MIP formulations for perishable fresh foods transportation

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ABSTRACT. This paper uses a mixed-integer programming model to solve the distribution problem of perishable food shipments from factories to warehouse and then to destinations. This model focus on adding a limit time which goods can be remained in the warehouse and ignores the transportation cost between factories and warehouse and the cost of warehouse's management. The result shows nearly 62% of the goods should be sent by full-truckload because the full-truckload can load more and cost less. What's more, the sensitivity analysis further discusses the influence of factory number on total transportation cost.

Keywords: Assignment Problem, Mixed-Integer Programming Model (MIP), Logistics Transportation, FICO Xpress

1 INTRODUCTION

The COVID-19 epidemic has been going on for three years, and the mutation and repetition of the epidemic has brought great uncertainty to the economies of all countries in the world. Also, the recurrence of the epidemic has had a huge impact on the entire logistics system. A large number of cities have experienced periods of lockdown. Offline brick-and-mortar stores have stagnated during the lockdown period. In this process, residents' daily material needs are all transferred to online e-commerce channels, especially fresh food such as vegetables and meat, which puts forward higher requirements for the rationality of the whole transportation and distribution system. The main purpose of logistics distribution is to ensure that products are delivered on time and in good condition, which will help you ensure that your customers receive their orders on time so that they can meet their deadlines. In addition, it helps reduce costs because there will be less handling by humans at each stage of the process. In recent years, the growing impact of logistics on China's economy. The total scale of logistics in china between 2015 and 2020 are shown on Table 1.

Table 1. The Total Scale of Logistics in China between 2015 and 2020

YEAR	The Total Scale of Logistics(billion)

V. Escudero et al. (Eds.): BADS 2022, AHCS 11, pp. 233–243, 2023.
https://doi.org/10.2991/978-94-6463-102-9_27

2015	109000
2016	111000
2017	121000
2018	133000
2019	146000
2020	149000

In 2020, the scale of logistics could up to 149000 billion, which has a great impact on the economy and trade of the whole society. Therefore, it is necessary to seek scientific and reasonable distribution methods, reduce unnecessary fuel consumption and other energy saving behaviours, and promote the rapid and sustainable development of logistics.

In recent years, many scholars have studied logistics and transportation scheduling. The food hub concept is applied on delivering food to urban customers which construct a consolidation as an urban distribution centre [1]. This consolidation idea is also applied on transported flowers from California [2]. A novel mixed integer programming formulation is conducting to solve the problem of a two-level supply chain which contains production sites, client areas and a discrete time horizon [3]. Because different products have different characteristics, the model needs to be adjusted accordingly. Product quality decay and its heterogeneity are integrated in a network design model which is also based on a mixed integer linear programming formulation, which has been tested very effectively in garden networks [4]. Daham et. established a distributed mixed integer linear programming model, which can solve the problem of how to combine orders in distribution to save the total transportation cost when single-destination and multi-destination orders exist simultaneously [5]. To precisely evaluate passenger satisfaction level, a quadratic model which represents the traveling distance of transfer passengers is transformed to an equivalent MIP model which is proven to be more efficient [6]. Belmonte et. used a MIILP model to achieve the goal of cost optimization for fixed route transportation systems [7]. Pathan and Shrivastava present an end-to-end framework for the assignment problem and used reinforcement learning to find near optional solutions to minimize total cost which demonstrated on bin packing and capacitated vehicle problem [8]. Gholami et. proposed iterative algorithm decouples the nested equilibria into separate interdependent sub-problems and the model have the assumption that all the variables are time independent. This framework provides the solution algorithm to address the distribution problem for perishable goods of an uncertain dynamic demand and this method could find equilibrium results for a diverse set of scenarios at different times effectively [9]. The mathematical programming models-based decision tool are built through analysing the covid dataset in Spain. The result shows how to distribute equipments through a given network of units along a time horizon and how to share the extra stock received at multiperiod, such that a global measure of the stochastic demand of the units is minimized [10].

From previous research by scholars, most of the production and sales problems are concerned with the lowest shipping costs, so there is a lack of restrictions on the delivery time. However, due to the characteristics of fresh and corrosive foods, the time spent in the transit station warehouse must be considered. The model in this paper just solves this problem and this is also an innovative point of this paper.

This thesis is organized as follows and can be divided into four parts: Part 1 declares the general introduction of the distribution problem of perishable food shipments and the situation of logistics in china. In addition, previous researchers who have done relevant studies are discussed and evaluated their methods and models. In Part 2 describes the principal of MIP. Chapter 3 describes the methodology part. Transfer the actual model into a mathematical model and describe the parameters and decision variables. And then Chapter 4 analyses the outcome of models and use the sensitivity analysis further discusses the influence of factory number on total transportation cost. Chapter 5 states the conclusions of the thesis, give some further discussion and the possible extensions of my work which researchers could continue to explore.

2 THESiS

Models without any quadratic characteristics are often referred to as mixed integer linear programming (MILP) problems. These problems are usually solved by branch-and-bound algorithms based on linear programming.

Branch and bound is a kind of exact algorithm that is often used to solve MIP. This algorithm can find the optimal solution efficiently by constructing a tree solution space and pruning the solution space in the form of boundary. In our production scheduling problem, the branch and bound take the non-optimal efficient solution as the upper bound, and the optimal solution of the relaxation problem (invalid solution) as the lower bound. The boundary solution is continuously decomposed into subproblems by branching and node selection rules. They are solved separately until the optimal solution is found. Due to the existence of upper and lower boundaries, most of the intermediate nodes will be pruned because they exceed the existing effective solution range, thereby rapidly reducing the solution space and improving the efficiency of the algorithm.

In the research of combinatorial optimization problem, most scholars choose to design efficient heuristic algorithm to solve practical problems. Heuristic algorithms are proposed relative to exact algorithms. It refers to an algorithm that can give feasible solutions to optimization problems at acceptable cost in both computation time and space.

3 METHODOLOGY

This is a hybrid integer programming optimization model for fixed charge network flow problem, whose goal is to minimize the fresh transport cost in different scenarios. To simplify the model, we make following adjustments:

- Fresh goods can only be kept in the warehouse for a maximum of one day.
- Consider only the cost of transportation between the warehouse and the destination. Fresh products have different origins, here we do not consider the cost of transportation from the origin to the warehouse.
- The capacity of the warehouse is not considered.

3.1 Parameters and Decision Variables

3.1.1. Parameters

C: set of factories

D: set of destinations

t=1…T: Time index

d_{ijt}: Demand at destination j to be satisfied by factory i that must leave the warehouse by time t,

∀i∈G, j∈D, s= 1…T, t=1…T.

c_{jF}: Transportation cost for a full truck from the warehouse to destination j, ∀j∈D.

c_{jL}: Transportation cost for an LTL unit from the warehouse to destination j, ∀j∈D.

c_{jU}: Transportation cost for a small volume from the warehouse to destination j, ∀j ∈D.

θ: Maximum time to stay in warehouse.

k_F: Maximum capacity for a truck in cubic meter

k_L: LTL units in cubic meter

3.1.2. Decision Variables

x_{jtF}: Number of full trucks from warehouse to destination j at time t, ∀j∈D, t= 1...T.

x_{jtL}: Number of LTL units from warehouse to destination j at time t, ∀j∈D, t= 1...T.

x_{jtU}: Number of courier units from warehouse to destination j at time t, ∀j∈D, t= 1...T

y_{ijstF}: Amount of goods transported by full truck from factory i to destination j on period s, which should be transported by period t, ∀i∈G, j∈D, s= 1...T, t=1…T, t=s…min {s+ θ, T}.

y_{ijstL}: Amount of goods transported by full truck from factory i to destination j on period s, which should be transported by period t, ∀i∈G, j∈D, s= 1...T, t=1…T, t=s…min {s+ θ, T}.

y_{ijstU}: Amount of goods transported by full truck from factory i to destination j on period s, which should be transported by period t, ∀i∈G, j∈D, s= 1…T, t=1…T, t= s…min {s+ θ, T}.

3.2 MODEL

The objective function represents the total transportation cost. Our goal is to find the optimal distribution scheme that shows the number of products in different modes of transport from factory I to destination J. There are three main modes of transportation for fresh food, including full-truckload, less-than-truckload and express delivery services. They have three types of cost (i.e., C_{jF}, C_{jL} and C_{jU}) in the objective function.

The maximum storage time of perishable food in the warehouse is one day, 0≤t-s ≤1. Where, s represents the time when the product arrives at the warehouse, and t represents the time when the product leaves the warehouse.

The first three constraints are similar, indicating that fresh food should be delivered at time t, t ranges from s to min {s+ θ, T}. And here we have factors α, $\boldsymbol{k_F}$ and $\boldsymbol{k_L}$ to convert the unit. It should be mentioned that the "S" in x_{jsU}, x_{jsF}, x_{jsL} is just used as a time index, we can say that they are equivalent to x_{jtU}, x_{jtF}, x_{jtL} respectively.

The last constraint is a demand equation. The right-hand side of the equation is the amount of demand at destination j to be satisfied by factory i that must leave the warehouse by time t, which should exactly equal to the total amount of the last two days transportation in three methods (i.e., FTL, LTL and Courier).

As x_{jtF} indicates the number of full trucks, it should be an integer. x_{jtL} indicates the LTL units, it should also be an integer because we will charge for per cubic meter in general.

Minimize

$$\sum_{t=1..T}\sum_{j\in D}(C_{jF}x_{jtF} + C_{jL}x_{jtL}) + C_{jU}\sum_{t=1..T}\sum_{j\in D}x_{jtU} \tag{1}$$

Subject to

$$\sum_{i\in G}\sum_{t=s}^{min\{s+\theta,T\}} y_{ijstU} = \alpha x_{jsU}, \quad \forall j \in D, s = 1..T \tag{2}$$

$$\sum_{i\in G}\sum_{t=s}^{min\{s+\theta,T\}} y_{ijstL} \le \kappa_L x_{jsL}, \quad \forall j \in D, s = 1..T \tag{3}$$

$$\sum_{i\in G}\sum_{t=s}^{min\,\{s+\theta,T\}} y_{ijstF} \le \kappa_F x_{jsF}, \quad \forall j \in D, s = 1..T \tag{4}$$

$$\sum_{s=max\{1,t-\theta\}}^{t} y_{ijstF} + y_{ijstL} + y_{ijstU} = d_{ijt}, \forall j \in G, j \in D, t = 1 \dots T \quad (5)$$

$$y_{ijstF} \geq 0, \forall i \in G, j \in D, s = 1 \dots T, t = 1..T \quad (6)$$

$$y_{ijstL} \geq 0, \forall i \in G, j \in D, s = 1 \dots T, t = 1..T \quad (7)$$

$$y_{ijstU} \geq 0, \forall i \in G, j \in D, s = 1 \dots T, t = 1..T \quad (8)$$

$$x_{jtF} \geq 0, x_{jtF} \in \mathbb{Z}, \forall j \in D, t = 1 \dots T \quad (9)$$

$$x_{jtL} \geq 0, x_{jtL} \in \mathbb{Z}, \forall j \in D, t = 1 \dots T \quad (10)$$

$$x_{jtU} \geq 0, \forall j \in D, t = 1..T \quad (11)$$

3.3 MODELLING IN XPRESS

The size of the data is reduced to facilitate calculation. This paper sets 10 factories and 10 destinations, and the simulation time is 7 days. The demand for all destinations is generated randomly between 50 and 800. The production for all suppliers is generated randomly between 60 and 600. In general, the output of a specific supplier i is relatively stable, which means that there exists mass supplier and small-scale supplier. The program code can be shown in the Appendix part.

4 RESULT AND ANALYSIS

The software combines integer programming principle to solve the objective function, and obtains the optimal scheme of commodity transportation and distribution. As the integer constraints, the optimal solution chosen is extremely close to the low bound which the gap between the best solution and the solution we choose is exactly less than 0.5% and it makes the optimal solution chosen reasonable. In this case, the best solution is to ship about 62% of the cargo through FTL at a cost of 4,165,240. To verify the reasonableness of the analysis results, sensitivity analysis is used to verify the robustness of the results. We change the number of factories by 10, 20 and 30 respectively to analyse the impact of the number of factories, as shown in Table 2.

Table 2. The Total Transportation Cost under the 3 scenarios

Scenarios	Transportation Cost
Scenario1	4165240
Scenario2	7997760
Scenario3	12069900

Table 3. The Volume Transported by FLT and LTL under the 3 scenarios

Scenarios	Volume Transported by FLT	Volume Transported by LTL
Scenario1	217231	18950
Scenario2	425327	16789
Scenario3	647235	11342

The amount of full-truckload transportation increase significantly, but LTL shows the opposite trend, with shipments sent by LTL falling by nearly half. As the number of factories increase, the cheaper transportation method full-truckload would be chosen more. As a result, distribution centers can take advantage of mass economy transportation costs to save money.

5 conclusion

This paper only discusses the ideal state when supply and demand are balanced and stable. The objective of this project is to minimize the transportation cost and the optimization model based on MIP provides the distribution plan. The result show approximately 62% of the product should by transported by FTL. This is because the whole vehicle can carry a large number of goods, the unit price is cheaper. Furthermore, the sensitive test shows that with the increasing number of factories, the proportion of vehicle transportation will continue to increase. Therefore, we recommend that the vehicle with the largest cargo should be used first for delivery, which will minimize the total far away and cannot be classified into site groups, if providing services for them, the required delivery time is long, and the delivery cost is high, so express delivery needs to be used. The specific scheduling quantity and time can refer to the MIP model which is proven to be effective.

There are also some limitations on this model. Firstly, the logistics transportation cost can be optimized, but the actual state is difficult to be in the moderate state of supply and demand balance. How to further optimize and solve the logistics and transportation distribution method under the state of non-supply and demand balance deserve further study. Secondly, this article ignores the transportation costs of factories and warehouses to a certain extent. In a reality word, this part cannot be saved. Thirdly, the capacity of the warehouse should be also considerate.

REFERENCES

1. Morganti E, Gonzalez-Feliu J. City logistics for perishable products. The case of the Parma's Food Hub, in: Case Studies on Transport Policy, 2015, pp. 120-128. DOI: https://doi.org/10.1016/j.cstp.2014.08.003
2. Nguyen C, Toriello A, Dessouky M, et al. Evaluation of transportation practices in the California cut flower industry, in: Interfaces, 2013, pp. 182-193. DOI: https://doi.org/10.1287/inte.1120.0654
3. Melo R A, Wolsey L A. MIP formulations and heuristics for two-level production-transportation problems, in: Computers & Operations Research, 2012,pp. 2776-2786. DOI: https://doi.org/10.1016/j.cor.2012.02.011
4. de Keizer M, Akkerman R, Grunow M, et al. Logistics network design for perishable products with heterogeneous quality decay, in: European Journal of Operational Research, 2017, pp. 535-549. DOI: https://doi.org/10.1016/j.ejor.2017.03.049
5. Yu, C., Zhang, D., & Lau, H. Y. MIP-based heuristics for solving robust gate assignment problems, in: Computers & Industrial Engineering, 2016, pp. 171-191. DOI: https://doi.org/10.1016/j.cie.2015.12.013
6. Daham H A, Yang X, Warnes M K. An efficient mixed integer programming model for pairing containers in inland transportation based on the assignment of orders, in: Journal of the Operational Research Society, 2017, pp. 678-694. DOI: https://doi.org/10.1057/s41274-016-0132-0
7. Blat Belmonte B D, Rinderknecht S. Optimization Approach for Long-Term Planning of Charging Infrastructure for Fixed-Route Transportation Systems, in: World Electric Vehicle Journal, 2021, pp. 258. DOI: https://www.mdpi.com/2032-6653/12/4/258
8. Pathan S, Shrivastava V. Reinforcement Learning for Assignment Problem with Time Constraints, in: arXiv preprint arXiv:2106.02856, 2021, DOI: https://doi.org/10.48550/arXiv.2106.02856
9. Gholami R A, Sandal L K, Ubøe J. A solution algorithm for multi-period bi-level channel optimization with dynamic price-dependent stochastic demand, in: Omega, 2021, 102: 102297. DOI: https://doi.org/10.1016/j.omega.2020.102297
10. Blanco V, Gázquez R, Leal M. Reallocating and sharing health equipments in sanitary emergency situations: The COVID-19 case in Spain, in: arXiv preprint arXiv:2012.02062, 2020.DOI: https://doi.org/10.48550/arXiv.2012.02062

APPENDIX

```
model ModelName
uses "mmxprs"
!uses "mminsight" ! uncomment this line for an Xpress Insight model
 declarations
 growers = 1..10
 destinations = 1..10
 time = 1..7
 sent = 1..7
```

```
NB = 3
BREAK1 = 1..NB                    ! Price breaks
BREAK0 = 0..NB   ! Price breaks including 0
cost_ltl: array(destinations,BREAK1) of real  ! Unit cost
BR: array(destinations,BREAK0) of real  Breakpoints (quantities at which unit ! cost changes)
CBR: array(destinations,time,BREAK0) of real   ! Total cost at break points
cost_fulltruck:array(destinations) of real
cost_small:real
demand:array(growers,destinations,time) of real
number_fulltruck:array(destinations,time) of mpvar
number_ltl:array(destinations,time) of mpvar
number_small:array(destinations,time) of mpvar
amount_fulltruck:array(growers,destinations,sent,time) of mpvar
amount_ltl:array(growers,destinations,sent,time,BREAK1) of mpvar
amount_small:array(growers,destinations,sent,time) of mpvar
w: array(destinations,time,BREAK0) of mpvar
end-declarations
initialisations from "or.dat"
demand cost_fulltruck cost_ltl cost_small  BR
end-initialisations
forall(j in destinations,t in time) do
 CBR(j,t,0):= 0
 forall(b in BREAK1) CBR(j,t,b):= CBR(j,t,b-1) + cost_ltl(j,b)*(BR(j,b)-BR(j,b-1))
end-do
forall(j in destinations,t in time)
 Number_ltl(j,t):=sum(b in BREAK1) BR(j,b) * w(j,t,b)=number_ltl(j,t)
!objective
cost:= sum(t in time, j in destinations) cost_fulltruck(j)*number_fulltruck(j,t)+sum(j in destinations,t in time,b in BREAK1) CBR(j,t,b)*w(j,t,b)+ cost_small*sum(j in destinations, t in time) number_small(j,t)
```

```
!Integer
forall(j in destinations, t in time)
  number_fulltruck(j,t) is_integer

!full
forall(j in destinations,s in sent)
  sum(i in growers) sum(t in time|t>=s and t<=s+1) amount_fulltruck(i,j,s,t) <=
    600*number_fulltruck(j,s)

! The convexity row (w sum to 1)
forall(j in destinations) OneW(j):= sum(b in BREAK0, t in time) w(j,t,b) = 1
!low
forall(j in destinations,s in sent)
  sum(i in growers,b in BREAK1) sum(t in time|t>=s and t<=s+1) amount_ltl(i,j,s,t,b)
    <= number_ltl(j,s)
!small
forall(j in destinations,s in sent)
  sum(i in growers) sum(t in time|t>=s and t<=s+1) amount_small(i,j,s,t) =
    (1/7.2)*number_small(j,s)
!demand
forall(i in growers, j in destinations, t in time)
  sum(s in sent|s>=t-1 and s<=t) amount_fulltruck(i,j,s,t) + sum(b in BREAK1) sum(s
    in sent|s>=t-1 and s<=t) amount_ltl(i,j,s,t,b) + sum(s in sent|s>=t-1 and s<=t)
    amount_small(i,j,s,t) = demand(i,j,t)
forall(j in destinations)
!SOS2
forall(m in destinations) XSet(m):= sum(b in BREAK1) b*cost_ltl(m,b) is_sos2
! print
minimise(cost)
writeln;writeln
writeln("Objective total cost(consolidation: ",getsol(cost)," dollar")
end-model
```