How to plan the future e-truck infrastructural network?

Année 2023-2024

Yoan CHARPENTIER
Élève ingénieur 4ème année
Département Ingénierie Mathématiques et Data Science

POLYTECH CLERMONT - UNIVERSITÉ CLERMONT AUVERGNE

Campus Universitaire des Cézeaux – 2 Av. Blaise Pascal

63100 AUBIERE, FRANCE

Tél. (33) 04.73.40.75.00

`https://polytech-clermont.fr/`

Acknowledgment

I would like to thank Hao Yu for supervising my internship. The great autonomy he granted me, both in substance and form, has developed my taste for research and taking initiative. I have grown intellectually from this experience. Thank you once again.

I would also like to thank Xu Sun for attending our meetings.

I am also grateful to the jury members, Pierre Druilhet and Stéphanie Léger, for the time they dedicated to reading this report and for the subsequent discussion.

This internship would not have been possible without the financial support of several institutions. Therefore, I would like to thank CROUS, the Auvergne Rhône-Alpes region, and the Polytech Foundation.

The practical aspects of daily life inevitably impact the quality of the internship. I cannot, therefore, fail to express my gratitude to my family. Their advice and support were invaluable to me. Dad, Mom, I sincerely thank you.

Finally, Mélodie provided unwavering support throughout these five months, for which I am truly grateful.

Comment planifier le futur réseau d'infrastructure de camions électriques ?

Résumé

Ce rapport rend compte du stage de recherche effectuée à l'Université Arctique de Norvège dans le département d'Ingénierie Industrielle de Narvik. Les voitures et camions électriques voient leur utilisation se démocratiser depuis les sept dernières années. En conséquence, cette électrification des véhicules de transport de marchandise va naturellement impacter les chaînes d'approvisionnement, qui doivent donc être révisées. C'est dans ce cadre contemporain que s'inscrit ce rapport où l'on se propose d'étudier conjointement le placement optimal des bornes de rechargement et des infrastructures logistiques. L'étude, réalisée en autonomie et sous la supervision d'un maître de stage, a abouti à la réalisation d'un modèle d'optimisation sous contrainte répondant à cette problématique. Le coeur de ce stage est la méthodologie permettant de parvenir à un tel modèle. En premier lieu, ce rapport établira un état de l'art du sujet. Par la suite, on présentera et mettra en perspective des modèles issus de la littératures. Finalement, il sera présenté le modèle développé lors de ce stage.
À l'issu de cette étude, le lecteur sera en mesure de comprendre les questions méthodologiques d'un stage de recherche et du développement d'un modèle logistique. Le lecteur aura également acquis le contexte et les enjeux d'un problème d'optimisation appliqué à une chaîne d'approvisionnement.

Mots-clés : AMPL, chaîne d'approvisionnement, borne de chargement, problème de localisation, camions électriques, développement durable

How to plan the future e-truck infrastructural network?

Abstract

This report documents the research internship carried out at the Arctic University of Norway in the Industrial Engineering Department of Narvik. Over the past seven years, the use of electric cars and trucks has become increasingly widespread. Consequently, this electrification of freight transport vehicles will naturally impact supply chains, which must therefore be revised. This report is situated within this contemporary context, proposing to jointly study the optimal placement of charging stations and logistics infrastructures. The study, conducted independently and under the supervision of an internship advisor, resulted in the creation of a constraint-based optimization model addressing this issue. The core of this internship is the methodology that enables the development of such a model. Firstly, this report will establish a state-of-the-art on the subject. Subsequently, we will present and put into perspective models from the literature. Finally, the model developed during this internship will be presented.
At the end of this study, the reader will be able to understand the methodological questions of a research internship and the development of a logistics model. The reader will also have acquired the context and challenges of an optimization problem applied to a supply chain.

Keywords : AMPL, supply chain, charging stations, location problem, e-trucks, sustainable development

Contents

CHAPTER A

Introduction

At a time where technological innovation is transforming various industries, this internship studies the contemporary challenges of freight transportation within a supply chain. As transportation is increasingly subject to environmental regulations, the supply chains transportation must adapt to the electrification of vehicles, including Electric Trucks (ET). Hence, the internship seeks to design the future supply routes with an ecological constraint in mind. The objective of this internship is therefore to explore methods to shape the distribution network of tomorrow.

To address this issue, a five-month research internship was conducted at the Arctic University of Norway, located in Narvik . The university is distinguished by a recognized department in logistics. This internship enabled a review of current solutions and contributed to the development of new solutions related to a smart creation of a supply chain.

More specifically, the internship focused on the creation of a model that is able to simultaneously positioning distribution infrastructures and Charging Station (CS). Thus, this project addresses several issues: economic (optimality of business decisions, ...), scientific (contribution to mathematical optimization applied to an industrial challenge) and ecological (implementation of a distribution network using electric vehicles). So, how can we develop the future e-truck infrastructural network with all these constraints ?

This introduction will be supplemented with details on three forementioned elements: the host university, the socio-ecological challenges, and the study itself. In the chapter B, we will go deeper into the methodology of the internship and the various steps that led to a satisfactory result. Precisely, we will detail the state-of-the-art and then develop our own model. Finally, we will conclude with the outcomes of this internship, both on a personal level and from a technical perspective.

A.1 University Overview

The Arctic University of Norway has 17,808 students[1] across 11 campuses. The main campus, located in Tromsø, lends a part of its name to the university: Universitet i Tromsø (UiT) . The internship took place at the Narvik campus A.1.1. Perched on the heights of the city, the campus provides a particularly aesthetic view of the city center and the surrounding fjords. Beyond the panorama, the university provides modern facilities and several services, including a cafeteria, a library, study and relaxation rooms, among others. The campus also houses the student services office, Samskipnaden [1]. This service helps students renting apartments, cars, and dining options. I completed my internship in the Department of Industrial Engineering, which includes research groups focused on materials

[1] Which is essentially the Norwegian equivalent of the French CROUS

science, Arctic technology, and smart logistics and production [2]. I worked in this latter group under the guidance of Hao Yu, the head of the industrial engineering master's program. This group is involved in projects related to robotics, production engineering, and logistics.

Figure A.1.1: Arctic University of Norway - Narvik Campus

A.2 Sustainable Development and CSR Overview

The current environmental context encourages an awakening among the population regarding the impact they can have on the climate. For example, this internship benefited from the Erasmus+ Polytech Green grant, encouraging environmentally focused projects and green travel. Hence, the ecological issue played a central role in the internship. In this section, we will observe the societal and environmental dimensions of the internship project and analyze its impact. We will start by estimating the carbon footprint of the round trip. Next, we will justify the environmental relevance of the project. We will then highlight possible actions that a student and the host university can take for sustainable development. This supplement will conclude with an observation made on-site, in Narvik.

We examine in this paragraph the impact of transportation on the carbon footprint of the internship. This issue is particularly important as it is one of the main economic sectors responsible for greenhouse gas emissions[3]. Therefore, we will estimate the carbon footprint of the internship based on this emission category. We will consider several options for the Cérans-Foulletourte - Narvik journey. For practical reasons, the study is limited to transportation methods that have non-zero carbon emissions. Consequently, we exclude options such as walking or cycling. The various analyses are summarized in Table A.2.1.

Methods	**Duration (h)**	**Emission (kg)**	**% emission**	**Cost (€)**
Go	50	43	0.07%	550
Return	76	94	0.16%	300
Plane	7	400	8.89%	280
Thermal vehicle	37	723	16.07%	425
TGV	1	9.74	0.02%	-

Table A.2.1: Comparison of Transportation Methods

Table A.2.1 presents a comparative analysis of different transportation methods. They are compared based on their duration (in hours), emissions (in kilograms), the percentage of these emissions relative to the annual carbon footprint of an average French citizen, and their cost (in euro).

Several methods are considered for the outbound (Go) and return (Return) journeys, including plane, thermal vehicle, and high-speed train (TGV) [2]. The outbound and return trips combine various modes of transportation.

This comparison highlights that the TGV journey is the most efficient in terms of carbon dioxide emissions. However, this option is not feasible due to technical reasons (no direct high-speed train route to Narvik). Nevertheless, it provides a useful lower bound for emissions. It is reasuring to see that using a conventional vehicle without carpooling is the worst option (723 kg of CO_2). Indeed, such a trip would emit the equivalent of two months of CO_2 emissions for an average French person in a year.

Since it is not feasible to use only one mode of transportation, mixed journeys are preferred. For the outbound trip (Go), we mainly combine the TGV (from Cérans-Foulletourte to Hambourg) with night trains (from Hambourg to Narvik). This method results in a **CO_2 emission of 43 kg**, which is satisfactory because this represents less than 1% of the annual emissions of an average French person. However, the cost of this journey does not encourage the use of this method. Indeed, as shown in Table A.2.1, the price of a flight is 50% cheaper and the journey takes nearly 7 times less time than the mixed outbound method.

For the return trip, a different mixed method (Return) was preferred, offering a better trade-off between the budget and environmental impact. This time, the journey combines a night train and bus' between Stockholm and Cérans-Foulletourte. This combination provides a balanced approach between budget constraints and carbon dioxide emissions. For this part, the trip emits **96 kg of CO_2**. Although the greenhouse gas emissions are higher than the outbound trip, they remain within an acceptable range (less than 0.16% of the annual emissions of an average French person) and has the advantage of being more economical. On the other hand, the travel time is 52% longer.

In total, considering both the outbound and return trips, the journey emitted **137 kg of CO_2**.

The project is fully aligned with a sustainable development approach, specifically following the 9th Sustainable Development Goal of the United Nations, which is "Industry, Innovation, and Infrastructure" [4]. Indeed, developing a network that promotes electric vehicle transportation has become a crucial issue. The transport of goods is expected to be carried out using electric trucks , and the placement of charging stations for these trucks is a *sine qua non* condition for their deployment. Their locations must meet criteria for equitable, livable, and viable development, which necessarily leads to the establishment of sustainable charging stations (A.2.1).

On-site, the environmental impact was minimized as much as possible, notably by using the Too Good To Go app for grocery stores. Purchases made through this app helped avoid the emission of 146 kg of CO_2. Additionally, the proximity between the appartment and the university made possible the trips between them on foot.

We now consider the environmental values of UiT, the host institution. It is observed that a range of measures has been implemented, including planning and short- to medium-term goals [5]. These measures cover various aspects of sustainable development. For instance, by the end of 2023, nearly 90% of the campus lighting was provided by LEDs, and this figure is expected to reach 96% by 2024.

Another crucial area is transportation, given the presence of 11 campuses, including one in the Svalbard archipelago, which poses significant challenges. The university's environmental objectives include replacing its entire fleet of thermal vessels with electric-powered ships. Efforts are also

[2]TGV: Train à Grande Vitesse (high-speed train)

Figure A.2.1: Definition of Sustainable Development

underway to encourage the use of personal electric vehicles, with a goal of achieving an 85% market share. This is supported by incentives such as paid parking and an increase in parking spaces for cyclists.

Regarding biodiversity, UiT is committed to reducing parking lot areas and replacing them with green spaces. Additionally, the university is increasing its initiatives to create botanical gardens to protect and develop local species.

Overall, UiT is taking significant steps towards sustainable development, aiming to reduce its climate footprint by 55% by 2030 compared to 2022.

To conclude our reflection on the societal and environmental impact of the internship, I want to share a personal observation that has affected me and, I hope, will also resonate in the reader's mind. I had the opportunity to witness the fragility of an environment based on the temperature to which it is exposed. During the second half of April, the average temperature changes from -1°C to 0.5/1°C. This change of just 1 degree may seem insignificant, but it is precisely at this moment that we observe the melting of snow and ice piles that have accumulated over the past months. This melting reveals areas that were previously inaccessible or difficult to reach. Fortunately, these temperatures are quite normal for the region. However, this observation makes us imagine the impact of temperature increases on Earth's surface in areas where temperatures are typically always below freezing.

A.3 Presentation of the Study

The study lasted 5 months and has for topic this problematic : "How to plan the future e-truck infrastructural network?". This project has a significant contemporary challenge. Indeed, the development of electric vehicles is continually advancing [6]. Whether in France or within the European Union [7], regulations mantate a complete transition from thermal classical vehicle to electric ones. It is clear that electric trucks are destined for the same future. Therefore, it is essential to consider the placement of infrastructure that will support the future "all-electric" transportation network.

In this context, the objective of the internship is to develop a mathematical optimization model to determine the optimal locations for electric truck charging stations and logistics infrastructures necessary for operating a distribution network. Following the development of the model, it is expected to test it and evaluated it on local data from the Nordland region in Norway.

Given the scope of the work, task planning was crucial. The goal of this planning was to ensure that the internship followed a steady pace and included checkpoints corresponding to the end of one phase and the beginning of another one. This planning was established at the very begining of the internship and refined as it progressed. This approach led to a planning schedule as illustrated in the Gantt chart A.3.1 below:

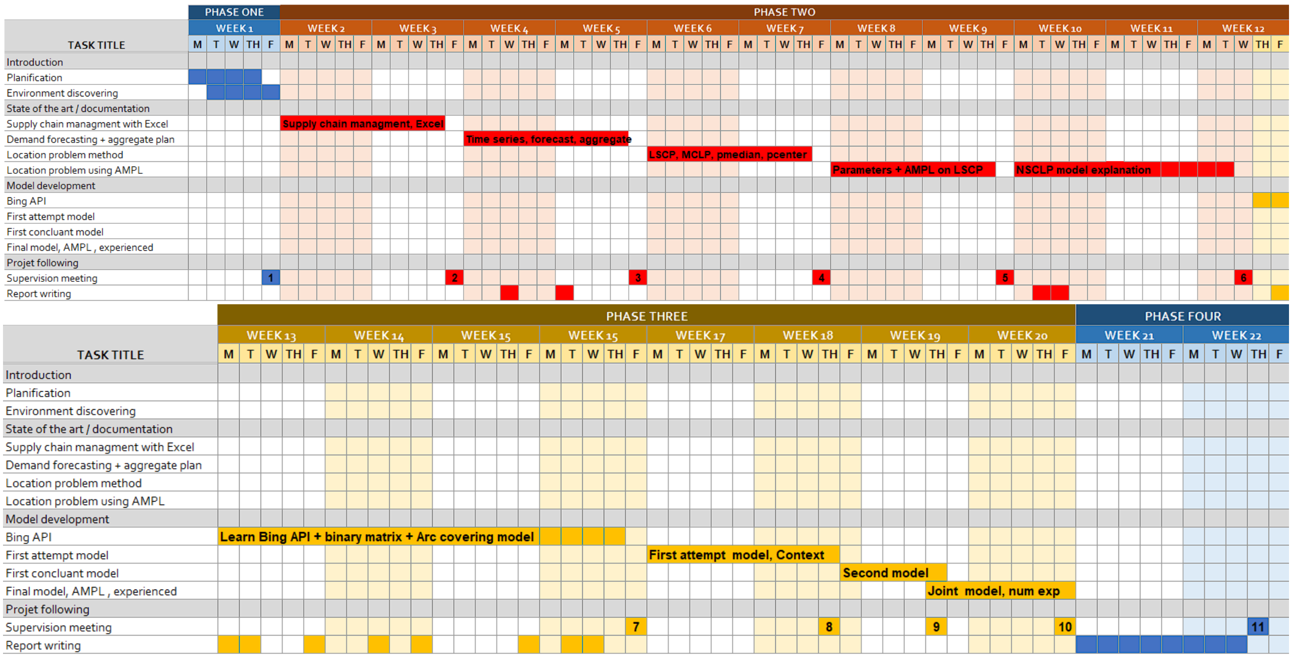


Figure A.3.1: Project's GANTT Diagram

As shown in Figure A.3.1, the project was divided into two main parts (documentation and model development), interspersed with supervision meetings with the internship supervisor, Hao Yu.

What is referred as "phase two" on the chart concerns the state of the art and is divided into two sub-parts: the study of logistical infrastructure placement problems and covering problems. The assumption was that synthesizing these two state of the art would allow the creation of a model combining these two fields of applied optimization.

In the following phase, the objective was to use the knowledge from "phase two" to construct the model in question (data preparation, data processing, mathematical formulation, software development, and improvement).

It should be noted that the internship was regularly punctuated by supervision meetings. The purpose of these meetings was to explain, through presentations in a free format, the various advancements, learnings, questions, etc.

The final stages were dedicated to writing the report and preparing the presentation slides.

CHAPTER B

Methodology and Completed Work

We recall in this paragraph, the study objectives and the methodology used to contuct it.

Recent regulations on electric trucks raise important questions. Indeed, these new vehicles will alter the way supply chains are constructed and conducted. Here, we study new challenges that transportation will pose to this logistic area. The goal of this research is to create a model that can simultaneously place logistical infrastructure (plants, warehouses, etc.) and charging stations to enable all the roads of electric trucks within this network of infrastructure. This objective leads to the approach we detail bellow.

First, we will study the issues related to the placement of infrastructure in a supply chain and demand fulfillment. This contextual understanding will allow us to study related instrastructural optimization models. Next, we will address the topic of placing charging stations. By exploring models that facilitate this task, we will be able to grasp the challenges associated with covering problem. Finally, we will see the method to achieve the objective of simultaneously placing logistical infrastructure and charging stations that enable movement between each infrastructure and the demand points to be served.

Before starting the study, we will clarify some notations and common practices used in this report:

- → All sets and parameters are specified in Appendix A. For easier reading, here are some details about these parameters:
  - Warehouses, plants, and facilities are indicated by the index i.
  - Covering infrastructure (mainly charging stations) are indicated by the index j.
  - Demand points are indicated by the index k.
- → Decision variables are defined before each model and are highlighted in red.

We will develop the mathematical models and solve them using AMPL. AMPL is a modeling language developed since 1983. It is well-suited for solving optimization problems and offers several solvers (both linear and nonlinear). This language has the advantage of being usable on most collaborative platforms (Google Colab, Jupyter, Kaggle, etc.), deployment platforms (Azure, AWS, Docker, etc.) and can connect to various other development languages via APIs (such as Python, R, Java, C++, etc.). The proliferation of these platforms has popularized AMPL in the private industry: UPS, Zara, Siemens among others. In practice, an AMPL model combines three files: the model file, the data file, and optionally a "run" file that can compile everything automatically.

We will now start, as forementionned in this chapter plan, by having an overview on the logistical infrastructure placement methods and concepts.

B.1 Logistical Infrastructure Placement

B.1.1 Supply chain design

To effectively conduct the analysis outlined in the study presentation, it is essential to perform a literature review on logistical infrastructure location problems. The first two months were dedicated to reviewing articles on this topic. This preliminary work aims to frame the right questions, understand the context and is divided into two distinct stages. In the first introductory part, we will present the various stakes related to supply chain . Consequently, we will illustrate these challenges using basic models. These models will then serve as a foundation for studying more contemporary models, which will ultimately be applied to our final model.

Some definitions or concepts comes from the logistics of goods production. We

Definition B.1.1 (Supply Chain[8])**.** All parties involved, directly or indirectly, in fulfilling a customer request. Products or supply moves from suppliers to manufacturers to distributors to retailers to customers along the chain. It is a dynamic process that involves the constant flow of information, product and funds between different stages (one player involved). [1]

A supply chain is built with **key drivers** (constituent elements of a supply chain), which are listed and detailed below:

- → Facilities (e.g., plants)
- → Inventory : management of stock levels within each facility (e.g., warehouses)
- → Transportation : methods to move goods or information across the supply chain
- → Information: methods to report indicators and data to decision-makers
- → Sourcing: methods related to production, transportation, and whether all of it is done locally or outsourced
- → Cost: all elements related to the pricing of the other key drivers.

Each of these key drivers affects the overall performance of the network. The performance can be evaluated using two criteria: responsiveness and effectiveness . The book Supply Chain Management [8] provides comprehensive definitions of these two concepts:

Definition B.1.2 (Responsiveness)**.** The ability of a supply chain to respond to the following points: addressing a wide range of demand across various products, responding quickly to this demand, and being capable of handling significant uncertainty in demand.

Definition B.1.3 (Efficiency)**.** The ability of a supply chain to achieve the following: meeting demand across a wide range of products while minimizing costs and waste, ensuring optimal resource utilization, and maintaining cost-effectiveness in the face of varying demand levels.

[1] Given this definition, it would be more accurate to refer to it as a "supply network". However, for the sake of clarity, we will retain the term "supply chain."

The choice of key drivers directly impacts performance criteria and is often the result of strategic decisions made by the company. Here are some examples of possible choices to illustrate these influences:

- Inventory: Increasing the overall inventory level will make the network more responsive but will raise the holding costs, thereby reducing efficiency. Conversely, lowing the general inventory levels improves efficiency by promoting faster turnover of items. However, reducing inventory can lead to stockouts, which decreases responsiveness.
- Facilities: Increasing the number of facilities will reduce travel times, resulting in a more responsive network. However, it will decrease efficiency due to the higher inventory costs associated with more facilities. On the other hand, reducing the number of facilities will significantly lower costs, making the network more efficient. The downside is that this will increase the distance between facilities, causing less frequent and slower circulation of goods, which negatively impacts responsiveness.

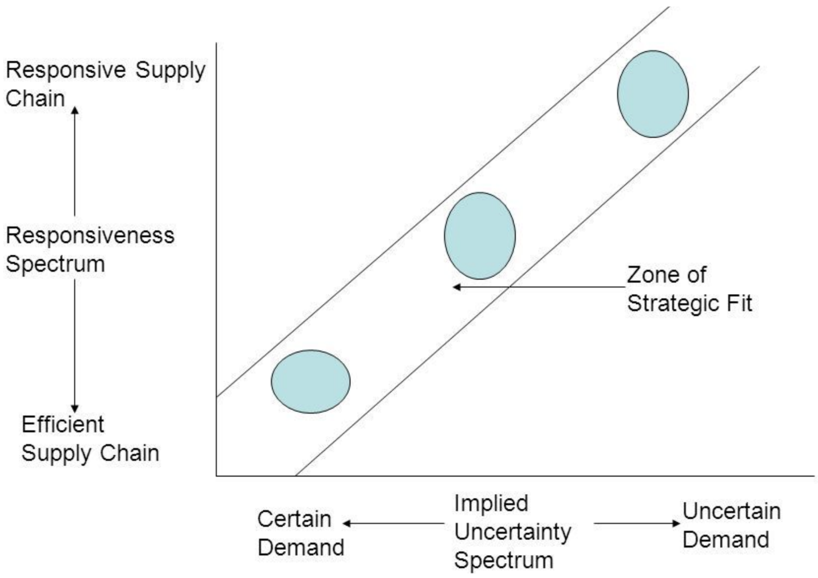


Figure B.1.1: Zone of strategic fit in supply chain

Thus, different supply chain strategies can be positioned on a spectrum of responsiveness B.1.1. On one hand of the spectrum, we find highly efficient supply chains where production is planned weeks or months in advance, with low variety and low flexibility, resulting in reduced costs. On the other hand of the spectrum, we have highly responsive supply chains characterized by nearly daily inventory replenishments. This organization prevents stockouts, is fast and flexible, but comes with high costs.

These examples and the spectrum detail illustrate that choices about key factors influence network performance through decision levers: strategic, technological, macroeconomic, political, infrastructural, and competitive. It is also observed that these decision levers often improve responsiveness at the cost of efficiency, and vice versa. Therefore, the challenge is to find a trade-off between responsiveness and efficiency. [2]

In our case, we will focus on the final part of the supply chain , specifically the step of directly distributing energy to the vehicle. To revisit what was mentioned earlier, the main trade-off of the study will concentrate on the key drivers of transportation, pricing, and infrastructure. [3]

[2]To justify the search for a good trade-off between these two evaluation measures, it is noted that the supply chain affects 35% of financial performance in the apparel retail sector.

[3]However, one could imagine a more comprehensive model that involves the electricity supplier (inventory aspect) and monitoring of electricity consumption (information aspect).

Toutes ces décisions sont prises préalablement de la construction de la chaine. Une fois cela fais, on peut construire des modèles d'optimisation. L'objectif des ces modèles est souvent de placer des infrastructures capable de maximiser la rente généré (ou réciproquement de minimiser les coûts). Un cadre de travail est proposé par Chopra [8] dans la figure B.1.2.

All these decisions are made before the construction of the supply chain. Once this is done, optimization models can be developed. The goal of these models is often to place infrastructures that maximize the generated revenue (or conversely, minimize costs). A working framework is proposed by Sunil Chopra [8] in Figure B.1.2.

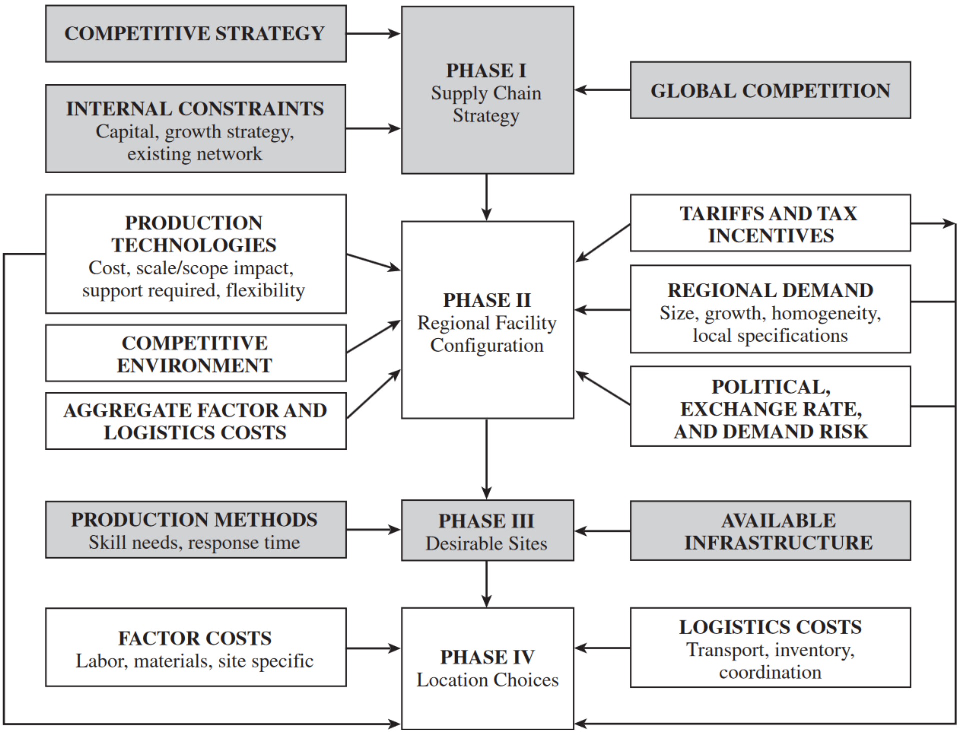


Figure B.1.2: Framework for Network Design Decisions

It is interesting to note that this framework functions like a funnel, with decisions moving from the broadest level to the most detailed. We also observe that the questions we need to address in phases I and II have been already covered.

Following the high-level issues, we then focus on technological decision levers. In Phase III, we primarily establish a preliminary list of "candidate" infrastructures for potential opening. These are sites that meet the decision criteria from Phases I and II. To make this selection, factors such as accessibility, environmental conditions, and the cost of the location are considered [9].

Once the candidate locations are chosen, Phase IV is dedicated to selecting the final locations, with particular emphasis on cost constraints.

B.1.2 Models

With the foundational logistics established earlier, we continue our literature review focusing on optimization models. The following steps of the literature review will cover a studsy of three known models used in logistical instrastructural optimization.

As introduced in the subsection, we aim to solve a well-studied problem in the literature: the Capacited Plant Location Model (CPLM). As the name suggests, this model addresses the placement of plants while considering their capacities. The model must therefore meet demand without exceeding the capacities of the sender plant.

The B.1.1 decision variables are described as follow :

→ s_{ik} : quantity to be shipped from a plant i to customer k.

Model B.1.1 (CPLM).

$$\text{Objective function :} \quad \min \sum_{i \ \mathcal{I}} c_i x_i + \sum_{i \in \mathcal{I}} \sum_{k \in \mathcal{K}} a_{ik} s_{ik} \tag{CPLM1}$$

$$\text{subject to (s.t.)} \quad \sum_{k \in \mathcal{K}} s_{ik} \leq K_i x_i \quad \forall i \in \mathcal{I} \tag{CPLM2}$$

$$\sum_{i \in \mathcal{I}} s_{ik} = d_k \quad \forall k \in \mathcal{K} \tag{CPLM3}$$

$$x_i \in \{0, 1\} \quad \forall i \in \mathcal{I} \tag{CPLM4}$$

$$s_{ik} \geq 0 \quad \forall (k, i) \ \in \mathcal{K} \times \mathcal{I} \tag{CPLM5}$$

As the goal of the model we described before, the objective function CPLM1 minimize the network's total shipping costs and openning costs. The second constraint CPLM2 ensure that the quantity shipped from a warehouse i does not exceed its capacity. Constraints CPLM3 seeks to meet demand for each demand point k. The last set of constraints CPLM4 and CPLM5 ensure respectively the decision variables integerness and positiveness.

For specific reasons, network managers might require that the demand at a particular point k be fulfilled by only one infrastructure. This constraint simplifies the supply chain network but reduces the flexibility of the infrastructures. This condition is incorporated into the model known as the Single Source Capacited Plant Location Model (SSCPLM).

→ x_i : 1 if the infrastructure is located at point i, 0 otherwise

→ x_{ik} : 1 if the infrastructure i supplies demand k, 0 otherwise

Model B.1.2 (SSCPLM).

$$\text{Objective function :} \quad \min \sum_{i \in \mathcal{I}} c_i x_i + \sum_{i \in \mathcal{I}} \sum_{k \in \mathcal{K}} d_k \times a_{ik} \times x_{ik} \tag{SSC1}$$

$$\text{s.t.} \quad \sum_{i \in \mathcal{I}} x_{ik} = 1 \quad \forall k \in \mathcal{K} \tag{SSC2}$$

$$\sum_{k \in \mathcal{K}} d_k x_{ik} \leq K_i x_i \quad \forall i \in \mathcal{I} \tag{SSC3}$$

$$x_i, x_{ik} \in \{0, 1\} \quad \forall i \ \forall k \tag{SSC4}$$

In this case, the objective function SSC1 remains essentially the same as CPLM1. Additionally, the capacity constraint SSC3 is identical to CPLM2. However, there is a new constraint SSC2 that ensures the sum of shipments to a demand point comes from only one plant. Finally, the constraint SSC4 specifies the integrity and positivity of the decision variables.

A model that could serve as inspiration is one designed to place multiple infrastructures within a distribution network, including suppliers, factories, warehouses, and stores. Mathematically, this model does not differ significantly from those discussed earlier. However, its value lies in offering a high-level perspective on the distribution network as a whole. Here are the Locating Infrastructures Simultaneously Model (LISM) decision variables : [4]

- → x_i : 1 if a warehouse is located at point i, 0 otherwise
- → x_e : 1 if a factory is located at point e, 0 otherwise
- → s_{he} : quantity to be shipped from supplier h to factory e
- → s_{ei} : quantity to be shipped from factory e to warehouse i
- → s_{ik} : quantity to be shipped from warehouse i to demand cluster k

Model B.1.3 (LISM)**.**

$$\text{Objective function :} \quad \min \sum_{e\in\mathcal{E}} f_e x_e + \sum_{i\in\mathcal{I}} c_i x_i + \sum_{h\in\mathcal{H}} \sum_{e\in\mathcal{E}} a_{he} s_{he} + \sum_{e\in\mathcal{E}} \sum_{i\in\mathcal{I}} a_{ei} s_{ei} + \sum_{i\in\mathcal{I}} \sum_{k\in\mathcal{K}} a_{ik} s_{ik} \tag{LISM1}$$

$$\text{s.t.} \quad \sum_{e\in\mathcal{E}} s_{he} \leq S_h \quad \forall h \in \mathcal{H} \tag{LISM2}$$

$$\sum_{h\in\mathcal{H}} s_{he} \geq \sum_{i\in\mathcal{I}} s_{ei} \quad \forall e \in \mathcal{E} \tag{LISM3}$$

$$\sum_{i\in\mathcal{I}} s_{ei} \leq F_e x_e \quad \forall e \in \mathcal{E} \tag{LISM4}$$

$$\sum_{e\in\mathcal{E}} s_{ei} \geq \sum_{k\in\mathcal{K}} s_{ik} \quad \forall i \in \mathcal{I} \tag{LISM5}$$

$$\sum_{k\in\mathcal{K}} s_{ik} \leq K_i x_i \quad \forall i \in \mathcal{I} \tag{LISM6}$$

$$\sum_{i\in\mathcal{I}} s_{ik} = d_k \quad \forall k \in \mathcal{K} \tag{LISM7}$$

$$x_e, x_i \in \{0,1\}, s_{he}, s_{ei}, s_{ik} \geq 0 \quad \forall e \; \forall i \; \forall k \; \forall h \tag{LISM8}$$

Essentially, the model B.1.3 incorporates the same constraints as the problems presented earlier. Constraints LISM3 and LISM5 ensure that an infrastructure cannot ship more products than it receives. For example, in constraint LISM3, a factory cannot ship more finished products than the raw materials it receives from suppliers. Constraints LISM1, LISM4, and LISM6 ensure that an infrastructure does not ship more than its capacity, specifically for suppliers, factories, and warehouses, respectively. To meet customer demand, it is essential that all shipments to locations with demand (such as stores) match the quantity requested (LISM7). Integrity conditions are specified in constraint LISM8, where variables are binary for the placement of infrastructures and positive for shipment quantities.

In its current form, one criticism that can be made of this solution is the comparison of different types of quantities in constraint LISM3, which could lead to unused capacities. To recap, ss represents the quantity sent from one point to another. However, in the specific case of LISM3, a comparison is made between quantities of raw materials and finished products. If, for example, a supplier ships 50 units of raw materials to a factory, and the factory sends 30 units of finished products to a warehouse, two issues arise:

[4] Sets $\mathcal{H}$ and $\mathcal{E}$ are only used in this model. For further detail, we suggest the reader to take a new look on the sets and parameter appendix A

- The first issue is a differential of 20 units, resulting in unused capacity.
- The second issue stems from the first: the comparison involves units of raw materials and units of finished products, making the constraint non-homogeneous!

To solve this problem, it would be a good starting point to separate a factory's capacity into two distinct parts: one for storing raw materials and another for temporarily store finished goods awaiting transfer to any inventory facility.

In this chapter, we conducted a thorough review of the essential logistics and supply chain management concepts needed for the continuation of our study. We started by describing the critical elements of supply chain design, highlighting the importance of key factors. We also identified the evaluation criteria for such a network, particularly focusing on responsiveness and efficiency. We then illustrated how strategic decisions regarding these key factors impact the trade-off between responsiveness and efficiency.

Building on these fundamental logistics concepts, we examined three optimization models. The first one is a foundational model, which often serves as a basis for other models. Additionally, we studied the SSCPLM and the LISM, which offer more comprehensive frameworks for placing multiple types of infrastructure within a distribution network.

The critical analysis of these models highlighted their strengths and potential limitations.

In summary, this chapter established a solid theoretical foundation for our study, providing essential insights and tools for optimizing infrastructure placement. The knowledge gained here will serve as the groundwork for developing effective strategies for a joint transportation distribution model.

B.2 Covering Problems

B.2.1 Introduction

Covering optimization models first emerged with Hakimi in 1964 [10], introducing the p-median and p-center methods for telecommunications. A few years later, the concept of a coverage radius was introduced in a 1971 paper by Toregas, which focused on the placement of emergency facilities [11]. This concept was further refined three years later with the development of the Maximal Covering Location Problem (MCLP) model, which aimed to maximize coverage [12]. A comprehensive overview of the main methods and their applications was provided by D. Schilling et al. in 1993.

We provide an example of case study of firestations placement in Nanjing region of China in a paper written by Yao, Jing et. al. in 2019 [13].

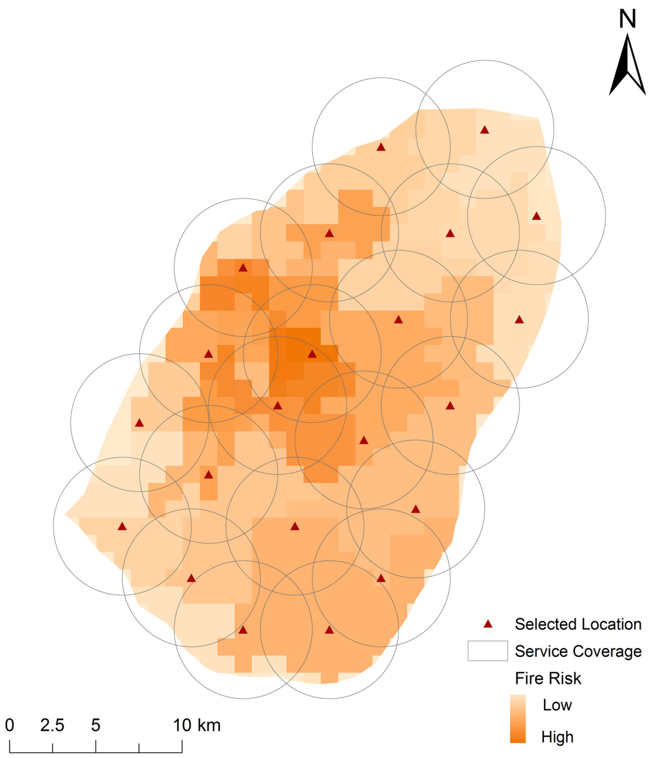


Figure B.2.1: LSCP applied on fire station placement in Nanjing, China

In this section, we study covering problems . Unlike the previous section, here we focus on placing infrastructures designed to cover a specific area. We will explore Set Covering Problems (LSCP) Location Set Covering Problem (LSCP) and Maximum Covering Location Problem (MCLP) in the context of charging stations. The goal of the LSCP is to minimize the number of stations needed while ensuring that every part of the road network is covered by these stations. On the other hand, the MCLP aims to maximize the coverage of road network routes within the radius of the charging stations .

By revisiting the responsiveness and cost criteria discussed in the logistics section, we can better understand the strengths and weaknesses of these models. Specifically, the MCLP focuses on cost savings, while the LSCP prioritizes the network's responsiveness to demand.

Here are the objectives of each model studied during the internship:

→ Minimize the maximum distance between any ET and the nearest CS (p-center)

- → Maximize the coverage of ET routes within a specified distance from CS (range is easy to implement) (MCLP [5])
- → Minimize the number of CS required while ensuring that every segment of the ET network is within reach of a CS (LSCP [6])
- → Minimize overall travel distance for the entire ET fleet to reach the nearest CS (p-median)

Now that the framework for covering problems is established, we can study specific models to gain insight into the technical aspects of solving these problems. We will examine the MCLP, the LSCP, and an extension of the latter proposed by Hao Yu.

B.2.2 Models

Now that we have examined the issues related to covering problems and the nuances between each, our literature review naturally shifts towards models that facilitate this task. In our case, we aim to find the locations for electric vehicle charging stations capable of covering an area. We will present the models introduced in the previous section. The model's decision variable descriptions are detailed below:

- → $y_j = 1$ if a charging station is placed position j, 0 otherwise

Model B.2.1 (LSCP)**.**

$$\text{Objective function :} \quad \min \sum_{j \in \mathcal{J}} b_j y_j \tag{LSCP 1}$$

$$\text{s.t.} \quad \sum_{j \in \mathcal{J}} \mathbb{1}_{\{d_{jk} \leq r\}} y_j \geq 1 \quad \forall k \tag{LSCP 2}$$

$$y_j \in \{0, 1\} \quad \forall j \tag{LSCP 3}$$

The objective function LSCP 1 involves minimizing the number of charging stations to be placed through the cost parameter. Constraint LSCP 2 ensures that each demand point will be covered by at least one charging station. Constraint LSCP 3 ensures that the decision variable is binary. This model is suitable for our study because it allows for placement decisions in space that satisfy a service coverage constraint, specifically: the charging of electric trucks .

We can also consider a coverage problem through the maximization of demand satisfaction, which is exactly what the MCLP model addresses. The decision variables used here are as follows:

- → $y_j = 1$ if a charging station is placed position j, 0 otherwise
- → $x_k = 1$ if demand k is covered within the service standard r, 0 otherwise

[5] Maximum Covering Location Problem
[6] Location Set Covering Problem

Model B.2.2 (MCLP).

$$\text{Objective function :} \quad \max \sum_{k \in \mathcal{K}} d_k x_k \tag{1}$$

$$\text{s.t.} \quad \sum_{j \in \mathcal{J}} \mathbb{1}_{\{d_{jk} \leq r\}} y_j \geq x_k \quad \forall k \in \mathcal{K} \tag{2}$$

$$\sum_{j \in \mathcal{J}} y_j = p \tag{3}$$

$$x_k \in \{0,1\} \quad \forall k \in \mathcal{K} \tag{4}$$

$$y_j \in \{0,1\} \quad \forall j \in \mathcal{J} \tag{5}$$

The objective function 1 seeks to maximize the total amount of demand covered by placing p facilities. Constraint 2 ensures that a demand k is covered by at least one charging station. It guarentee that if no charging station (CS) j is in the range of a demand point k, the model will set to 0 the variable x_k (demand is not covered by CS j). Constraints 3 force the model to place p facilies. Finally, 4 and 5 are integrality constraints, ensuring each decision variable is binary.

As is commonly done in the literature, the objective now is to study a model based on another one. In our case, we aim to study the Network-based set covering location problem (NSCLP) model developed in the paper *A Network-based Set Covering Model for Charging Station Location Problem: A Case Study in Norway* [14] and summarized below in B.2.3, which is an evolution of the LSCP model. The decision variables are:

→ $y_j, y_{j'} = 1$ if a charging station j is placed, 0 otherwise

Model B.2.3 (NSCLP).

$$\text{Objective function :} \quad \min \sum_{j \in \mathcal{J}} b_j y_j \tag{NSCLP 1}$$

$$\text{s.t.} \quad \sum_{j \in \mathcal{J}} \mathbb{1}_{\{d_{jk} \leq r\}} y_j \geq 1 \quad \forall k \in \mathcal{K} \tag{NSCLP 2}$$

$$y_j \leq \sum_{j' \in \mathcal{J} \setminus \{j' \neq j\}} \mathbb{1}_{\{d_{jj'} \leq r\}} y_{j'} \quad \forall j \in \mathcal{J} \tag{NSCLP 3}$$

$$y_j \in \{0,1\} \quad \forall j \tag{NSCLP 4}$$

It is coherent for the objective function of NSCLP (NSCLP 1) to be the same as that of the LSCP model (LSCP 1), as the NSCLP aims to be an extension of the LSCP. To recall, the objective of this function is to minimize the cost of placing the charging stations. The first set of constraints NSCLP 2 ensures that a charging station j can be found from a demand cluster k within a radius r. Second constraint NSCLP 3 is the novelty of the model. It ensures that each opened charging station can be reached by the others (providing that it is open). The last constraint NSCLP 4 is the decision variable binrary constraint.

We aim to rise properties over this model to understand in which condition it can be solved. This reflexion have a sense here because when we will implement these models in AMPL, it is proper to create an exception for unsolvable cases, rather than let the program crashes itself.

Proposition B.2.1 (Non solvable problem). *For a given $A \in \mathcal{M}_{M \times N}(\{0,1\})$, a necessary and sufficient condition for the covering problem not to be solvable is that $\forall i \in \mathcal{D}$, $\sum_{j \in \mathcal{C}} a_{i,j} = 0$.*
In other words, the covering problem is not solvable if a demand point isn't covered by any candidate location.

Proof of B.2.1: Consider a demand point m that is not in any of candidate location's radius. Indeed, we have for this particular demand location : $d_{m,j} \geq S \ \forall j \in \mathcal{C}$. Hence, the row associated to the demand point m has binary value 0. However, condition 1 from model (B.2.3) is not respected for $i = m$: $\sum_{j \in \mathcal{C}} a_{mj} x_j = 0$. □

As remarked before, this property has a direct impact on the AMPL code by using **check** keyword. This ensures the code not to crash because there is no solution to the coded model.

This model has an issue that was highlighted during the internship. It is presented as a proposal called pair selection.

Proposition B.2.2 (Pair selection)**.** *In the NSCLP model (B.2.3), if two candidate locations $w \in \mathcal{C}$ and $v \in \mathcal{C}$ are close enough. Then we have :*

$$x_w = x_v$$

In other words, if a charging station is open, then the second one will be open too, and conversely.

Proof of B.2.2: Consider two candidate points $w, v \in \mathcal{C}$ where we apply condition 2 (NSCLP 3) from model B.2.3. We also assume that only w and v are close enough, i.e., $d_{w,v} \leq S$.
From the perspective of point w, we can write:

$$x_w \leq \sum_{k \in \mathcal{C} \setminus \{w\}} b_{wk} x_k \Leftrightarrow x_w \leq x_v$$

And from the perspective of point v:

$$x_v \leq \sum_{k \in \mathcal{C} \setminus \{v\}} b_{vk} x_k \Leftrightarrow x_v \leq x_w$$

Hence, $x_v = x_w$. □

As we did before, finding properties on a new model is crucial to understand its strength and weakness. We will apply this same philosophy in the next part of the study.

B.3 Joint Model

B.3.1 Context

As a reminder, the goal of this project is to place warehouses and charging stations simultaneously. In this part, we combine what has been learned in the previous sections to address this requirement. We are working within a fictional scenario involving a request from *Posten*, the Norwegian company responsible for mail distribution. Due to new regulations on electric transportation, the company's truck fleet must be entirely renewed to switch to "all-electric" vehicles. Since electric trucks are not yet fully integrated throughout the territory, the company is seeking assistance from the local university to place its new infrastructure and the charging stations that will enable its trucks to operate on a new network to be developed. *Posten* is therefore considering a major overhaul of its network. We will not be designing the truck movement networks within cities; instead, we will focus on "clusters" of demand.

The following information is available:

- Information about the demand clusters (coordinates and approximate quantities)
- Information about the new warehouses to be placed (coordinates and capacity)

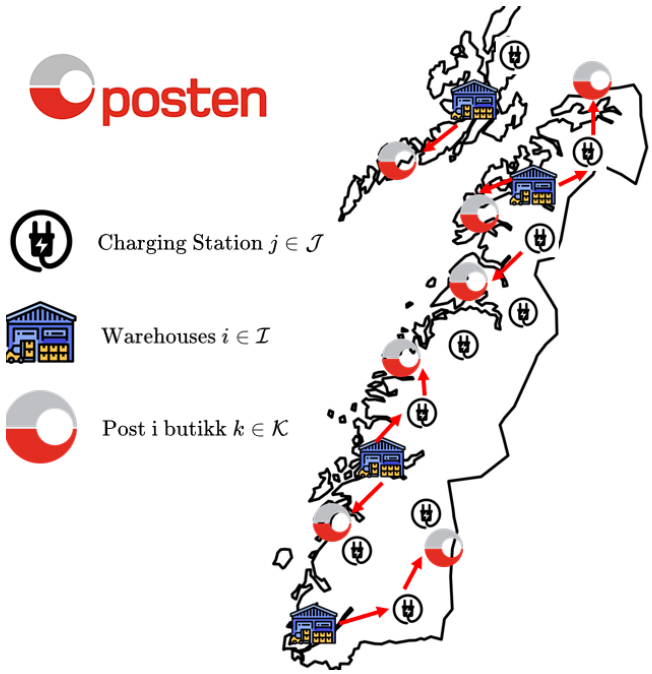


Figure B.3.1: Summary of the Context in the Nordland Region, Norway

B.3.2 Joint Model Development

Initially, I proposed a model with incorrect constraints and unresolved issues. We then propose several models that are essentially combinations of the models studied previously. We will detail the found models. The goal is to minimize the costs associated with placing the different infrastructures. The decision variables are described below:

- x_i : binary value equal to 1 if warehouse i is open, 0 otherwise

→ y_j : binary value equal to 1 if charging station j is open, 0 otherwise

→ s_{ik} : quantity to be shipped

Model B.3.1 (Joint Model)**.**

$$\text{Objective function :} \quad \min \sum_{i\in\mathcal{I}} c_i x_i + \sum_{j\in\mathcal{J}} b_j y_j + \sum_{i\in\mathcal{I}} \sum_{k\in\mathcal{K}} a_{ik} s_{ik} \tag{JM 1}$$

$$\text{s.t.} \quad \sum_{k\in\mathcal{K}} s_{ik} \leq C_i x_i \quad \forall i \in \mathcal{I} \tag{JM 2}$$

$$\sum_{i\in\mathcal{I}} s_{ik} = d_k \quad \forall k \in \mathcal{K} \tag{JM 3}$$

$$\sum_{j\in\mathcal{J}} \mathbb{1}_{\{d_{ij}\leq r\}} \mathbb{1}_{\{d_{jk}\leq r\}} y_j \geq x_i \quad \forall k \; \forall i \tag{JM 4}$$

$$s_{ik} \geq 0 \quad \forall k \; \forall i \tag{JM 5}$$

$$y_j, x_i \in \{0,1\} \quad \forall j \; \forall i \tag{JM 6}$$

The objective function JM 1 minimizes the cost of the network being optimized. Constraint JM 2 ensures that the quantities shipped from a warehouse do not exceed its capacity. Clearly, shipments to demand points must meet their required quantities (JM 3). The integrity constraints JM 5 and JM 6 ensure that the quantities shipped are positive and that the infrastructure opening variables are binary.

The novelty in this model primarily lies in constraint JM 4. It ensures that a charging station is selected if and only if it guarantees a route between a warehouse and a demand point. Initially, the following constraint was proposed:

$$\sum_{j\in\mathcal{J}} \mathbb{1}_{\{d_{ij}+d_{jk}\leq r\}} y_j \geq x_i \quad \forall k \; \forall i \tag{JM 4 - Alternative}$$

The issue with the above constraint is illustrated in the figure below : B.3.2:

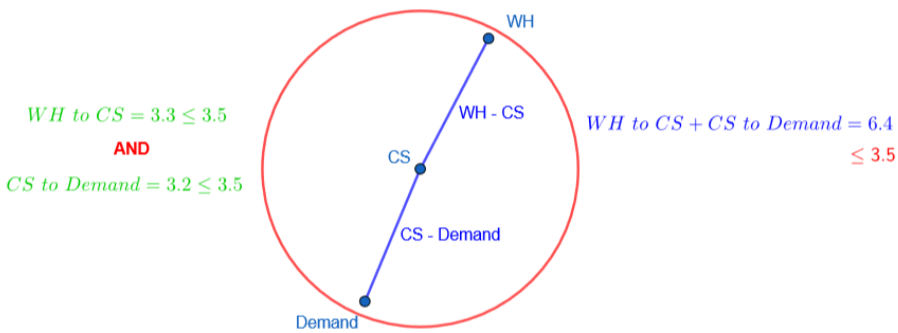


Figure B.3.2: Issue highlight

In this example, the constraint we wish to verify is indeed satisfied (both the warehouse and the demand are within the coverage radius of a charging station). However, with the condition JM 4 - Alternative, illustrated in blue in figure B.3.2, it is clear that the condition is not met (the sum of the distances exceeds the coverage radius of the station). This is why condition JM 4 is preferred. It translates, via an indicator function product, the AND condition.

Nevertheless, constraint JM 4 has a drawback: it only allows for one intermediate charging station to be proposed.

We address this problem by breaking down this condition and adding a constraint on the positions of the charging stations. This leads to the model stated below in B.3.2.

- x_i : binary value equal to 1 if warehouse i is open, 0 otherwise
- y_j : binary value equal to 1 if charging station j is open, 0 otherwise
- s_{ik} : quantity to be shipped from warehouse i to demand cluster k

Model B.3.2 (Final Joint Model)**.**

$$\text{Objective function : } \quad \min \sum_{i \in \mathcal{I}} c_i x_i + \sum_{j \in \mathcal{J}} b_j y_j + \sum_{i \in \mathcal{I}} \sum_{k \in \mathcal{K}} a_{ik} s_{ik} \tag{FJM 1}$$

$$\text{s.t.} \quad \sum_{k \in \mathcal{K}} s_{ik} \le C_i x_i \quad \forall i \in \mathcal{I} \tag{FJM 2}$$

$$\sum_{i \in \mathcal{I}} s_{ik} = d_k \quad \forall k \in \mathcal{K} \tag{FJM 3}$$

$$\sum_{j \in \mathcal{J}} \mathbb{1}_{\{d_{ij} \le r\}} y_j \ge x_i \quad \forall i \in \mathcal{I} \tag{FJM 4}$$

$$\sum_{j \in \mathcal{J}} \mathbb{1}_{\{d_{jk} \le r\}} y_j \ge 1 \quad \forall k \in \mathcal{K} \tag{FJM 5}$$

$$\sum_{m \in \mathcal{J}} \mathbb{1}_{\{d_{jm} \le r\}} y_m \ge y_j \quad \forall j \in \mathcal{J} \tag{FJM 6}$$

$$s_{ik} \ge 0 \quad \forall i \in \mathcal{I}, \forall k \in \mathcal{K} \tag{FJM 7}$$

$$y_j, x_i \in \{0, 1\} \quad \forall j \in \mathcal{J}, \forall i \in \mathcal{I} \tag{FJM 8}$$

The objective function FJM 1 and the constraints FJM 2, FJM 3, FJM 7, FJM 8 are identical to JM 1, JM 2, JM 3, JM 5, JM 6. Additionally, constraint JM 4 is split into two separate constraints. Thus, FJM 4 allows for the selection of a charging station only if it guarantees a connection between a warehouse and a demand point. As shown, condition FJM 6 exactly matches condition NSCLP 3 from model (B.2.3). Thus, this model addresses the problem observed earlier but introduces the drawback discussed in property B.2.2.

Now we have develop a model, we will code it, test it and evaluate it by making assuptions.

B.4 Numerical study and results

In this section, the focus is on evaluating the performance of model B.3.2. The model development itself, all else being equal, does not present significant difficulty as it remains unchanged and the structure is straightforward. However, creating a data file proves to be more complex. The study requires including:

- Between 5 and 10 candidate warehouses
- Between 30 and 40 candidate charging stations
- Approximately 30 demand points

Here is the contextual map of the different candidate locations for this study: B.4.1:

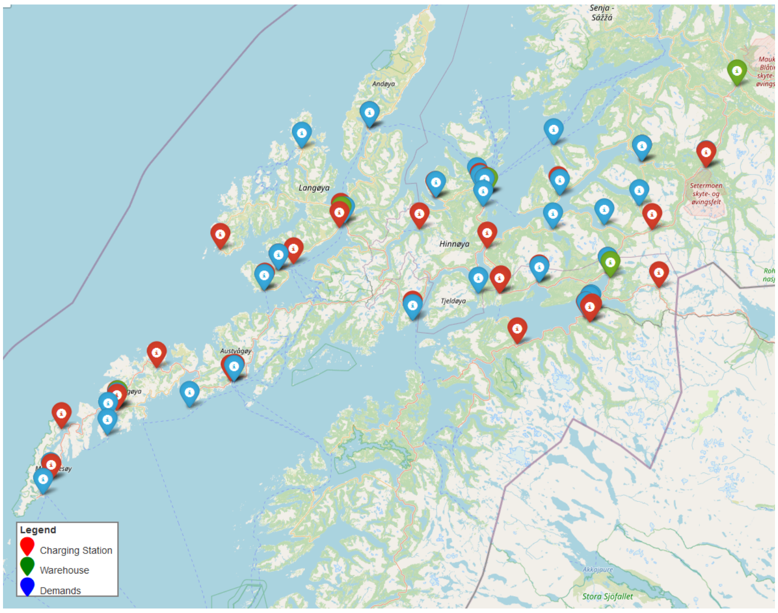


Figure B.4.1: Map with all candidate locations

However, the parameters include distance matrices that can reach dimensions of 40×30. It is also worth noting that adding, for example, an additional warehouse affects several other parameters (adding a new capacity, a new installation cost, adding shipping costs to all demand points, etc.). Therefore, manually modifying this file is not practical. This section focuses on automating the creation of the data file that can be interpreted by AMPL. The process for creating this data file is summarized in Figure B.4.2.

Once the data is collected from appropriate platforms, a query is made via the Bing API to obtain a distance matrix. After this, the matrices are transformed to be binary. Once this is done, the matrix is written in a format interpretable by AMPL. Finally, all other data is processed and consolidated into the final file called data.dat.

Once this file is created, it can be combined with the other two elements necessary for launching a model resolution in AMPL: the model (B) and the init.run script. The results are then retrieved from a text file and finally read and visualized. The entire process is detailed in Figure B.4.2.

We aim to understand the model's behavior as the coverage radius of the charging stations changes. Therefore, strong assumptions are made:

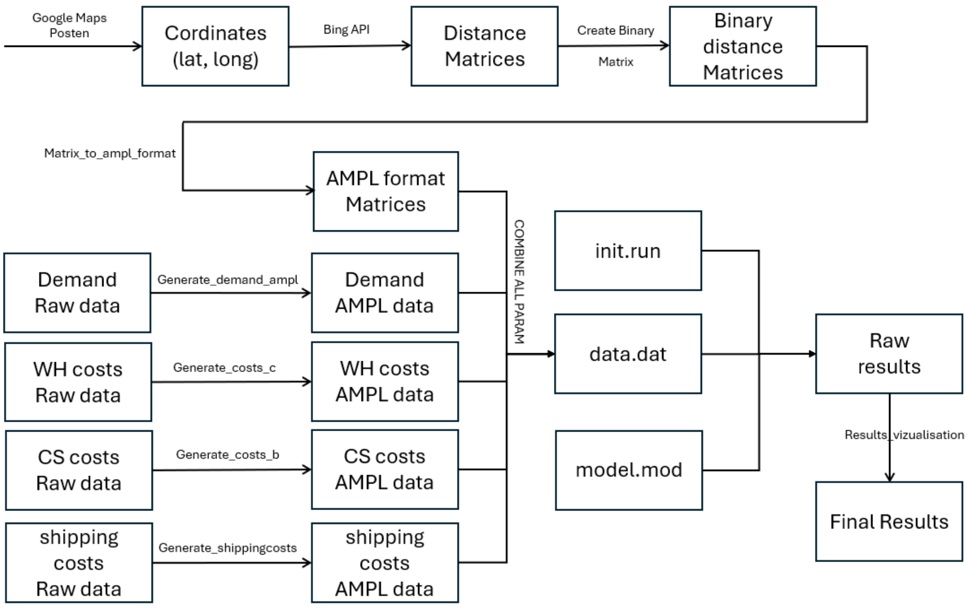


Figure B.4.2: Global Analysis Process

- All prices are considered equal to 1 (b_j, c_i, a_{ik})
- Each demand requires 10 units
- Each warehouse has a capacity of 100 units

Due to the non-realistic nature of most of the data, this experiment is classified as numerical rather than a real case study. To visualize the results, points are plotted on a map with high opacity, while the other points (not selected by the model) have lower opacity. The described process allows for a quick comparison of the different trials.

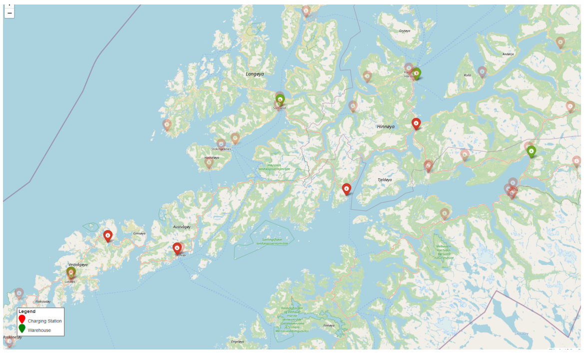
Here are the maps were selected infrastructures have been selected by the coded model in B.4.3

The results should be considered with the assumptions made about prices, demand quantities, and warehouse inventories. Given the current state, the only analysis we can conduct concerns the charging stations, as they only have a single variable, which is their price. Conversely, the placement of warehouses is influenced by their inventories, prices, and demand quantities.

In the small region studied, we observe that 4 warehouses are opened. This result is clearly unrealistic (as it is too large) and does not allow us to draw any conclusions regarding warehouse placement. Realistic data on warehouse capacities and an estimate of demand would be required to make preliminary conclusions about warehouse placement. However, as mentioned at the beginning of the paragraph, charging stations are only conditioned by their price (and their relative placement with respect to demand points and warehouses). Therefore, numerical observations can be made regarding the number of charging stations placed.

We observe several things in the graph B.4.4. First, it is reassuring to find a decreasing trend, which reflects the phenomenon that loading stations with low efficiency require a larger number of them. As this efficiency (range of action) increases, fewer intermediate loading stations are needed. It is also noted that this decrease is not strict and exhibits a plateau shape. For "short" action distances, more stations are indeed needed compared to when they have a "long" action distance.

(a) Joint Model result with $r = 90$



(b) Joint Model result with $r = 120$

(c) Joint Model result with $r = 150$

Figure B.4.3: Final results

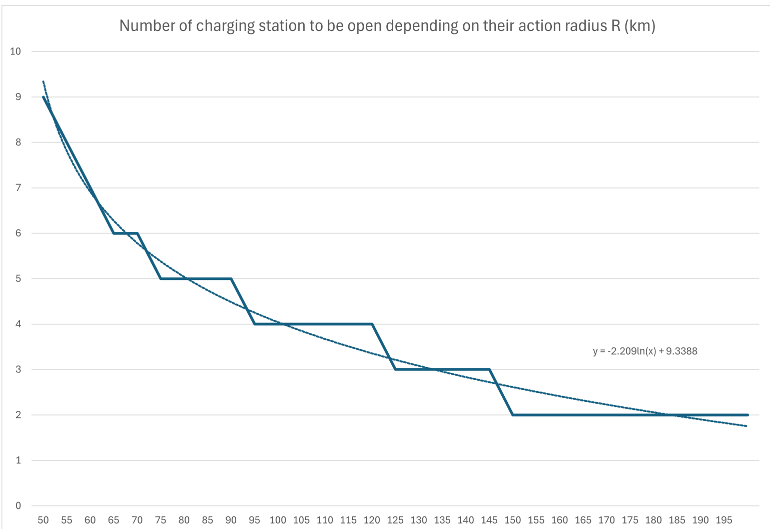


Figure B.4.4: Number of charging station to be open depending charging station action radius

CHAPTER C

Conclusion

This assessment will be divided into two parts. Given that this report accounts for an internship, the first part will be dedicated to a personal assessment. The second part will focus on evaluating the work completed.

In the strict context of production, the research conducted during this internship led to the development of literature reviews on supply chain design optimization and methods for solving covering problems. This knowledge provided a better understanding of their issues, implications, and outcomes. This foundation enabled the creation of a model capable of simultaneously placing warehouses and charging stations in such a way that the routes between warehouses and demands are feasible. This research topic is still in development, and the construction of this model will likely inspire future work. However, the model cannot be fully validated due to the assumptions made regarding prices. We are satisfied with the overall behavior of the model, which remains to be explored further.

From a more personal perspective, completing my internship at a university has partly clarified my professional project. Indeed, these five months confirmed my interest in research and learning. What I discovered, however, is my preference for public-interest topics that give societal meaning to a scientist's missions. Working on a research topic, especially one that is current, was a real source of motivation throughout the internship. The internship was carried out independently. The positive aspect of this is that I gained autonomy and initiative, but I regret not having had more social contact with other colleagues.

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Appendices

Appendices table

APPENDIX A

Sets and parameters

Parameters	Description
$\mathcal{I}$	Set of candidate warehouses $i \in \{1, \ldots, n\}$
$\mathcal{J}$	Set of candidate charging stations $j \in \{1, \ldots, N\}$
$\mathcal{K}$	Set of demand clusters $k \in \{1, \ldots, m\}$
$\mathcal{E}$	Set of factories $e \in \{1, \ldots, t\}$
$\mathcal{H}$	Set of suppliers $h \in \{1, \ldots, q\}$
f_e	Cost of setting up a factory ar location e
c_i	Cost of setting up a warehouse at location i
b_j	Cost of setting up a charging station at location j
d_k	Demand of customer k
K_i	Capacity of warehouse i
S_h	Supply capacity of supplier h
F_e	Capacity of factory e
$d_{i,j}$	Distance matrix between warehouse i and charging station j
$d_{j,k}$	Distance matrix between charging station j and demand cluster k
r	Action radius around a charging station (in km)
a_{ik}	Shipping price of one unit from warehouse i to charging station j
a_{he}	Shipping price of one unit from supplier h to factory e
a_{ei}	Shipping price of one unit from factory e to warehouse i
p	Number of charging station to be located

Table A.0.1: Model parameters

APPENDIX B

Final Joint Model

```
# Define sets
set WH;  # Set of candidate warehouses
set CS;  # Set of candidate charging stations
set DE;  # Set of demand clusters

# Define parameters
param a1{WH, CS} binary;          # CS is in the range of WH
param a2{CS, DE} binary;          # DE is in range of CS
param a3{CS, CS} binary;          # CS is in range of another CS
param dk{DE} >= 0;                # Demand at cluster k
param a_ik{WH, DE} >= 0;          # Cost to ship from WH to DE
param c{WH} >= 0;                 # Cost of setting up a warehouse
param b{CS} >= 0;                 # Cost of setting up a charging station
param K{WH} >= 0;                 # WH capacity

# Define decision variables
var x{WH} binary;
var y{CS} binary;
var s{WH, DE} >= 0;

# Define objective function
minimize Cost: sum {i in WH} c[i] * x[i] + sum {j in CS} b[j] * y[j] +
sum {i in WH, k in DE} a_ik[i,k] * s[i,k];

subject to WhCapacity {i in WH}:
sum {k in DE} s[i,k] <= K[i] * x[i];

subject to DemandMeeting {k in DE}:
sum {i in WH} s[i,k] = dk[k];

subject to FeasibleTrip_WH_CS {i in WH}:
sum {j in CS} a1[i,j] * y[j] >= x[i];

subject to FeasibleTrip_CS_DE {k in DE}:
sum {j in CS} a2[j,k] * y[j] >= 1;

subject to FeasibleTrip_CS_CS {j in CS}:
sum {j_prime in CS: j_prime != j} a3[j,j_prime] * y[j_prime] >= y[j];
```

APPENDIX C

Numerical map results

Figure C.0.1: Joint Model result with $r = 90$

Figure C.0.2: Joint Model result with $r = 120$

Figure C.0.3: Joint Model result with $r = 130$