok")
368        } else {
369          if (ok_fascia20/length(dist) <= fascia20) {
370            risfascia20 <- c("Non rispettato")
371          }
372          if (ok_fascia50/length(dist) <= fascia50) {
373            risfascia50 <- c("Non rispettato")
374          }
375        }
376
377        #COSTI DI TRASPORTO
378        num_trasp_tp_sc_i<-NULL
379
380        for (f in 1:k) {
381          num_trasp_tp_sc_i[f] <- round(sum(uscite[which(uscite$cluster
           == f), c("Totale")])/ftl_tp)
382        }
383
384        num_trasp_tp_sc <- sum(num_trasp_tp_sc_i)
385
386        dist_media <- mean(dist)
387        costo_carb_un <- costo_diesel/consumo_kml*dist_media #costo
           unitario nel senso che considero il costo medio di ciascun
           viaggio
388
389        durata_media_un <- dist_media/vel_media
390        costo_mezzoaut_un <- durata_media_un*(c_autista+c_mezzo)
391
392        c_trasp_tp_sc <-
           round((costo_carb_un+costo_mezzoaut_un)*num_trasp_tp_sc)
393
394        #COSTI DI MAGAZZINO
395        num_tp <- k
396
397        #area necessaria dei TP
398        area_tp_tot <- area_tp_un*num_tp # !!! num_tp è il mio k del
           clustering!
399
400        #mezzi, celle, muletti e transpallet
401        muletti_tot <- num_tp*muletti_tp
402        transpallet_tot <- num_tp*transpallet_tp
403        mezzi_tot <- num_tp*mezzi_tp
404        celle_tot <- num_tp*celle_tp
405
406        #personale
407        uscite_provv <- NULL
```

```
408     pers_ric_stocc <- NULL
409     pers_carico <- NULL
410     pers_amministr <- NULL
411     FTE <- NULL
412
413     for (a in 1:k) {
414       uscite_provv <- ceiling( sum(uscite[which(uscite$cluster ==
          a), c("Totale")])/(peso_pl*48) ) #pl/w
415       pers_ric_stocc <-
          ceiling(uscite_provv/(ricevimento_scarico*40))
416       pers_carico <- ceiling(uscite_provv/(carico*40))
417       pers_amministr <-
          ceiling(uscite_provv/(attività_amministrative*40))
418
419       FTE[a] <- pers_amministr + pers_ric_stocc + pers_carico
420     }
421
422     FTE_tp <- sum(FTE)
423     FTE_vol_tp <- perc_vol*FTE_tp
424     FTE_empl_tp <- FTE_tp-FTE_vol_tp
425
426     #il costo finale è dato da : costo dello spazio + personale +
          energia + utenze + manutenzione
427     costo_mag <- round(area_tp_tot*c_spazio + (FTE_vol_tp*c_vol +
          FTE_empl_tp*c_empl) + (area_tp_tot)*c_energia +
          (FTE_tp)*c_utenze +
          (c_manut_muletto*muletti_tot+c_manut_transpallet*transpallet_tot+
          c_manut_mezzo*mezzi_tot+c_manut_cella*celle_tot))
428
429     #COSTO TOTALE
430     costo_tot <- costo_mag + c_trasp_tp_sc
431
432     #ragguppo k, costi e il risultato della prova sul livello di
          servizio
433     RIS <- rbind(RIS, c(k, costo_tot, c_trasp_tp_sc,
          costo_mag,risfascia20, risfascia50))
434
435     #salvo il vettore dei cluster e le coordinate dei cluster
436     write.csv(coord_centr, paste0("coord_centr_tp_k=", k,".csv"))
437     write.csv(elenco_sc$clust, paste0("elenco_sc$clust_k=",
          k,".csv"))
438
439     #aumento k
440     k <- k+1
441
442   }
443
444   #raccolgo i risultati del clustering delle SC
445
446     #inserisco un nome alle colonne della matrice dei risultati RIS
447     RIStp <- RIS
448     colnames(RIStp) <- c("k", "costo_tot", "c_trasp_tp_sc",
          "costo_mag", "risfascia20", "risfascia50")
449     write.csv2(RIStp,
          "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
          modello\\Risultati\\RIStp.csv")
450
451     #con questa parte di codice mi mando un'email quando il ciclo
          while sopra è concluso
```

```
452    from <- sprintf("<sendmailR@\\%s>", Sys.info()[4])
453    subject <- "Ciclo while del clustering delle SC concluso"
454    body <- list("Tornare al PC al più presto!", mime_part(iris))
455    sendmail(from, to, subject, body,
       control=list(smtpServer="ASPMX.L.GOOGLE.COM"))
456
457    beep(8)
458
459
460  #rifaccio il clustering sulle sc per il k migliore
461
462    #selziono il k ottimale che rispetta il vincolo sul livello di
       servizio e minimizza i costi
463    RIS_provv <- RIS[which(RIS[,6] == "Ok"),]
464    RIS_provv <- RIS[which(RIS[,5] == "Ok"),]
465    k_provv <- as.numeric(RIS_provv[which.min(RIS_provv[,2]), 1])
466
467    #applico il k-means clustering
468    clusters <- kmeans(elenco_sc[, c('lon', 'lat')], k_provv,
       iter.max = 7)
469
470    #creo la tabella delle coordinate del centroide
471    coord_centr <- clusters$centers
472
473    #salvo il magazzino di riferimento in una colonna di elenco_sc
       e in uscite
474    elenco_sc$clust <- as.factor(clusters$cluster)
475    uscite$cluster <- elenco_sc[match(uscite$`Codice SC`,
       elenco_sc$Struttura), c("clust")]
476
477    #calcolo la distanza tra ciascun centroide e ciascuna sc
478    dist_provv <- NULL
479    tempo_provv <- NULL
480    elenco_provv <-NULL
481    coordinata_centroide_k <- NULL
482    elenco_sc_n <- NULL
483
484    for (o in 1:k_provv) {
485      elenco_provv <- elenco_sc[which(elenco_sc[, c('clust')] == o),]
486      coordinata_centroide_k <- coord_centr[o,]
487      dist_provv <- c()
488      tempo_provv <- c()
489
490      for (p in 1:dim(elenco_provv)[1]) {
491        dist_provv[p] <- distVincentySphere(coordinata_centroide_k,
         elenco_provv[p, c('lon', 'lat')])*1.05/1000 #divido per
         mille per avere chilometri
492        tempo_provv[p] <- dist_provv[p]/vel_media+tempo_car_scar*2
493      }
494
495      elenco_provv$dist <- dist_provv
496      elenco_provv$tempo <- tempo_provv
497      elenco_sc_n <- rbind(elenco_sc_n, elenco_provv)
498    }
499
500    #ricalcolo i costi associati a questa configurazione
501      #COSTI DI TRASPORTO
502      num_trasp_tp_sc_i<-NULL
503
```

```
504     for (f in 1:k_provv) {
505       num_trasp_tp_sc_i[f] <-
          round(sum(uscite[which(uscite$cluster == f),
          c("Totale")])/ftl_tp)
506     }
507
508     num_trasp_tp_sc <- sum(num_trasp_tp_sc_i)
509
510     dist_media <- mean(dist)
511     costo_carb_un <- costo_diesel/consumo_kml*dist_media #costo
        unitario nel senso che considero il costo medio di ciascun
        viaggio
512
513     durata_media_un <- dist_media/vel_media
514     costo_mezzoaut_un <- durata_media_un*(c_autista+c_mezzo)
515
516     c_trasp_tp_sc <-
        round((costo_carb_un+costo_mezzoaut_un)*num_trasp_tp_sc)
517
518     #COSTI DI MAGAZZINO
519     num_tp <- k_provv
520
521     #area necessaria dei TP
522     area_tp_tot <- area_tp_un*num_tp #num_tp è il mio k del
        clustering!
523
524     #mezzi, celle, muletti e transpallet
525     muletti_tot <- num_tp*muletti_tp
526     transpallet_tot <- num_tp*transpallet_tp
527     mezzi_tot <- num_tp*mezzi_tp
528     celle_tot <- num_tp*celle_tp
529
530     #personale
531     uscite_provv <- NULL
532     pers_ric_stocc <- NULL
533     pers_carico <- NULL
534     pers_amministr <- NULL
535     FTE <- NULL
536
537     for (a in 1:k_provv) {
538       uscite_provv <- ceiling( sum(uscite[which(uscite$cluster ==
          a), c("Totale")])/(peso_pl*48) ) #pl/w
539
540       pers_ric_stocc <- uscite_provv/(ricevimento_scarico*40)
541       pers_carico <- uscite_provv/(carico*40)
542       pers_amministr <- uscite_provv/(attività_amministrative*40)
543
544       FTE[a] <- ceiling(pers_amministr + pers_ric_stocc +
          pers_carico)
545     }
546
547     FTE_tp <- sum(FTE)
548     FTE_vol_tp <- round(perc_vol*FTE_tp)
549     FTE_empl_tp <- FTE_tp-FTE_vol_tp
550
551     #il costo finale è dato da : costo dello spazio + personale +
        energia + utenze + manutenzione
552     costo_mag_tp <- round(area_tp_tot*c_spazio +
        (FTE_vol_tp*c_vol + FTE_empl_tp*c_empl) +
```

```
                (area_tp_tot)*c_energia + (FTE_tp)*c_utenze +
                (c_manut_muletto*muletti_tot+c_manut_transpallet*transpallet_to
                t+c_manut_mezzo*mezzi_tot+c_manut_cella*celle_tot))
553
554             #COSTO TOTALE
555             costo_tot_tp <- costo_mag_tp + c_trasp_tp_sc
556
557         #rappresento le SC su una mappa suddivise in cluster
558         ggmap(map) + geom_point(aes(x = elenco_sc$lon, y =
            elenco_sc$lat), data = elenco_sc[,6:7], alpha = .5, colour =
            as.factor(elenco_sc$clust)) + geom_point(aes(x =
            coord_centr[,1], y = coord_centr[,2]), data =
            as.data.frame(coord_centr), alpha = 1, size = 3, colour =
            "white")
559
560
561     #aggrego i flussi uscenti in base al transit point
562     uscite$cluster <- elenco_sc_n[match(uscite$`Codice SC`,
        elenco_sc_n$Struttura),8]
563     uscite$long <- elenco_sc_n[match(uscite$`Codice SC`,
        elenco_sc_n$Struttura),6]
564     uscite$lat <- elenco_sc_n[match(uscite$`Codice SC`,
        elenco_sc_n$Struttura),7]
565     flusso_uscente_tp <- NULL
566
567     for (q in 1:dim(coord_centr)[1]) {
568       flusso_uscente_tp[q] <- sum(uscite[which(uscite$cluster == q),
        c("Totale")])
569     }
570
571     flusso_uscita <- as.data.frame(cbind(c(1:k_provv),
        flusso_uscente_tp, coord_centr[,c("lon")], coord_centr[,c("lat")]))
572     colnames(flusso_uscita) <- c("Codice TP", "Kg", "Longitudine",
        "Latitudine")
573
574     rm(flusso_uscente_tp)
575
576     #aggrego i flussi entranti in base al donatore; spedisco al
        magazzino centrale più vicino
577     flussi_coord <- flussi_coord[flussi_coord$Provenienza %in%
        c("AGEA", "CAL", "DSTR", "GNCA", "IND", "OF"), ]
578     livelli_ingr <- unique(flussi_coord$Codice.donatore)
579     flussi_ingr_provv <- NULL
580     flusso_entrante_cw <- NULL
581     flusso_entrata <- NULL
582
583     for (t in 1:length(livelli_ingr)) {
584       flussi_ingr_provv <- flussi_coord[
          which(flussi_coord[,c("Codice.donatore")] == livelli_ingr[t]), ]
585       flusso_entrante_cw <- sum(flussi_ingr_provv[,c("Qta")])
586       riga <- c(flusso_entrante_cw, flussi_ingr_provv[1, 11],
          flussi_ingr_provv[1, 12])
587       flusso_entrata <- rbind(flusso_entrata, riga)
588     }
589
590     flusso_entrata <- as.data.frame(flusso_entrata)
591     flusso_entrata$`Codice donatore` <- livelli_ingr
592
593     colnames(flusso_entrata) <- c("Kg", "Longitudine", "Latitudine",
```

```
          "Codice donatore")
594
595    rm(flusso_entrante_cw)
596
597    #salvataggio temporaneo
598    save.image("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
       modello\\Salvataggi\\Salvataggio provvisorio clustering CW.RData")
599
600    #ora dispongo dei flussi in ingresso e di quelli in uscita, delle
       coordinate dei donatori e dei transit point
601    #posso procedere calcolando il numero e la posizione dei
       magazzini centrali
602
603
604
605    #CLUSTERING DEI TRANSIT POINT PER TROVARE LE COORDINATE DEI
       MAGAZZINI
       CENTRALI#########################################################
       #####
606
607    #salvataggio temporaneo
608    load("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
       modello\\Salvataggi\\Salvataggio provvisorio clustering CW.RData")
609
610    #creo per comodità una tabella che contiene flussi e chili sia in
       entrata sia in uscita (SOLO coordinate e peso!)
611    #assegno per la prima iterazione il magazzino 1
612    flussi_mix_entr <- as.data.frame(flusso_entrata[,
       c("Longitudine", "Latitudine", "Kg")])
613    flussi_mix_entr <- cbind(flussi_mix_entr, c(rep(c("Entrata"),
       dim(flussi_mix_entr)[1])))
614
615    flussi_mix_usc <- as.data.frame(flusso_uscita[, c("Longitudine",
       "Latitudine", "Kg")])
616    flussi_mix_usc <- cbind(flussi_mix_usc, c(rep(c("Uscita"),
       dim(flussi_mix_usc)[1])))
617
618    colnames(flussi_mix_entr) <- c("V1", "V2", "V3", "V4")
619    colnames(flussi_mix_usc) <- c("V1", "V2", "V3", "V4")
620
621    flussi_mix <- rbind(flussi_mix_entr, flussi_mix_usc)
622    flussi_mix$cluster <- c(rep(1, dim(flussi_mix)[1]))
623
624    colnames(flussi_mix) <- c("Longitudine", "Latitudine", "Peso",
       "Tipo", "Cluster")
625
626    #resetto la tabella dei risultati
627    RIS <- NULL
628
629    #preparo il dataframe flussi_ingr, che contiene il mese in cui si
       è ricevuta la merce
630    flussi_ingr <-
       read.csv2("C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
       modello\\Dati\\Elenco entrate 2018 CSV.csv")
631    flussi_ingr <- as.data.frame(flussi_ingr)
632    flussi_ingr$QuantitÃ. <- as.numeric(flussi_ingr$QuantitÃ.)
633    flussi_ingr <- drop_na(flussi_ingr, c("QuantitÃ."))
634    flussi_ingr <- flussi_ingr[-which(flussi_ingr$Prov..prod. ==
       "SGDO"),]
```

```r
635    flussi_ingr <- flussi_ingr[-which(flussi_ingr$Prov..prod. ==
       "SRIS"),]
636    flussi_ingr <- flussi_ingr[-which(flussi_ingr$Prov..prod. ==
       "sGDO"),]
637
638    flussi_ingr <- merge(flussi_ingr, codici_magazzini, by.x =
       c("Divisione", "Magaz."), by.y = c("Divisione", "Codice"))
639    flussi_ingr <- drop_na(flussi_ingr, c("Donatore.Prodotto", "Nome
       magazzino"))
640    flussi_ingr <- merge(flussi_ingr, donatori, by.x =
       "Donatore.Prodotto", by.y = "Codice donatore")
641
642    #questo ciclo itera una serie di operazion e di calcolo della
       posizione dei magazzini centrali e calcolo dei costi
643    while (k_cw<=k_cw_max) {
644
645      iter <- 7 #iter dopo il quarto passaggio cambia di pochissimo,
       ma lo faccio per sicurezza
646
647      #itero 5 volte questo passaggio per trovare una soluzione
       sempre più precisa
648      for (i in 1:iter) {
649
650        #le coordinate del centroide j-esimo vengono calcolate come
         media pesata dei latitudine/longitudine delle righe
         riguardanti un cluster pesate dal flusso
651        #rbind mi serve solo ad evitare un altro ciclo for
652        coord_centroide <- NULL
653
654        for (j in 1:k_cw) {
655          coord_centroide <- rbind(coord_centroide, c(
           weighted.mean(flussi_mix[which(flussi_mix$Cluster == j),
           c("Longitudine")], flussi_mix[which(flussi_mix$Cluster ==
           j), c("Peso")]) ,
           weighted.mean(flussi_mix[which(flussi_mix$Cluster == j),
           c("Latitudine")], flussi_mix[which(flussi_mix$Cluster ==
           j), c("Peso")])))
656        }
657
658      #creo la matrice delle distanze per ciascuna riga della tabella
       uscite tra sc e tp
659      matrice_distanze = as.data.frame(matrix(, nrow =
       dim(flussi_mix)[1], ncol = k_cw))
660      matrice_tempi = as.data.frame(matrix(, nrow =
       dim(flussi_mix)[1], ncol = k_cw))
661
662      #calcolo la distanza, i tempi ed i costi tra ciascun centroide
       e ciascuna sc
663      #il secondo ciclo è per ciascun cluster, il primo scorre in
       verticale la tabella uscite
664      for (p in 1:dim(flussi_mix)[1]) {
665        for (o in 1:k_cw) {
666          matrice_distanze[p,o] <-
           distVincentySphere(coord_centroide[o,], flussi_mix[p,
           c("Longitudine", "Latitudine")])*1.05/1000 #divido per
           mille per avere chilometri
667          matrice_tempi[p,o] <-
           matrice_distanze[p,o]/vel_media+tempo_car_scar*2
668        }
```

```
669        }
670
671        #seleziono il percorso meno lungo ed aggiorno il vettore dei
           cluster; creo il vettore dist della distanza minima
672        dist <- NULL
673        cluster <- NULL
674
675        for (h in 1:dim(flussi_mix)[1]) {
676          cluster[h] <- which.min(matrice_distanze[h,])
677          dist[h] <- min(matrice_distanze[h,])
678        }
679
680        #aggiorno i cluster in flussi_mix
681        flussi_mix$Cluster <- cluster
682        flussi_mix$Distanza <- dist
683
684        }
685
686        #plotto il risultato del clustering
687        ggmap(map) + geom_point(aes(x = Longitudine[], y =
           Latitudine[]), data = flussi_mix, alpha = .5, colour =
           as.factor(flussi_mix$Cluster))
688
689        #COSTI DI TRASPORTO IN ENTRATA
690
691          #calcolo il numero di trasporti necessari in ftl per ogni
             cluster
692          num_trasp_don_cw_i <- NULL
693          provvtrasp <- flussi_mix[which(flussi_mix$Tipo == "Entrata"),]
694
695          for (f in 1:k_cw) {
696            num_trasp_don_cw_i[f] <-
               round(sum(provvtrasp[which(provvtrasp$Cluster == f),
               c("Peso")])/ftl)
697          }
698
699          num_trasp_don_cw <- sum(num_trasp_don_cw_i)
700
701        dist_media_don_cw <- mean(flussi_mix[which(flussi_mix$Tipo ==
           "Entrata"), c("Distanza")])
702        costo_carb_un_don_cw <-
           costo_diesel/consumo_kml*dist_media_don_cw #costo unitario nel
           senso che considero il costo medio di ciascun viaggio
703
704        durata_media_un_don_cw <- dist_media_don_cw/vel_media
705        costo_mezzoaut_un_don_cw <-
           durata_media_un_don_cw*(c_autista+c_mezzo)
706
707        c_trasp_don_cw <-
           (costo_carb_un_don_cw+costo_mezzoaut_un_don_cw)*num_trasp_don_cw
708        c_trasp_don_cw
709
710        #COSTI DI TRASPORTO IN USCITA
711          #calcolo il numero di trasporti necessari in ftl per ogni
             cluster
712          num_trasp_cw_tp_i <- NULL
713          provvtrasp <- flussi_mix[which(flussi_mix$Tipo == "Uscita"),]
714
715          for (f in 1:k_cw) {
```

```
716        num_trasp_cw_tp_i[f] <-
           round(sum(provvtrasp[which(provvtrasp$Cluster == f),
           c("Peso")])/ftl)
717      }
718
719    num_trasp_cw_tp <- sum(num_trasp_cw_tp_i)
720
721  dist_media_cw_tp <- mean(flussi_mix[which(flussi_mix$Tipo ==
     "Uscita"), c("Distanza")])
722  costo_carb_un_cw_tp <-
     costo_diesel/consumo_kml*dist_media_cw_tp #costo unitario nel
     senso che considero il costo medio di ciascun viaggio
723
724  durata_media_un_cw_tp <- dist_media_cw_tp/vel_media
725  costo_mezzoaut_un_cw_tp <-
     durata_media_un_cw_tp*(c_autista+c_mezzo)
726
727  c_trasp_cw_tp <-
     (costo_carb_un_cw_tp+costo_mezzoaut_un_cw_tp)*num_trasp_cw_tp
728  c_trasp_cw_tp
729
730
731  #COSTI DI TRASPORTO TRA MAGAZZINI CENTRALI
732  #calcolo il costo trovando con l'algoritmo di Dijkstra un
     percorso minimo tra i miei magazzini centrali
733  #considero una spedizione al mese, con un tir per andata e
     ritorno (magari mettere nei dati)
734  if (k_cw != 1) {
735
736    #creo la lista dei vettori non selezionati ed una matrice con
       il percorso
737    non_sel <- as.data.frame(cbind(c(1:dim(coord_centroide)[1]),
       coord_centroide))
738    percorso <- matrix(, ncol = 3)
739
740    #creo la matrice vuota delle distanze dal punto selezionato a
       tutti i punti sono selezionati
741    dijkstra_distanze <- as.data.frame(matrix(, ncol = 3))
742    dijkstra_tempi <- as.data.frame(matrix(, ncol = 3))
743
744    #seleziono il punto più a nord e lo tolgo dall'elenco dei non
       selezionati
745    centr_scelto <-
       coord_centroide[which.max(coord_centroide[,2]),]
746    percorso[1,] <- c(0,
       coord_centroide[which.max(coord_centroide[,2]),])
747    non_sel <- non_sel[-which.max(coord_centroide[,2]),]
748
749    #itero questi passaggi
750    while (dim(non_sel)[1] >= 1) {
751
752      #calcolo la distanza tra il centroide più a nord con gli
         altri
753      for (d in 1:dim(non_sel)[1]) {
754        dijkstra_distanze[d,1] <- distVincentySphere(non_sel[d,
           2:3], centr_scelto)*1.05/1000 #divido per mille per avere
           chilometri
755        dijkstra_tempi[d] <-
           matrice_distanze[d,1]/vel_media+tempo_car_scar*2
```

```
756          dijkstra_distanze[d, 2:3] <- non_sel[d, 2:3]
757          dijkstra_tempi[d, 2:3] <- non_sel[d, 2:3]
758        }
759
760        #seleziono il percorso meno lungo, riporto tutto nella
           matrice percorso e cancello dalla lista dei non selezionati
761        dist_min <- min(dijkstra_distanze[,1])
762        percorso <- rbind(percorso,
           dijkstra_distanze[which.min(dijkstra_tempi[,1]),])
763        non_sel <- non_sel[-which.min(dijkstra_tempi[,1]),]
764        centr_scelto <-
           dijkstra_distanze[which.min(dijkstra_tempi[,1]), 2:3]
765
766      }
767
768    #calcolo il costo del percorso di Dijkstra con ritorno per un
       anno
769    dist_cw_cw <- sum(percorso[,1])
770    tempo_cw_cw <- dist_cw_cw/vel_media+tempo_car_scar*k_cw
771
772    costo_mezzoaut_cw_cw <- tempo_cw_cw*(c_autista+c_mezzo)
773    costo_carb <- costo_diesel/consumo_kml*dist_cw_cw
774    num_trasp_cw_cw <- trasporti_annuali_cw_cw*2
775
776    c_trasp_cw_cw <-
       (costo_carb+costo_mezzoaut_cw_cw)*num_trasp_cw_cw
777
778  } else {
779    c_trasp_cw_cw <- 0
780  }
781
782
783
784    #COSTI DI MAGAZZINO
785
786  #mezzi, celle, muletti e transpallet
787    #numero massimo di livelli (considero altezza massima e
       altezza massima raggiunta dal muletto)
788    num_livelli <- min( ceiling(h_max_muletto/H),
       floor(h_max_edificio/H) )
789
790    #calcolo il numero di pl per torre (modulo*num livelli)
791    num_pl_torre <- num_livelli*6
792
793    #calcolo l'area utilizzata, U e V reali, SC reale
794        ingresso <- NULL
795        flussi_ingr_provv <- NULL
796
797        for (g in 1:12) {
798          flussi_ingr_provv <-
             flussi_ingr[which(flussi_ingr$ï..Mese == g), ]
799          ingresso[g] <- sum(flussi_ingr_provv$QuantitÃ.)
800        }
801
802        cum_ingr <- cumsum(ingresso)
803        usc <- c(rep(sum(uscite$Totale)/12, 12))
804        cum_usc <- cumsum(usc)
805
806        rees <- NULL
```

```r
807              for (g in 1:12) {
808                rees[g] <- cum_ingr[g] - cum_usc[g]
809              }
810
811          pl_richiesti <- ceiling(max(rees)/peso_pl)
812          A <- ceiling(pl_richiesti/(num_pl_torre*k_cw)*D*W)
813
814          num_corridoi <- round(sqrt(A)/W)
815          num_torri_corridoio <-
             ceiling(pl_richiesti/(num_pl_torre*num_corridoi))
816
817          U_reale <- num_corridoi*W
818          V_reale <- num_torri_corridoio*D
819          SC_reale <- num_corridoi*num_torri_corridoio*num_pl_torre
820
821          #muletto
822          trag_orizz <- 2*(U_reale/2 + V_reale/2 + corridoio)
823          trag_vert <- H*(num_livelli-1)
824
825          Tvar <- trag_orizz/vel_orizz_muletto +
             trag_vert/vel_vert_muletto
826          Tsc <- Tfissi + Tvar
827
828          TCmuletto <- floor(FU*3600/Tsc)
829          TCrichiesta <- ceiling(sum(uscite$Totale)/(peso_pl*48*5*8))
830
831          muletti <- ceiling(TCrichiesta/TCmuletto)
832
833          #transpallet
834          Tvar <- trag_orizz/vel_orizz_transpallet
835          Tsc <- Tfissi + Tvar
836          TCtranspallet <- floor(FU*3600/Tsc)
837          transpallet <- ceiling(TCrichiesta/TCtranspallet)
838
839          #personale
840          uscite_provv <- NULL
841          entrate_provv <- NULL
842          pers_ric_stocc <- NULL
843          pers_prelievo <- NULL
844          pers_carico <- NULL
845          pers_amministr <- NULL
846          FTE <- NULL
847
848          for (a in 1:k_cw) {
849            uscite_provv <- ceiling(
             sum(flussi_mix[which(flussi_mix$Cluster == a &
             flussi_mix$Tipo == "Uscita"), c("Peso")])/(peso_pl*48) )
             #pl/w
850            entrate_provv <- ceiling(
             sum(flussi_mix[which(flussi_mix$Cluster == a &
             flussi_mix$Tipo == "Entrata"), c("Peso")])/(peso_pl*48) )
             #pl/w
851
852            #calcoli per la preparazione ordine
853            Tsc <- tempi_fissi +
             viaggi_per_pallet*(corridoio_pick+U_reale/2+sqrt(corridoio_
             pick^2+(U_reale/2)^2))/velocità_operatore
854            prep_ordine <- 3600/Tsc
855
```

```
856        pers_prep_ordine <- ceiling(uscite_provv/(prep_ordine*40))
857        pers_ric_stocc <-
           ceiling(entrate_provv/(ricevimento_scarico*40))
858        pers_prelievo <- ceiling(uscite_provv/(prelievo*40))
859        pers_carico <- ceiling(uscite_provv/(carico*40))
860        pers_amministr <-
           ceiling(uscite_provv/(attività_amministrative*40))
861
862        FTE[a] <- pers_amministr + pers_prelievo + pers_ric_stocc
           + pers_prep_ordine + pers_carico + org_ritiri_cw
863      }
864
865    FTE_cw <- sum(FTE)
866    FTE_vol_cw <- perc_vol*FTE_cw
867    FTE_empl_cw <- FTE_cw-FTE_vol_cw
868
869    #calcolo il numero di muletti richiesti
870    muletti_cw <- muletti*k_cw
871    transpallet_cw <- transpallet*k_cw
872
873    #mezzi, celle
874    mezzi_cw <- mezzi_rete*tot_flussi/tot_flussi_2019
875    celle_cw_tot <- celle_cw*k_cw
876
877    #area totale di magazzino della rete; area totale compresi
       spazi di ufficio
878      area_mag_calc <- ceiling(k_cw*( U_reale*V_reale +
           corridoio*U_reale*2 + corridoio_pick*U_reale))
879      area_nec_uffici <- ceiling(0.1*area_mag_calc)
880
881    area_cw_tot <- area_mag_calc+area_nec_uffici
882
883    #il costo finale è dato da : costo dello spazio + personale +
       energia + utenze + manutenzione
884    costo_mag <- area_cw_tot*c_spazio + (FTE_empl_cw*c_empl +
       FTE_vol_cw*c_vol) + area_cw_tot*c_energia + FTE_cw*c_utenze +
       (c_manut_cella*celle_cw_tot + c_manut_mezzo*mezzi_cw +
       c_manut_muletto*muletti_cw + c_manut_transpallet*transpallet_cw)
885
886
887    #COSTO TOTALE
888    costo_tot <- costo_mag + c_trasp_don_cw + c_trasp_cw_cw +
       c_trasp_cw_tp
889    costo_tot
890
891    #aggiungo il risultato dei miei calcoli alla tabella
       riassuntiva RIS
892    RIS <- rbind(RIS, c(k_cw, costo_tot, c_trasp_don_cw,
       c_trasp_cw_tp, c_trasp_cw_cw, costo_mag))
893
894
895    #calcolo i costi di trasporto in entrata ed uscita ad ogni
       cluster
896    flussi_provv <- NULL
897    ris <- NULL
898
899    for (a in 1:k_cw) {
900
901      flussi_provv <- flussi_mix[which(flussi_mix$Cluster == a),]
```

```r
902
903        #COSTI DI TRASPORTO IN ENTRATA
904        num_trasp_don_cw <-
           round(sum(flussi_provv[which(flussi_provv$Tipo == "Entrata"),
           c("Peso")])/ftl)
905        dist_media_don_cw <-
           mean(flussi_provv[which(flussi_provv$Tipo == "Entrata"),
           c("Distanza")])
906        costo_carb_un_don_cw <-
           costo_diesel/consumo_kml*dist_media_don_cw #costo unitario
           nel senso che considero il costo medio di ciascun viaggio
907
908        durata_media_un_don_cw <- dist_media_don_cw/vel_media
909        costo_mezzoaut_un_don_cw <-
           durata_media_un_don_cw*(c_autista+c_mezzo)
910
911        c_trasp_don_cw_i <-
           (costo_carb_un_don_cw+costo_mezzoaut_un_don_cw)*num_trasp_don_c
           w
912
913        #COSTI DI TRASPORTO IN USCITA
914        num_trasp_cw_tp <- round(sum(flussi_mix[which(flussi_mix$Tipo
           == "Uscita"), c("Peso")])/ftl)
915        dist_media_cw_tp <- mean(flussi_mix[which(flussi_mix$Tipo ==
           "Uscita"), c("Distanza")])
916        costo_carb_un_cw_tp <-
           costo_diesel/consumo_kml*dist_media_cw_tp #costo unitario nel
           senso che considero il costo medio di ciascun viaggio
917
918        durata_media_un_cw_tp <- dist_media_cw_tp/vel_media
919        costo_mezzoaut_un_cw_tp <-
           durata_media_un_cw_tp*(c_autista+c_mezzo)
920
921        c_trasp_cw_tp_i <-
           (costo_carb_un_cw_tp+costo_mezzoaut_un_cw_tp)*num_trasp_cw_tp
922
923        #totale
924        tot_cluster <- c_trasp_don_cw_i + c_trasp_cw_tp_i
925        ris <- rbind(ris, c(tot_cluster))
926
927      }
928
929      #seleziono il cluster con la distanza media maggiore da
         dividere in due parti
930      clust_selez <- which.max(ris)
931      clust_selez
932
933      #incremento il numero di centroidi
934      k_cw <- k_cw+1
935
936      #divido il cluster più costoso in due parti assegnando i punti
         del vecchio cluster casualmente a tutti gli altri cluster
937      for (q in 1:length(cluster)) {
938        if (flussi_mix$Cluster[q] == clust_selez) {
939          flussi_mix$Cluster[q] <- sample(c(1:k_cw), 1, replace = TRUE)
940        }
941      }
942
943    }
```

```
944
945    #fine ciclo while sulle SC per trovare CW
946    beep(8)
947
948
949    #do un nome alle colonne di RIS e lo salvo
950    colnames(RIS) <- c("k_cw", "costo_tot", "c_trasp_don_cw",
       "c_trasp_cw_tp", "c_trasp_cw_cw", "costo_mag")
951    RIScw <- RIS
952    write.csv2(RIScw, "C:\\Users\\lello\\OneDrive\\Desktop\\Directory
       del modello\\Risultati\\RIScw.csv")
953
954    #riprendo il numero di cluster ottimo
955    k_cw_ott <- RIS[which.min(RIS[,c("costo_tot")]), c("k_cw")]
956    k_cw <- k_cw_ott
957
958    #sistemo la tabella dei centroidi
959    colnames(coord_centroide) <- c("Longitudine", "Latitudine")
960
961
962    #ricalcolo le coordinate dei k centroidi ottimali
963      for (i in 1:iter) {
964
965        #le coordinate del centroide j-esimo vengono calcolate come
           media pesata dei latitudine/longitudine delle righe
           riguardanti un cluster pesate dal flusso
966        #rbind mi serve solo ad evitare un altro ciclo for
967        coord_centroide <- NULL
968
969        for (j in 1:k_cw_ott) {
970          coord_centroide <- rbind(coord_centroide, c(
             weighted.mean(flussi_mix[which(flussi_mix$Cluster == j),
             c("Longitudine")], flussi_mix[which(flussi_mix$Cluster ==
             j), c("Peso")]) ,
             weighted.mean(flussi_mix[which(flussi_mix$Cluster == j),
             c("Latitudine")], flussi_mix[which(flussi_mix$Cluster ==
             j), c("Peso")])))
971        }
972
973        #creo la matrice delle distanze per ciascuna riga della
           tabella uscite tra sc e tp
974        matrice_distanze = as.data.frame(matrix(, nrow =
           dim(flussi_mix)[1], ncol = k_cw_ott))
975        matrice_tempi = as.data.frame(matrix(, nrow =
           dim(flussi_mix)[1], ncol = k_cw_ott))
976
977        #calcolo la distanza, i tempi ed i costi tra ciascun
           centroide e ciascuna sc
978        #il secondo ciclo è per ciascun cluster, il primo scorre in
           verticale la tabella uscite
979        for (p in 1:dim(flussi_mix)[1]) {
980          for (o in 1:k_cw_ott) {
981            matrice_distanze[p,o] <-
               distVincentySphere(coord_centroide[o,], flussi_mix[p,
               c("Longitudine", "Latitudine")])*1.05/1000 #divido per
               mille per avere chilometri
982            matrice_tempi[p,o] <-
               matrice_distanze[p,o]/vel_media+tempo_car_scar*2
983          }
```

```
984        }
985
986      #seleziono il percorso meno lungo ed aggiorno il vettore dei
         cluster; creo il vettore dist della distanza minima
987      dist <- NULL
988      cluster <- NULL
989
990      for (h in 1:dim(flussi_mix)[1]) {
991        cluster[h] <- which.min(matrice_distanze[h,])
992        dist[h] <- min(matrice_distanze[h,])
993      }
994
995      #aggiorno i cluster in flussi_mix
996      flussi_mix$Cluster <- cluster
997      flussi_mix$Distanza <- dist
998
999    }
1000
1001    #ricalcolo i costi delle configurazione attuale
1002
1003      #COSTI DI TRASPORTO IN ENTRATA
1004
1005      #calcolo il numero di trasporti necessari in ftl per ogni
         cluster
1006      num_trasp_don_cw_i <- NULL
1007      provvtrasp <- flussi_mix[which(flussi_mix$Tipo == "Entrata"),]
1008
1009      for (f in 1:k_cw) {
1010        num_trasp_don_cw_i[f] <-
           round(sum(provvtrasp[which(provvtrasp$Cluster == f),
           c("Peso")])/ftl)
1011      }
1012
1013      num_trasp_don_cw <- sum(num_trasp_don_cw_i)
1014
1015      dist_media_don_cw <- mean(flussi_mix[which(flussi_mix$Tipo ==
         "Entrata"), c("Distanza")])
1016      costo_carb_un_don_cw <-
         costo_diesel/consumo_kml*dist_media_don_cw #costo unitario
         nel senso che considero il costo medio di ciascun viaggio
1017
1018      durata_media_un_don_cw <- dist_media_don_cw/vel_media
1019      costo_mezzoaut_un_don_cw <-
         durata_media_un_don_cw*(c_autista+c_mezzo)
1020
1021      c_trasp_don_cw <-
         (costo_carb_un_don_cw+costo_mezzoaut_un_don_cw)*num_trasp_don_c
         w
1022      c_trasp_don_cw
1023
1024      #COSTI DI TRASPORTO IN USCITA
1025      #calcolo il numero di trasporti necessari in ftl per ogni
         cluster
1026      num_trasp_cw_tp_i <- NULL
1027      provvtrasp <- flussi_mix[which(flussi_mix$Tipo == "Uscita"),]
1028
1029      for (f in 1:k_cw) {
1030        num_trasp_cw_tp_i[f] <-
           round(sum(provvtrasp[which(provvtrasp$Cluster == f),
```

```
                c("Peso")])/ftl)
1031            }
1032
1033            num_trasp_cw_tp <- sum(num_trasp_cw_tp_i)
1034
1035            dist_media_cw_tp <- mean(flussi_mix[which(flussi_mix$Tipo ==
                "Uscita"), c("Distanza")])
1036            costo_carb_un_cw_tp <-
                costo_diesel/consumo_kml*dist_media_cw_tp #costo unitario nel
                senso che considero il costo medio di ciascun viaggio
1037
1038            durata_media_un_cw_tp <- dist_media_cw_tp/vel_media
1039            costo_mezzoaut_un_cw_tp <-
                durata_media_un_cw_tp*(c_autista+c_mezzo)
1040
1041            c_trasp_cw_tp <-
                (costo_carb_un_cw_tp+costo_mezzoaut_un_cw_tp)*num_trasp_cw_tp
1042            c_trasp_cw_tp
1043
1044
1045            #COSTI DI TRASPORTO TRA MAGAZZINI CENTRALI
1046            #calcolo il costo trovando con l'algoritmo di Dijkstra un
                percorso minimo tra i miei magazzini centrali
1047            #considero una spedizione al mese, con un tir per andata e
                ritorno (magari mettere nei dati)
1048            if (k_cw != 1) {
1049
1050              #creo la lista dei vettori non selezionati ed una matrice
                  con il percorso
1051              non_sel <-
                  as.data.frame(cbind(c(1:dim(coord_centroide)[1]),
                  coord_centroide))
1052              percorso <- matrix(, ncol = 3)
1053
1054              #creo la matrice vuota delle distanze dal punto selezionato
                  a tutti i punti sono selezionati
1055              dijkstra_distanze <- as.data.frame(matrix(, ncol = 3))
1056              dijkstra_tempi <- as.data.frame(matrix(, ncol = 3))
1057
1058              #seleziono il punto più a nord e lo tolgo dall'elenco dei
                  non selezionati
1059              centr_scelto <-
                  coord_centroide[which.max(coord_centroide[,2]),]
1060              percorso[1,] <- c(0,
                  coord_centroide[which.max(coord_centroide[,2]),])
1061              non_sel <- non_sel[-which.max(coord_centroide[,2]),]
1062
1063              #itero questi passaggi
1064              while (dim(non_sel)[1] >= 1) {
1065
1066                #calcolo la distanza tra il centroide piÃ¹ a nord con gli
                    altri
1067                for (d in 1:dim(non_sel)[1]) {
1068                  dijkstra_distanze[d,1] <- distVincentySphere(non_sel[d,
                      2:3], centr_scelto)*1.05/1000 #divido per mille per
                      avere chilometri
1069                  dijkstra_tempi[d] <-
                      matrice_distanze[d,1]/vel_media+tempo_car_scar*2
1070                  dijkstra_distanze[d, 2:3] <- non_sel[d, 2:3]
```

```
1071            dijkstra_tempi[d, 2:3] <- non_sel[d, 2:3]
1072          }
1073
1074          #seleziono il percorso meno lungo, riporto tutto nella
               matrice percorso e cancello dalla lista dei non selezionati
1075          dist_min <- min(dijkstra_distanze[,1])
1076          percorso <- rbind(percorso,
               dijkstra_distanze[which.min(dijkstra_tempi[,1]),])
1077          non_sel <- non_sel[-which.min(dijkstra_tempi[,1]),]
1078          centr_scelto <-
               dijkstra_distanze[which.min(dijkstra_tempi[,1]), 2:3]
1079
1080        }
1081
1082        #calcolo il costo del percorso di Dijkstra con ritorno per
             un anno
1083        dist_cw_cw <- sum(percorso[,1])
1084        tempo_cw_cw <- dist_cw_cw/vel_media+tempo_car_scar*k_cw
1085
1086        costo_mezzoaut_cw_cw <- tempo_cw_cw*(c_autista+c_mezzo)
1087        costo_carb <- costo_diesel/consumo_kml*dist_cw_cw
1088        num_trasp_cw_cw <- trasporti_annuali_cw_cw*2
1089
1090        c_trasp_cw_cw <-
             (costo_carb+costo_mezzoaut_cw_cw)*num_trasp_cw_cw
1091
1092      } else {
1093        c_trasp_cw_cw <- 0
1094      }
1095
1096
1097
1098      #COSTI DI MAGAZZINO
1099
1100      #mezzi, celle, muletti e transpallet
1101        #numero massimo di livelli (considero altezza massima e
             altezza massima raggiunta dal muletto)
1102        num_livelli <- min( ceiling(h_max_muletto/H),
             floor(h_max_edificio/H) )
1103
1104        #calcolo il numero di pl per torre (modulo*num livelli)
1105        num_pl_torre <- num_livelli*6
1106
1107        #calcolo l'area utilizzata, U e V reali, SC reale
1108        ingresso <- NULL
1109        flussi_ingr_provv <- NULL
1110
1111        for (g in 1:12) {
1112          flussi_ingr_provv <-
               flussi_ingr[which(flussi_ingr$ï..Mese == g), ]
1113          ingresso[g] <- sum(flussi_ingr_provv$QuantitÃ.)
1114        }
1115
1116        cum_ingr <- cumsum(ingresso)
1117        usc <- c(rep(sum(uscite$Totale)/12, 12))
1118        cum_usc <- cumsum(usc)
1119
1120        rees <- NULL
1121        for (g in 1:12) {
```

```
1122            rees[g] <- cum_ingr[g] - cum_usc[g]
1123          }
1124
1125        pl_richiesti <- ceiling(max(rees)/peso_pl)
1126        A <- ceiling(pl_richiesti/(num_pl_torre*k_cw)*D*W)
1127
1128        num_corridoi <- round(sqrt(A)/W)
1129        num_torri_corridoio <-
           ceiling(pl_richiesti/(num_pl_torre*num_corridoi))
1130
1131        U_reale <- num_corridoi*W
1132        V_reale <- num_torri_corridoio*D
1133        SC_reale <- num_corridoi*num_torri_corridoio*num_pl_torre
1134
1135    #muletto
1136        trag_orizz <- 2*(U_reale/2 + V_reale/2 + corridoio)
1137        trag_vert <- H*(num_livelli-1)
1138
1139        Tvar <- trag_orizz/vel_orizz_muletto +
           trag_vert/vel_vert_muletto
1140        Tsc <- Tfissi + Tvar
1141
1142        TCmuletto <- floor(FU*3600/Tsc)
1143        TCrichiesta <- ceiling(sum(uscite$Totale)/(peso_pl*48*5*8))
1144
1145    muletti <- ceiling(TCrichiesta/TCmuletto)
1146
1147    #transpallet
1148        Tvar <- trag_orizz/vel_orizz_transpallet
1149        Tsc <- Tfissi + Tvar
1150        TCtranspallet <- floor(FU*3600/Tsc)
1151
1152    transpallet <- ceiling(TCrichiesta/TCtranspallet)
1153
1154    #personale
1155        uscite_provv <- NULL
1156        entrate_provv <- NULL
1157        pers_ric_stocc <- NULL
1158        pers_prelievo <- NULL
1159        pers_carico <- NULL
1160        pers_amministr <- NULL
1161        FTE <- NULL
1162
1163        for (a in 1:k_cw) {
1164          uscite_provv <- ceiling(
           sum(flussi_mix[which(flussi_mix$Cluster == a &
           flussi_mix$Tipo == "Uscita"), c("Peso")])/(peso_pl*48) )
           #pl/w
1165          entrate_provv <- ceiling(
           sum(flussi_mix[which(flussi_mix$Cluster == a &
           flussi_mix$Tipo == "Entrata"), c("Peso")])/(peso_pl*48) )
           #pl/w
1166
1167          #calcoli per la preparazione ordine
1168          Tsc <- tempi_fissi +
           viaggi_per_pallet*(corridoio_pick+U_reale/2+sqrt(corridoio_
           pick^2+(U_reale/2)^2))/velocità_operatore
1169          prep_ordine <- 3600/Tsc
1170
```

```
1171            pers_prep_ordine <- ceiling(uscite_provv/(prep_ordine*40))
1172            pers_ric_stocc <-
                ceiling(entrate_provv/(ricevimento_scarico*40))
1173            pers_prelievo <- ceiling(uscite_provv/(prelievo*40))
1174            pers_carico <- ceiling(uscite_provv/(carico*40))
1175            pers_amministr <-
                ceiling(uscite_provv/(attività_amministrative*40))
1176
1177            FTE[a] <- pers_amministr + pers_prelievo + pers_ric_stocc
                + pers_prep_ordine + pers_carico + org_ritiri_cw
1178          }
1179
1180       FTE_cw <- sum(FTE)
1181       FTE_vol_cw <- perc_vol*FTE_cw
1182       FTE_empl_cw <- FTE_cw-FTE_vol_cw
1183
1184       #calcolo il numero di muletti richiesti
1185       muletti_cw <- muletti*k_cw
1186       transpallet_cw <- transpallet*k_cw
1187
1188       #mezzi, celle
1189       mezzi_cw <- mezzi_rete*tot_flussi/tot_flussi_2019
1190       celle_cw_tot <- celle_cw*k_cw
1191
1192       #area totale di magazzino della rete; area totale compresi
            spazi di ufficio
1193         area_mag_calc <- ceiling(k_cw*( U_reale*V_reale +
            corridoio*U_reale*2 + corridoio_pick*U_reale))
1194         area_nec_uffici <- ceiling(k_cw*0.1*area_mag_calc)
1195
1196       area_cw_tot <- area_mag_calc+area_nec_uffici
1197
1198       #il costo finale è dato da : costo dello spazio + personale +
            energia + utenze + manutenzione
1199       costo_mag <- area_cw_tot*c_spazio + (FTE_empl_cw*c_empl +
            FTE_vol_cw*c_vol) + area_cw_tot*c_energia + FTE_cw*c_utenze +
            (c_manut_cella*celle_cw_tot + c_manut_mezzo*mezzi_cw +
            c_manut_muletto*muletti_cw +
            c_manut_transpallet*transpallet_cw)
1200
1201
1202       #COSTO TOTALE
1203       costo_tot <- costo_mag + c_trasp_don_cw + c_trasp_cw_cw +
            c_trasp_cw_tp
1204       costo_tot
1205
1206       #aggiungo il risultato dei miei calcoli alla tabella
            riassuntiva RIS
1207       RIS_cw <- c(k_cw, costo_tot, c_trasp_don_cw, c_trasp_cw_tp,
            c_trasp_cw_cw, costo_mag)
1208
1209    #plotto il risultato del clustering dei transit per trovare i
        magazzini centrali
1210    colnames(coord_centroide) <- c("Longitudine", "Latitudine")
1211    ggmap(map) + geom_point(aes(x = Longitudine[], y = Latitudine[]),
        data = flussi_mix, colour = as.factor(flussi_mix$Cluster)) +
        geom_point(aes(x = Longitudine[], y = Latitudine[]), data =
        as.data.frame(coord_centroide), alpha = 1, size = 4, colour =
        'orange')
```

```
1212
1213
1214
1215    ###      RISULTATI      ###
1216
1217    #coordinate dei transit point e dei magazzini centrali
1218    write.csv2(coord_centr,
        "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
        modello\\Risultati\\Coordinate transit point.csv")
1219    write.csv2(coord_centroide,
        "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
        modello\\Risultati\\Coordinate magazzini centrali.csv")
1220
1221    #salvo anche la tabella flussi_mix, in modo tale che si possa
        andare a vedere quale fornitore e quale transit point appartenga
        a quale magazzino centrale
1222    write.csv2(flussi_mix[which(flussi_mix$Tipo == "Entrata"),],
        "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
        modello\\Risultati\\Associazione donatori CW.csv")
1223    write.csv2(flussi_mix[which(flussi_mix$Tipo == "Uscita"),],
        "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
        modello\\Risultati\\Associazione transit point CW.csv")
1224
1225    #salvo la tabella elenco_sc_n, che mi dice a che transit poit è
        associata una SC
1226    write.csv2(elenco_sc_n,
        "C:\\Users\\lello\\OneDrive\\Desktop\\Directory del
        modello\\Risultati\\Associazione SC TP.csv")
1227
1228    #stampo i costi totali della rete
1229    sprintf("Banco Alimentare deve dotarsi di una rete a due livelli
        con %s transit point e %s magazzini centrali, le cui posizioni
        sono indicate nei file salvati nella cartella Salvataggi. I costi
        totali della configurazione attuale ammontano a %s € all'anno, di
        cui %s in trasporti e %s in costi di magazzino.", k_provv,
        k_cw_ott, round(costo_tot_tp+costo_tot),
        round(c_trasp_tp_sc+c_trasp_don_cw+c_trasp_cw_tp+c_trasp_cw_cw),
        round(costo_mag+costo_mag_tp))
1230
1231    ###      FINE       ###
1232
```

RINGRAZIAMENTI

Il Canto del Figlio Errante

Il filo fra le mani della buona madre,
    l'abito sul corpo del figlio errante.
Egli è in procinto di partire,
    ella cuce punti fitti fitti,
temendo che il suo ritorno sia rimandato
    nel tempo.

Chi può mai dire se la tenerezza
    di un'erba alta una spanna
saprà contraccambiare il radioso sole
    di primavera?

孟郊 Mèng Jiāo

Questa poesia è stata composta da Mèng Jiāo (751–814 d.C.), un poeta della dinastia Táng. È molto famosa in Cina: viene spesso usata dai figli per ringraziare i propri genitori per tutto quello che hanno fatto per loro.
L'immagine usata per descrivere come i genitori crescano i propri figli è quella del sole primaverile che accudisce i fili d'erba. Nonostante tutti i ringraziamenti che si possano fare (con o senza tesi!), non saranno mai abbastanza per ripagare i miei genitori di tutti i sacrifici fatti per me e le mie sorelle. Dedico a voi, mamma e papà, questo mio piccolo lavoro, nella speranza che possa essere apprezzato.
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Non dimenticherò mai la mia esperienza al Banco, la giornata della Colletta e le visite ai magazzini. Oggi devo salutare il Banco, ma ho l'impressione che non sarà per sempre.

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Raffaello Barri

LIST OF TABLES

LIST OF FIGURES

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