Network design for mid-day meal program

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Summary: Akshaya Patra (an NGO) faced the challenge of fulfilling the growing demand of mid-day meals within short delivery windows while keeping the transportation costs and the fixed costs of the centralized kitchens low. The mid-day meal program is an initiative by the government of India to provide food to public school children. Keeping in mind that food is a highly perishable item and has a very short delivery window (four hours), we designed a network of centralized kitchens for Akshaya Patra to serve mid-day meals in Uttar Pradesh, the most populous state in India. We used a Mixed Integer Linear Programming to design a network and tested various scenarios such as cross docking and the use of insulated containers. Our recommended network of centralized kitchens would help Akshaya Patra in fulfilling the total demand of mid-day meals at lowest possible cost. The model can be replicated in other states by using state specific data and can also be used by other businesses also constrained by a short delivery window.

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KEY INSIGHTS

1. The major constraint in case of perishable items like food is the short delivery window (four hours in this project) and it has huge impact on transportation cost and fixed cost
2. High variation in number of opened centralized kitchens when fixed cost spread over one year (10-38 kitchens) or five years (42-59 kitchens)
3. Cross docking helps in reduction of transportation cost

Introduction

In partnership with the Government of India and the state governments, Akshaya Patra provides mid-day meals to government schools and government-aided schools. The motivation behind this cause is two-fold. First is to reduce the number of dropouts in the government schools. Children from poor financial backgrounds often work earn money to feed themselves and their families rather than going to school. Second is to fight against malnutrition, which affects children's mental and physical growth and causes poor academic performance.

Akshaya Patra is serving meals to around 1.6 million children every day in 12 states with 26 centralized and two decentralized kitchens and has two reasons to consider the design of kitchen network.

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First, if the state government provides the opportunity to serve all the government schools of UP state, then Akshaya Patra must create an optimal network to serve the children. Second, as demand for meals increases in current serving locations, Akshaya Patra has to investigate various kitchen options to fulfill the growing needs. A huge cost, minimum 10 million INR (Indian Rupee), is involved in the setup of a centralized kitchen. If the kitchen network design of Akshaya Patra is not optimal, then it will have high impact on transportation costs, cost of meal per plate, and the quality of food (fresh food should reach to schools within four hours of cooking otherwise food will get spoiled).

Methodology Overview

The objective of this project is to design a network of centralized kitchens to serve meals to maximum number of children with the lowest possible cost. Geographic scope of this project is limited to UP state in India. Input data included daily demand of meals, centralized kitchens capacities, cross docking, transportation details, and truck sizes. Our model incorporated input data, parameters, decision variables, assumptions, cost components, and constraints. For optimization we used a Mixed Integer Linear Programing (MILP) method and Gurobi (mathematical programing solver) with Python for modeling a MILP to design a kitchen network.

Network design in various scenarios

Scenario 1 is 'network design without capacity constraint'. The model considered a network where food is directly delivered from centralized kitchens to schools in mid-size trucks. We did not include the kitchens' capacity constraint here to explore the option of 'Super Kitchens' or 'Mega Kitchens' with a high capacity. The total number of opened kitchens in this scenario is 10.

Scenario 2 is 'network design with capacity constraint'. We added a capacity constraint to the centralized kitchens. This setting is more realistic and matches the current operational situation of Akshaya Patra. The total number of kitchens opened in this scenario is 37.

Scenario 3 is 'network design with insulated containers'. By using this scenario, we tested the impact of delivery time window on our network configuration while keeping the other variables constant. We included the insulated containers in our model in addition to the cooking capacity and delivery time window constraints. 36 kitchens are opened in this scenario.

Scenario 4 is 'network design considering currently opened kitchens'. We considered the centralized kitchens already opened in UP state. At present, Akshaya Patra has kitchens in Vrindavan and Lucknow. The total number of kitchens opened in this scenario is 37.

Scenario 5 is Network design with cross docking and capacity constraint". Cross docking helped in reducing the transportation costs. However, it also reduced the delivery time window by half an hour (time needed to cross dock). 38 kitchens and 65 cross docking sites are opened in this scenario.

Scenario 6 is 'network design with cross docking and insulated containers'. In addition to all the constraints, we added insulated containers with cross docking. The total numbers of opened kitchens and cross docking sites are 37 and 64 respectively.

Five years cost analysis when fixed cost is spread over first year or five years

We analyzed the costs of different scenarios while keeping the fixed cost spread over one year. In this set up, model opened 10-38 kitchens to keep the fixed cost lower and fulfilled the total demand. Whereas, when we spread the fixed cost over five years, model opened a high number of kitchens (42-59 kitchens) to keep the transportation costs low. This shows the tradeoff between fixed cost and transportation cost. In both the set ups, network design with cross docking and insulated containers (scenario 6) has lowest total costs.

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Table 1: Five year cost analysis

Network designs scenarios	Five year cost analysis (in INR)			
	Total cost when fixed cost spread over 1st year	Kitchens opened	Total cost when fixed cost spread over 5 years	Kitchens opened
Without capacity constraint	7,183,297,000	10	3,500,232,250	58
With capacity constraint	4,060,911,250	37	3,685,030,250	59
With insulated containers	5,524,380,000	36	3,684,942,500	59
With Cross docking and capacity constraint	3,720,930,500	38	3,580,833,010	42
With Cross docking and insulated containers	3,478,717,000	37	3,442,977,860	42

Tradeoff between fixed cost and transportation cost

Opening more number of centralized kitchens leads into high fixed cost. We can notice in the figure 2 that when number of opened centralized kitchens are high then transportation cost is low. For instance, scenario 1 opened only 10 kitchens leading to lowest fixed cost and hence has highest transportation cost. Whereas in other scenarios, the number of opened kitchens are between 37 to 38 and transportation cost varied accordingly. The closer kitchens are to schools the lesser transportation cost Akshaya Patra will incur.

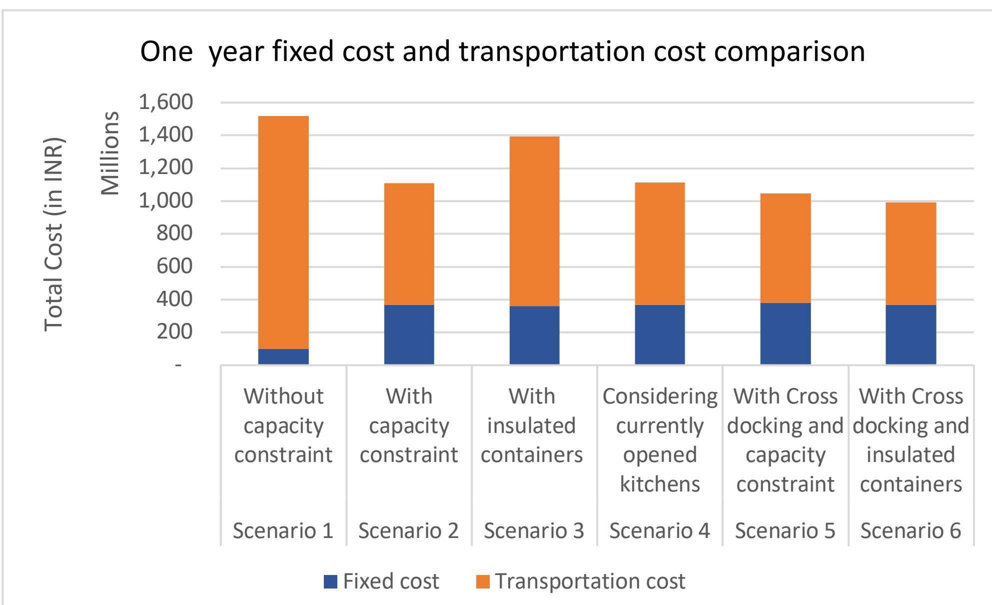

Figure 1: Tradeoff between fixed cost and transportation cost

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Utilization of trucks

We checked the utilization of the mid-size delivery trucks (900 kg capacity). If a truck carries less than a full truck load, then it will have some slack capacity.

Figure 2 shows the number of trucks required by block. Approximately 190 blocks require less than a full truckload. Median of number of trucks used by blocks is three. Further, we also analyzed that Akshaya Patra will need around 2927 mid-size trucks to make deliveries, if it does not share trucks between blocks. Out of the total number of required trucks, 63.4% (1902 trucks) are fully utilized and 36% trucks are underutilized. To mitigate the risk of underutilization of trucks 'routing optimization software' can be used.

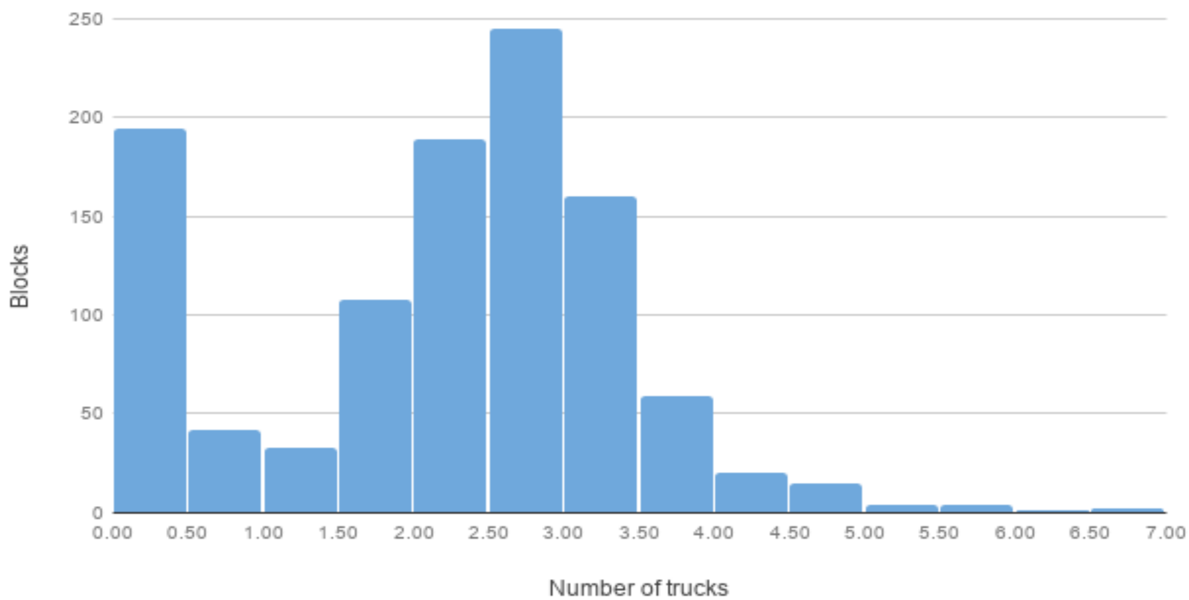

Figure 2: Histogram of number of trucks required by blocks

Conclusion

From our analysis, we found that investing in insulated containers (increasing the food serving time limit from four to six hours) along with consolidated deliveries within cities provides the most attractive solution. It satisfies all the constraints and gives lowest network cost where fixed cost of 37 centralized kitchens is spread over one year. It saves 116 million INR when compared to the current operational style of Akshaya Patra (scenario 2). Insulated containers used in scenario 6 also serves the purpose of sponsor company in keeping the food hot, fresh, and nutritional food for longer period of time.

Further, the methodology and model can be replicated by Akshaya Patra in other states of India to serve meals by just changing the data in the model. Other similar businesses where perishability of product is high (maximum life is one day) such as other food serving NGOs or restaurant chains can use a similar model to design a supply chain network for their business.