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Sustainable Logistics

Amazon warehouse location problem in Switzerland

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Executive summary

This project explores how many warehouses Amazon should build in Switzerland and where they should be located. An optimization model finds the optimal location in terms of the total costs of shipping packages to customers in 17 of the largest cities in the country. With our assumptions, the optimal result is Lausanne, Lucerne and Zürich. The project also examines where in Zürich a warehouse can be located using a model that can be easily tweaked to fit other cities.

Considered situation and set-up

Introduction

Amazon is one of the world's biggest corporations, with a market capitalization of 1.4 Trillion USD and a yearly revenue exceeding 469 Billion USD. The company ships to over 100 countries and has operational fulfillment centers in 13 of its largest consumer bases.

However, Amazon does not have any warehouses in Switzerland as of yet. In the past, this has been due to high government taxes on shipment and deliveries within Switzerland. However, Switzerland is a massive opportunity market for Amazon. Switzerland possesses one of the world's wealthiest populations with a high GDP per capita of 86K USD. 86.7% of the population has internet access, and online sales are expected to reach €18.16 Billion in 2022. This value has increased from €3.6 Billion in 2013 - a CAGR of 16%. The expected growth in the future is estimated to be the same as Switzerland's e-commerce market, which is set to grow by 18% per year. While Amazon enjoys a healthy market share of over 50% in North America, in Switzerland, its share is limited to 8% [1]. In order to tap into this wealthy market, locally shipped goods are paramount. Almost 90% of the total e-commerce transactions are local. [2].

Currently, shipments to satisfy Switzerland's large e-commerce demand are sent from the UK, France, Germany and Italy. However, this isn't economically and environmentally efficient for multiple reasons. Since Brexit, more taxes are levied on imports from the UK, making some deliveries prohibitively expensive; shipping from Italy and France incurs large freight costs that could be avoided by having warehouses within Switzerland. Moreover, the environmental costs of transporting approximately a billion packages from other countries are unconscionable.

In light of this situation, we propose that Amazon open a few warehouses within Switzerland to reduce their environmental footprint as well as improve their cost structure. While the initial outlay of approximately 15M USD is a steep cost, the overall benefits of reduced freight cost and reduced environmental cost will make up for this outlay over the next few years. By doing so, the consumer will benefit from reduced shipping costs. Amazon will save freight costs and increase its profitability per package delivered. Europe as a whole will benefit from reduced emissions due to transportation.

The Problem

The key questions to be answered in this project are: how many warehouses to build and where to build them. The objective will be to ensure that all demand nodes are serviced adequately while minimizing cost. The lowest number of warehouses will need to be built and travel distances will need to be minimized to minimize cost. By building warehouses within the country itself, Amazon will reduce emissions that come from transporting goods from Germany, France and Italy into Switzerland. Also, they will minimize last-mile emissions that come from third-party logistics, which have to ship the packages from other countries to their depots in Switzerland. Then from the depots to local city depots and finally to the last mile. In short, the optimal location of facilities will make Amazon's operations in Switzerland more environmentally and economically efficient.

The project also investigates where in Zürich, Switzerland's largest city in terms of population, a warehouse should be built to minimize the transport cost to its residents as a supplement to the main problem. The same steps can also be used to find the optimal location in the other cities but were not done in this project due to time constraints. In the rest of the report, this part of the project is referred to as the *Zürich Location Problem*.

Data description

The proposed model requires the following input sources in order to be built:

1. List of nodes (i.e. cities)
2. Distances between the nodes
3. Demand at each node
4. Potential locations for the warehouse

The cities were handpicked for the Switzerland Location Problem after considering their geospatial location within the country and their population. Demand was approximated based on the total number of packages shipped by Swiss Post, the market share of Amazon in Switzerland and the population in each of the cities under consideration. Population data for each of the 17 cities was gathered from the following data source: [3]. The data in which we used for the distances between the 17 cities is based upon the numbers found here [4]. We expanded this table, adding missing data between some of the cities. It can be found in our attached zip-file with the name; dist.csv.

Below, you can find a figure representing the selected cities' map. They are numbered in the same order as in [4], starting with Zürich as the first and ending with Montreux. All the red nodes, or cities, represent demand nodes and cities considered suitable places for fulfillment centers. In other words, all cities are considered as possible warehouse locations.

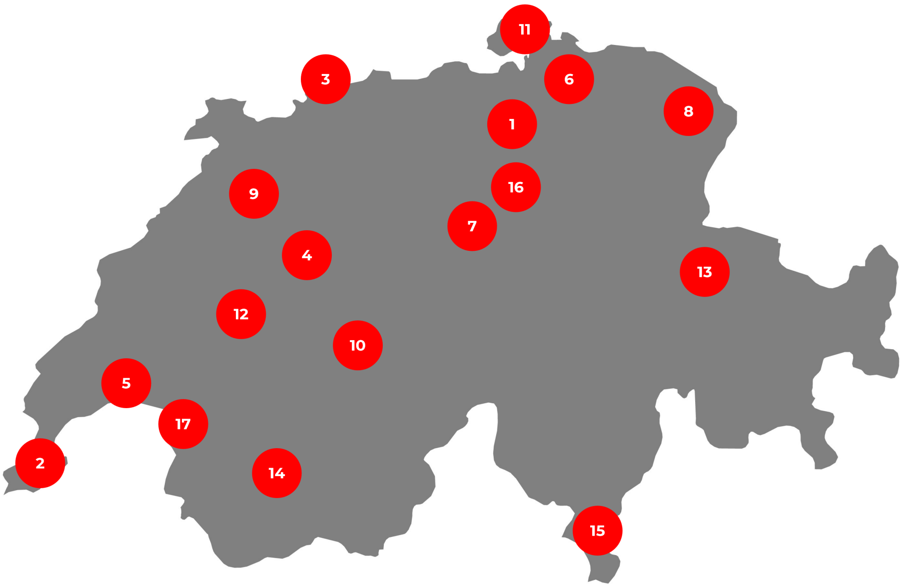

Figure 1: Map of Switzerland and selected cities

For the Zürich Location Problem, we gathered the population data for each postal code from here [5]. The population was used as demand in the optimization model. Further, the longitude and latitude of each postal code were collected from here [6]. Using the python library geopy, we calculated the distance between each pair of postal codes.

Mathematical modelling

The following section gives a mathematical formulation of both optimization problems explained above. That is a formulation of the objective function that our program is going to minimize and the variables involved in the model. Finally, the set of constraints that the model needs to consider is displayed.

Mathematical model of the Switzerland Location Problem

Minimize:

$$\sum_{i \in A} \sum_{j \in A} c_{ij} \cdot d_{ij} \cdot transportCost + \sum_{i \in A} x1_i \cdot smallCost + x2_i \cdot bigCost$$

Decision Variables:

$$c_{ij},\ i \in \{1, ..., n\},\ j \in \{1, ..., m\} \text{ (capacity served from } i \text{ to } j\text{)}$$
$$x1_i \in \{0, 1\} \text{ (whether city } i \text{ has a small warehouse)}$$
$$x2_i \in \{0, 1\} \text{ (whether city } i \text{ has a large warehouse)}$$

Constraints:

$$\sum_{i \in A} c_{ij} \geq h_j, j \in \{1, \dots, a\}$$
$$\sum_{j \in A} c_{ij} \leq x1_i \cdot smallCapacity + x2_i \cdot bigCapacity, i \in \{1, \dots, a\}$$
$$c_{ij} \geq 0, i \in \{1, \dots, a\} j \in \{1, \dots, a\}$$
$$x1_i + x2_i \leq 1, i \in \{1, \dots, a\}$$

Parameters:

d_{ij}, $i \in \{1, ..., n\}$, $j \in \{1, ..., m\}$ (distance between i and j)
$smallCost, bigCost \in \mathbb{R}^+$ (cost of a small and a large warehouse)
$smallCapacity, bigCapacity \in \mathbb{R}^+$ (capacity of a small and a large warehouse)
h_i, $i \in \{1, ..., n\}$ (demand at i)
$transportCost \in \mathbb{R}^+$ (cost of transporting 1 capacity 1 kilometre)
$A =$ set of all a cities

Mathematical model for the Zürich Location Problem

Minimize:

$$\sum_{i \in A} \sum_{j \in A} c_{ij} \cdot d_{ij} \cdot transportCost + \sum_{i \in A} x_i \cdot warehouseCost$$

Decision variables:

c_{ij}, $i \in \{1, ..., n\}$, $j \in \{1, ..., m\}$ (capacity served from i to j)
$x_i \in \{0, 1\}$ (whether postcode i has a warehouse)

Constraints:

$$\sum_{i \in A} c_{ij} \geq h_j, j \in \{1, \dots, a\}$$
$$\sum_{j \in A} c_{ij} \leq x_i \cdot warehouseCapacity, i \in \{1, \dots, a\}$$
$$c_{ij} \geq 0, i \in \{1, \dots, a\} j \in \{1, \dots, a\}$$

Parameters:

d_{ij}, $i \in \{1, ..., n\}$, $j \in \{1, ..., m\}$ (distance between i and j)
$warehouseCost \in \mathbb{R}^+$ (cost of a warehouse)
$warehouseCapacity \in \mathbb{R}^+$ (capacity of a warehouse)
h_i, $i \in \{1, ..., n\}$ (demand at i)
$transportCost \in \mathbb{R}^+$ (cost of transporting 1 capacity 1 kilometre)
$A =$ set of all a postal codes

Assumptions in the models above

Availability of data is a concern, therefore we will rely on a number of assumptions:

- The number of packages delivered to each city (node) will be proportional to the city's population

- The costs per kilometre of shipping will be fixed across all cities.
- Shipments are going to be sent from the warehouse to the city centre rather than any particular location.

Both models are simplifications of the real-world problem.

For both of the Facility Location Problems, we have assumed a predefined cost of building each warehouse and a predefined capacity of each warehouse.

For the Facility Location Problem considering the entirety of Switzerland, the model assumes a predefined cost for transportation. Although this cost might vary depending on the infrastructure, etc., and thereby supply for different routes. This is also true for the FLP within Zürich. However, these costs are likely to be more similar than for the entirety of Switzerland.

For the Zürich Location Problem, the distances between each postal code are calculated as a straight line between the center of each postal code. Also, each postal code has the same warehouse price, regardless of whether the warehouse is located in the city center or on the outskirts.

Implementation

The data we used, described in the data section, was converted into pandas dataframes, then some data preprocessing was added to get the data in the format we wanted before we sent it into the model. We used Google OR-tools to solve the optimization problems modeled in the previous section.

For the Switzerland Facility Location Problem we used the following parameters as a baseline and tested the sensitivity around them:

Warehouse sizes were chosen at 100000 and 250000 square feet to aim at 3 to 6 warehouses for Switzerland. This assumption is based on the total population in relation to other European countries with Amazon warehouses [7]. The sizes were also relatively small [8] as we modeled them being in the cities. The costs of the warehouses were set at 10 million and 25 million Euros. The currency was not considered in depth as the Euro, Dollar and CHF are all similarly priced now. This corresponds to 100 € per square foot, which we got from other warehouse prices being about 60 € per square feet [8] then multiplying by 33% for the higher construction costs [9] in Switzerland and rounding up as they are located in the cities. We assumed a warehouse needed 1 square feet per person served based on Amazon warehouse sizes in the USA per capita [10]. We used a market share of 20% based on the warehouses' need to be able to fulfill increased market share from their current 8% [1]. As the transportation cost would not be a fixed cost, we would need to account for a time frame to get a cost estimate. We chose 15 years as technology could change how Amazon operates its warehouses in the future, yet we have to assume they will be used for some time too. We chose a turnover of inventory to be 40 a year [11]. The capacity of a truck was chosen as 400 sq feet [12]. We did not consider volume but used the surface area for both trucks and warehouses as parcels could be any shape. The km. cost was set to 8 based on a conversion from 5 per mile based on Cass Inferred Freight Rates [13] and Swiss expensiveness. Transport cost is a combined cost parameter made of square feet per person, market share, time frame, turnover, truck capacity and kilometer cost.

$$transportCost = int(\frac{turnover \cdot timeFrame \cdot sqFeetPerPerson}{truckCapacity \cdot kmCost}) = 2$$

Results

We will present the results for the two different problems accordingly.

Switzerland Location Problem

Input parameter	Value
warehouseCost	[10000000,25000000]
warehouseCapacity	[100000,250000]
transportCost	2

Table 1: Input parameters and its values used to obtain the result

According to our model with the decision variables described previously, the optimal or best solution is to locate the warehouses in Lausanne, Lucerne and Zürich.

Graphical representation

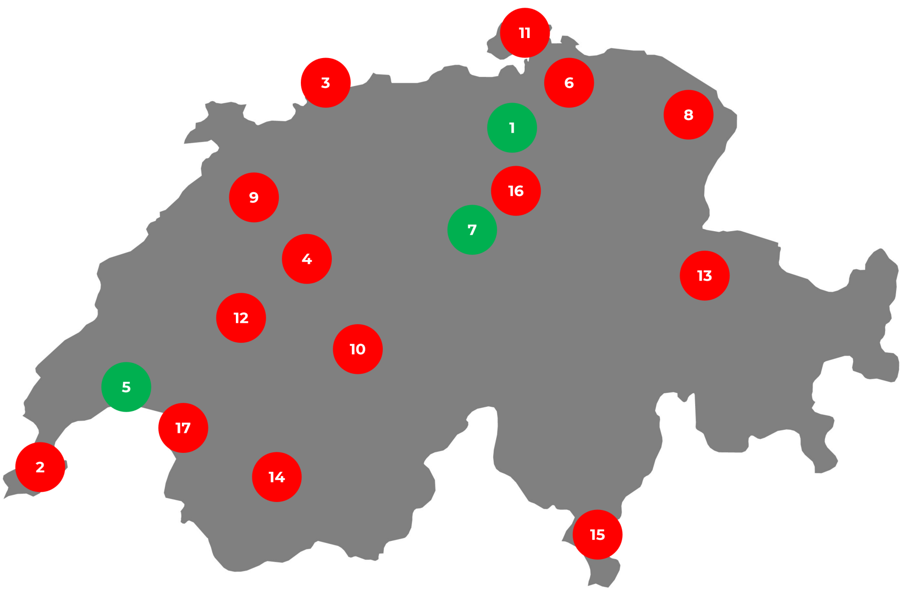

Figure 2: The optimal location for the warehouses in Switzerland

Zürich Location Problem

Input parameter	Value
warehouseCost	25000000
warehouseCapacity	250000
transportCost	2

Table 2: Input parameters and its values used to obtain the result

According to our model the best solution is to locate the warehouse in postal code 8005. From the figure below we can see that this is in the center of the city, which makes sense and is therefore quite a reasonable result.

Graphical representation

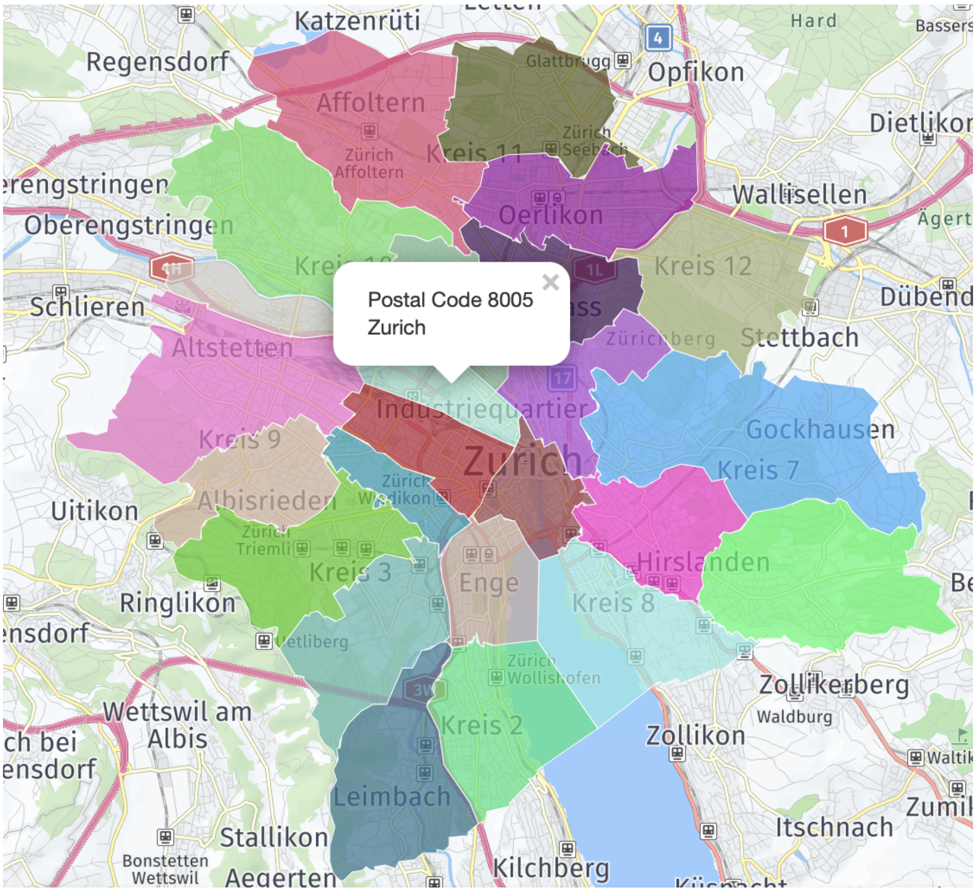

Figure 3: The optimal location for the warehouse in Zürich

Sensitivity analysis

The input parameters considered in the sensitivity analysis are market share percentage, cost per kilometer and warehouse cost for both types of warehouses. One variable was varied to conduct the sensitivity analysis while the rest were kept constant, and the solution space generated was analyzed. In terms of impact on cost, generally all three had a direct relationship. An increase in Amazon's market share percentage meant greater demand for their products and thus, more warehouses were required. The same could be said of cost per kilometer and warehouse cost. Predictably, an increase in either variable meant an increase in total costs. This can be shown in the figures below:

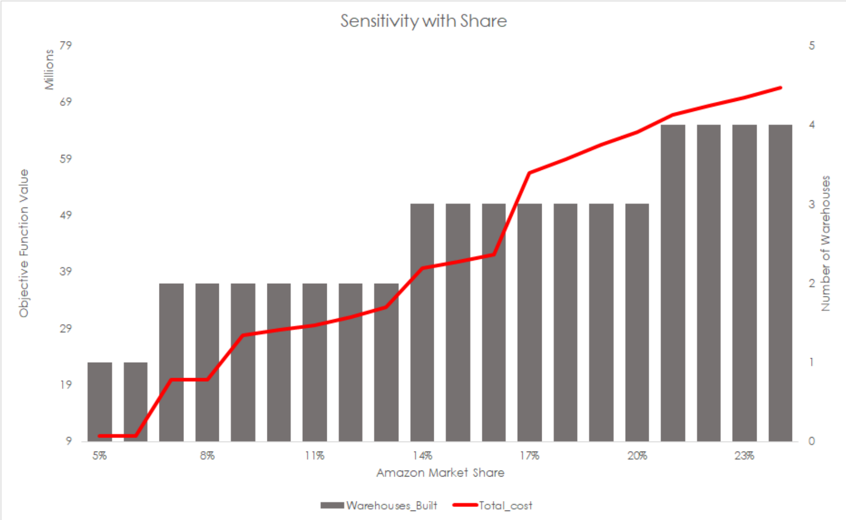

Figure 4: Number of warehouses and Total Cost by Market Share

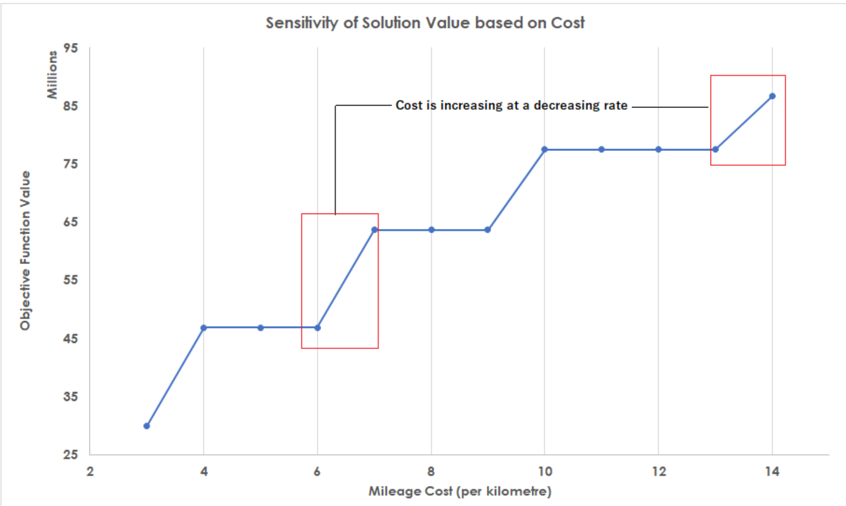

Figure 5: The correlation between Cost Per km and Total Costs

However, there is a clear notable difference in cost impact between the three variables. Increases in cost per kilometer and warehouse cost did not impact the solution space much, i.e., warehouses were still built in the same locations. Except for very low per-kilometer costs, three warehouses were built. Zürich, Lausanne and Lucerne were constants. However, after increasing the kilometer cost to more than €10, 5 warehouses were built in Basel, Bern, Geneva, replacing Lausanne and Lucerne. At high costs, it's more economically and environmentally efficient to be located closer to the population centers. Also notable is that the total costs do not increase linearly but at a decreasing rate. Thus, a rise in mileage costs should not be of much concern regarding where warehouses are built unless it is forecasted that they will be greater than €10. Further details regarding this can be found in the Appendix. Similarly, warehouse costs were varied between 5 million and 15 million for the smaller warehouse and 15 Million to 37.5 Million for the larger warehouse. Zürich was chosen as a warehouse location at all costs. However, Lausanne and Lucerne are only viable if the costs are greater than 10 Million and 25 Million per warehouse-size, respectively.

The objective function displays the highest sensitivity to the market share parameter. Shares (a proxy for total demand) were varied between 5% of total e-commerce market to 25%. The results are summarized in Appendix 5.

Interestingly, Zürich is not a viable warehouse location for a market share percentage below 8% despite having the largest population in the country. Instead, the cost was optimized if warehouses were built at Biel and Bern. However, at share percentages greater than 8%, Zürich becomes an optimal location. A similar threshold exists for Winterthur where shares below 21% make the location cost-inefficient. Zürich was also often co-supplied by neighboring warehouses depending on market share and the other parameters.

However, the sensitivity analysis indicated that some locations were not optimal for building a warehouse under any circumstances. In all of the iterations, no warehouse was built at Sion, Schaffhausen, Thun, Lugano, St Gallen, Chur, Fribourg and Montreux. This indicates that these locations should probably not be in the consideration set for warehouses. Basel is only cost-efficient in a small range of share-percentage (18-20%). Meanwhile, Bern and Lausanne's optimality behaves in a sinusoidal manner. There are certain share percentages above and below which they become less than optimal. In our model, we assumed that the share percentage at which Amazon will enter is 20%. Our optimal solution reflects this by choosing Lausanne as an optimal warehouse location. However, the sensitivity analysis shows that this is probably not optimal. As Amazon grows, Lausanne will become a more costly location because of the distances involved to meet the demand in other cities. In short, this solution can become quickly unsustainable.

Managerial insights and recommendations

This study has endeavoured to show the benefits of opening warehouses within Switzerland for Amazon to cater to its demand specifically. As aforementioned, the demand is currently being serviced by shipments from the UK, France, Italy and Germany. In a world where sustainability and environmental concerns are becoming increasingly important, not only the image but also the financial well-being of a company, such excessive transportation may become untenable. As an increasing number of governments create measures to combat emissions, the cost of shipments from other countries will become prohibitively expensive. Therefore, it will be worthwhile to act before costs become a concern.

Our model shows that three warehouses will be sufficient to cater to the current demand. The ideal locations for Amazon to open warehouses to cater to its current demand are Lausanne, Lucerne and Zürich.

However, as the sensitivity analysis has shown, this solution is very vulnerable to changes in demand and the market share that Amazon will enjoy. At the current level of demand (8%), it does not make sense for Amazon to open Warehouses in Geneva and Zürich, for example. However, relying on the current level of market share percentage and modelling the solution based on that will lead to problems in the long run as the locations currently envisioned become less than optimal. It is important that demand managers at the company have an accurate forecast of the potential demand and share percentage when Amazon enters the market locally. It is also important to note that the demand for Amazon's services will increase once the local population realises that they are no longer subject to high shipping fees. In terms of other variables such as warehouse costs and mileage costs, the objective solution's value is less sensitive and these can be considered as secondary parameters to consider once the demand and share percentage has been accurately estimated.

In fact, it would be optimal if Amazon decided on their desired shared percentage in Switzerland and then built the warehouses accordingly rather than focusing on what their current demand/share level or their point-of-market entry share level would be. This is an important consideration to make before building warehouses at any of these locations. Zürich is the only mainstay in all of the solutions owing to its high population. Therefore, if work has to begin, it should start with Zürich and focusing on fulfilling demand around the Zürich canton. Managers can rest easy that this location will never become unsustainable.

Limitations and Future Research

Despite the solution space and sensitivity analysis showing promising results for servicing the demand in Switzerland, the model is based on a few major assumptions and hence has the following limitations:

- The model is based on yearly demand patterns. Demand patterns within the year may make the solution less than optimal. This is somewhat mitigated by considering the sensitivity analysis which indicates that there are clear thresholds after which the solution changes.
- Actual demand may not be correlated with population. Wealthier areas and areas with a younger population will naturally have a higher purchase rate at e-commerce stores.
- Warehouse costs may vary from city to city.
- Warehouse capacity depends on availability and what Amazon could build which is not binary as considered in the model.
- Only some of the largest cities in Switzerland were considered. It is entirely possible that more rural locations are more cost-efficient.

There are other computational constraints within the model as well. For example, it is impossible to know the exact locations for parcel delivery within a city. While the model optimizes for the actual road-distance from each city, it is unlikely that the depots or service points are located within the city centre. A lot of mileage cost are incurred not during long-haul travel but within city limits. This not only adds more cost but also increases emissions. The model also assumes that last-mile delivery will remain the same as it is now.

The model also uses integer values for all numbers, this results in rounding of transport costs for example which is why the costs increased in steps in the transport cost sensitivity analysis.

Planning the construction of a facility is a dynamic process as variables tend to change frequently. Neither real-estate prices nor local fuel prices display stability in the medium-term. Moreover, as the model has shown, variations in these input parameters can have different solution sets. Therefore, before deciding to enter the market locally, it is imperative that these variables are forecasted. Future research on the subject can consider a wider set of locations for warehouse building and incorporate truck-fleet capacity constraints to better understand how to make market entry more sustainable for the world's biggest e-commerce company.

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Appendices

Tables used in sensitivity analysis

The tables below display where warehouses are located when different input parameters are changed. The other input parameters are the same as in 1. Notice that km_cost is not the same as transport_cost, transport_cost of 2 corresponds to a km_cost of 8. See the attached code for further explanation. Due to space limitations, cities where warehouses never occur were removed from the tables used in the report. The tables containing all cities can be found in the attached zip file.

Warehouse_cost	Total_cost	Warehouses_Built	Basel	Bern	Geneva	Lausanne	Lucerne	Winterthur	Zürich
[5000000, 15000000]	43313072	5	1	1	1	0	0	1	1
[10000000, 25000000]	63657930	3	0	0	0	1	1	0	1
[15000000, 37500000]	78657930	3	0	0	0	1	1	0	1

Table 3: Change in the warehouse cost

Km_cost	Total_cost	Warehouses_Built	Basel	Bern	Geneva	Lausanne	Lucerne	Sion	Winterthur	Zug	Zürich
3	30000000	3	0	0	0	0	0	1	0	1	1
4	46828965	3	0	0	0	1	1	0	0	0	1
5	46828965	3	0	0	0	1	1	0	0	0	1
6	46828965	3	0	0	0	1	1	0	0	0	1
7	63657930	3	0	0	0	1	1	0	0	0	1
8	63657930	3	0	0	0	1	1	0	0	0	1
9	63657930	3	0	0	0	1	1	0	0	0	1
10	77469608	5	1	1	1	0	0	0	1	0	1
11	77469608	5	1	1	1	0	0	0	1	0	1
12	77469608	5	1	1	1	0	0	0	1	0	1
13	77469608	5	1	1	1	0	0	0	1	0	1
14	86626144	5	1	1	1	0	0	0	1	0	1

Table 4: Change in km cost

Share	Total_cost	Warehouses_Built	Basel	Bern	Biel	Geneva	Lausanne	Lucerne	Winterthur	Zürich
0.05	10000000	1	0	1	0	0	0	0	0	0
0.06	10000000	1	0	1	0	0	0	0	0	0
0.07	20000000	2	0	1	1	0	0	0	0	0
0.08	20000000	2	0	1	1	0	0	0	0	0
0.09	27835047	2	0	0	0	0	1	0	0	1
0.1	28705769	2	0	0	0	0	1	0	0	1
0.11	29576300	2	0	0	0	0	1	0	0	1
0.12	30999181	2	0	0	0	0	1	0	0	1
0.13	32766102	2	0	0	0	0	1	0	0	1
0.14	39614731	3	0	1	0	1	0	0	0	1
0.15	40763855	3	0	1	0	1	0	0	0	1
0.16	41998061	3	0	1	0	1	0	0	0	1
0.17	56527040	3	1	0	0	0	1	0	0	1
0.18	58978308	3	1	0	0	0	1	0	0	1
0.19	61428978	3	0	0	0	0	1	1	0	1
0.2	63657930	3	0	0	0	0	1	1	0	1
0.21	66811454	4	0	1	0	1	0	0	1	1
0.22	68335960	4	0	1	0	1	0	0	1	1
0.23	69890186	4	0	1	0	1	0	0	1	1
0.24	71511246	4	0	1	0	1	0	0	1	1

Table 5: Change in share