END-SEMESTER BACHELORS THESIS PROJECT PRESENTATION

OPTIMIZATION OF VEHICLE ROUTING WITH INVENTORY ALLOCATION PROBLEMS IN COLD SUPPLY CHAIN LOGISTICS

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DECLARATION

I certify that

1. The work contained in this report has been done by me under the guidance of my supervisor.
2. The work has not been submitted to any other Institute for any degree or diploma.
3. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.
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Certificate

This is to certify that the project report entitled "**OPTIMIZATION OF VEHICLE ROUTING WITH INVENTORY ALLOCATION PROBLEMS IN COLD SUPPLY CHAIN LOGISTICS**" submitted by **Rupesh Garg** (Roll No. 19IM30019) to Indian Institute of Technology Kharagpur towards partial fulfilment of requirements for the award of degree of Bachelor of Technology in Industrial and Systems Engineering is a record of bona fide work carried out by him under my supervision and guidance during Autumn Semester, 2022-23

Dr. Balagopal G. Menon

Department of Industrial and Systems Engineering

Date:

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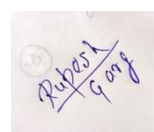
I would like to thank my supervisor, Prof. B. G. Menon, for assigning me this project. His friendly nature and supportive attitude were a great motivator for me. From him, I got to lot to learn a lot about research and how to pursue the same. I dedicate the work to Prof. B. G. Menon and the Department of Industrial and Systems Engineering, IIT Kharagpur.

Date: 29/11/2022



ABSTRACT

In this research, a new comprehensive mixed integer optimization model (IVRPCSC Model) is developed to minimise the total cost paid for Cold Supply Chain, including transportation and inventory costs and cooling costs incurred. Penalties are considered for late deliveries and unsatisfied demands. It is a NP-Hard Problem which makes it a bit complex to solve in CPLEX. At the end, optimized cost is shown with routes details and specifications.

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Chapter 1 Introduction

1. Introduction

Recent study has focused more on cold supply chain (CSC). This is because to the high cost of CSC, which is caused by the chains' increased cooling expenses in addition to their normal transportation costs and the demand for fresh, chilled, and frozen food's rapid growth. UNICEF provided an example of the high price paid for CSC by reporting that it spent more than $40 million USD in 2014 on just the CSC of vaccines (UNICEF, 2015).

We need to observe why are Cold Supply Chains handled differently than regular supply chains, here are some reasons I found –

• The high cost of CSC is related to the fact that these chains spend more on cooling costs in addition to standard transportation costs and that demand for fresh, chilled, and frozen foods is growing quickly. As an illustration of the hefty price tag associated with CSC, UNICEF estimated spending more than 40 million USD in 2014 on just the CSC of vaccines. The main justification for examining CSCs separately is the significant added cost.

• Customers require fresh, refrigerated, and frozen products at the lowest possible total cost. Therefore, we must maximise product cost optimization in order to increase profitability for commodities distribution organisations.

• There are many medicines and health supplements (like covid vaccines) which needs to be stored in cold storages. So, to maintain and optimize the logistics of these types of products, it is necessary to study CSCs in detail.

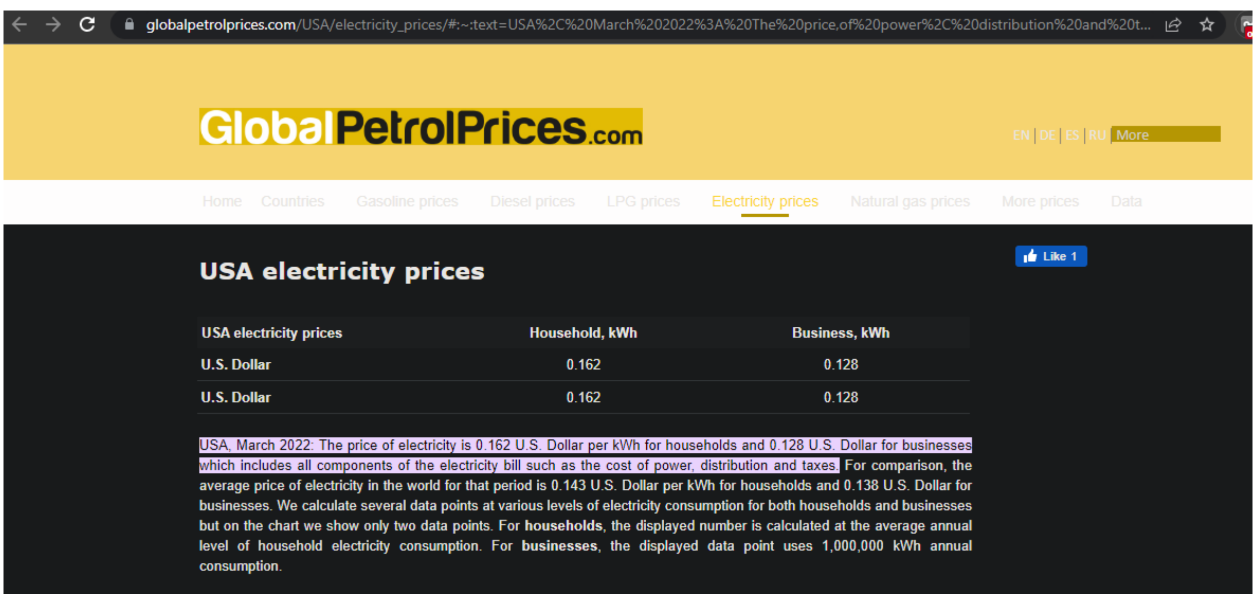
• All stages of the supply chain, from food processing to distribution to retail to final consumption, are affected by the limited shelf lives of perishable products and the continuous and significant quality value decline over time. To give the best quality value of products, we must thus optimise the time of the total process, including time frames for delivery of the product, etc.

Chapter 2 Model Development and Framework

2.1 Cooling costs calculation

I found the data of average energy consumption of cold storage supply chains and in the Cold Storage Case Study: Increasing Energy Efficiency I found the annual energy consumption of cold supply chain for refrigeration equal to 25 kwh per square feet of storage. I considered the size of 1 unit of the commodity to be of 10cm by 10cm, which means that each unit takes a space of 100 cm^2 or 100/930 ft^2 = 0.1075 ft^2.

I calculated the energy consumption per hour for 1 unit of commodity, which is (0.1075*25)/ (365*24) kwh per hour = 0.00031 kwh per hour per unit. I calculated the cost of this energy consumption in USA. For this I took data from GlobalPetrolPrices.com



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Like 1

USA electricity prices

USA electricity prices	Household, kWh	Business, kWh
U.S. Dollar	0.162	0.128
U.S. Dollar	0.162	0.128

USA, March 2022: The price of electricity is 0.162 U.S. Dollar per kWh for households and 0.128 U.S. Dollar for businesses which includes all components of the electricity bill such as the cost of power, distribution and taxes. For comparison, the average price of electricity in the world for that period is 0.143 U.S. Dollar per kWh for households and 0.138 U.S. Dollar for businesses. We calculate several data points at various levels of electricity consumption for both households and businesses but on the chart we show only two data points. For **households**, the displayed number is calculated at the average annual level of household electricity consumption. For **businesses**, the displayed data point uses 1,000,000 kWh annual consumption.

Price of 1 kwh for business purposes which also include Cold Supply Chains is 0.128 $/hr.

Thus, cost of 0.31 kwh will be 0.128*0.00031 $/hr per unit = **0.00004 $/hr per unit for refrigeration in cold supply chains**. After this, I calculated the cost for deep freezing the commodities. For this I used data from a site SaveJoules.com. I created a table of energy consumption from the data given on that site. The table is shown below –

Brand	Capacity (LTR)	Power (Watt)	Electricity Per Day (kWh)	Type
Dawlance DF-200ES GD ES Series GD	200	84	1.31	Single Door Freezer
Dawlance DF-200ES ES Series	200	84	1.31	Single Door Freezer
Dawlance DF200ES ES Series	200	101	1.58	Single Door Freezer
Dawlance DF200ES GD ES Series GD	200	101	1.58	Single Door Freezer
Waves WDF309 Regular	255	120	1.87	Single Door
Waves WDF310 Regular	311	120	1.87	Single Door
Waves WDF309 Stainless Steel	255	120	1.87	Single Door
Waves WDF310 Stainless Steel	311	120	1.87	Single Door
Dawlance DF-400ES ES Series	400	110	1.72	Single Door Freezer
Waves WDF310 Cool Bank	311	120	1.87	Single Door
Waves WDFT313TL Regular	368	120	1.87	Double Door DF & RF
Waves WDFT313TL Cool Bank	368	120	1.87	Double Door DF & RF

Waves WDFT313TL Stainless Steel	368	120	1.87	Double Door DF & RF
Waves WDF309 Alpha Glass Door	255	120	1.87	Single Door
Waves WDFT315TL Regular	425	120	1.87	Double Door DF & RF
Waves WDF310 Alpha Glass Door	311	120	1.87	Single Door
Waves WDFT315TL Cool Bank	425	120	1.87	Double Door DF & RF
Waves WDFT315TL Stainless Steel	425	120	1.87	Double Door DF & RF
Waves WDF313 Regular	368	138	2.15	Single Door
Waves WDF313 Stainless Steel	368	138	2.15	Single Door
Waves WDFT313TL Alpha Glass Door	368	120	1.87	Triplet (DF & RF)
Waves WDF313 Cool Bank	368	138	2.15	Single Door
Waves WDFT315TL Alpha Glass Door	425	120	1.87	Triplet (DF & RF)
Dawlance DF300ES ES Series	300	152	2.37	Single Door Freezer
Waves WDF313 Alpha Glass Door	368	138	2.15	Single Door

Average energy consumption of deep freezers is 1.8608 kwh per day (from table). Comparing this value with the average energy consumption of refrigerator which is 1 kwh per day, I found that cost of deep freezing a commodity must be 1.8 times the cost of refrigeration. Thus, **cost of deep freezing per hour per unit** = 1.8*0.04 = **0.00007 $/hr per unit.**

2.2 Model Development

2.2.1 Problem Statement

We are given a cold-chain logistic system consisting of multiple distribution centers (supply nodes), refrigerated commodity and deep-frozen commodity, and multiple demand nodes and warehouses.

The objective function is to minimize the total cost which includes transportation costs, penalty cost for late deliveries, cooling costs per hour, penalty costs for unsatisfied demands at demand nodes and the holding costs of storing both commodity types that remain unsold.

2.2.2 CPLEX Model Development

I took the supply of refrigerated commodity at supply node i Є sup as s_r_i and supply of deep-frozen commodity at supply node i Є sup as s_df_i, the demand of refrigerated commodity at demand node j Є dmnd as d_r_j and demand of deep-frozen commodity at demand node j Є dmnd as d_df_j.

I took the transportation cost of 1 unit of commodity to travel from supply node i Є sup to demand node j Є dmnd as $transport\_cost_{ij}$, the quantity of refrigerated commodity from supply node i to demand node j as q_r_{ij} and quantity of deep-frozen as q_df_{ij}, the time period required to travel from supply node i Є sup to demand node j Є dmnd as $time_{ij}$, the penalty cost due to late delivery for per late hour per unit as penalty and cooling costs per hour per unit of refrigerated and deep-frozen commodities as cooling_r and cooling_df respectively, unit penalty cost of unsatisfied commodity at demand node j Є dmnd as $penalty\_cost_j$, unit holding cost of inventory stored at demand node j Є dmnd as $holding\_cost_j$, unsatisfied quantity of refrigerated commodities deep-frozen commodities at demand node j as und_r_j and und_df_j, the inventories are inv_r_j and inv_df_j and the last variable z_{ij} tells whether the delivery is late or not.

Objective Function –

- Transportation cost for every route from i to j will be transport cost from i to j multiplied by total commodity delivered from i to j, i.e., $transport\_cost_{ij}*(q\_r_{ij} + q\_df_{ij})$. The delivery is considered late iff $time_{ij}$ is more than 3 hours. Thus, penalty for late delivery will be $penalty*(time_{ij} – 3)$ for every unit. Total penalty for late delivery = $penalty*(time_{ij} – 3) *(q\_r_{ij} + q\_df_{ij})$ for $time_{ij} > 3$. The cooling costs will be $(q\_r_{ij}*cooling\_r + q\_df_{ij}*cooling\_df) *(time_{ij})$. I chose penalty = 0.05 per late hour per unit by intuition. Cooling costs are already calculated as 0.00004 and 0.00007 $/hr per unit. This is the cost of every (i, j) pair, therefore we have to sum it over all i and j.
- Penalty for unsatisfied demand will be $(und\_r_j + und\_df_j) *penalty\_costj$ and holding cost will be $(inv\_r_j + inv\_df_j) *holding\_costj$. This cost is for every j, so will sum it over all j.

Constraints –

- I made the first constraint by equating the supply of any node i to the total delivery of that commodity from that node i because the warehouses are only at demand nodes, not at the supply nodes, so I have to deliver all the supply present there. For refrigerated commodities, the total delivery from any node i will be q_r_{ij} summed over all j Є dmnd.

- I made second constraint by equating the commodity delivered at a demand node j Є dmnd by demand of that commodity + inventory stored – unsatisfied demand at node j Є dmnd. The reason of this is that all the extra commodity delivered will be stored as inventory in the warehouses and all the demand unsatisfied will take a negative sign.

- I made the third constraint by making value $z_{ij} = 0$ if delivery is within 3 hours and $z_{ij} = 1$ if delivery time is more than 3 hours and so that z_{ij} can tell whether the delivery is late (>3 hrs) or not for every route (i, j).

Chapter 3 Results

3.1 Solutions of CPLEX Model

In this section, numerical results to assess the performance of the proposed MILP model are presented. The objective function with the formulated constraints has been solved in the C++ programming language with CPLEX Concert Technology, version 22.1.0 and run on an HP-DESKTOP-H7S0N46 version 22H2 with a Intel(R) Core (TM) i3-7020U CPU @ 2.30 GHz in 64-bit mode.

Here are the screenshots of the solutions of CPLEX model I generated.

```
Problems   Scripting log   Solutions ✕   Conflicts   Relaxations   Engine log   Statistics   Profiler
// solution (optimal) with objective 114715.4325
// Quality Incumbent solution:
// MIQP objective                                 1.1471543250e+05
// MIQP solution norm |x| (Total, Max)            4.33017e+05  5.00000e+04
// MIQP solution error (Ax=b) (Total, Max)        0.00000e+00  0.00000e+00
// MIQP x bound error (Total, Max)                0.00000e+00  0.00000e+00
// MIQP x integrality error (Total, Max)          0.00000e+00  0.00000e+00
// MIQP slack bound error (Total, Max)            0.00000e+00  0.00000e+00
//
```

The minimum cost is coming as 114715.4325 $.

```
q_r = [[0
             0 0 0 0 25000]
             [50000 0 0 0 0 0]
             [0 0 0 30000 0 0]
             [0 20000 0 15000 0 0]
             [0 0 0 0 10000 0]
             [0 0 20000 0 0 0]];
q_df = [[0 0 0 0 0 29000]
             [24000 0 0 0 0 0]
             [0 4000 0 36000 0 0]
             [0 30000 0 0 0 0]
             [0 0 0 0 29000 0]
             [0 0 33000 0 0 0]];
z = [[1 1 0 0 1 1]
             [1 1 1 0 1 0]
             [0 1 0 0 0 1]
             [0 0 1 1 0 0]
             [1 0 0 0 1 0]
             [0 1 0 1 0 1]];
und_r = [0 0 10000 0 10000 5000];
und_df = [2000 0 0 0 4000 11000];
inv_r = [5000 0 0 15000 0 0];
inv_df = [0 0 0 16000 0 0];
```

For refrigerated commodity –

Supply node 1 is supplying 25000 kgs to demand node 6. Supply node 2 is supplying 50000 kgs to demand node 1. Supply node 3 is supplying 30000 kgs to demand node 4. Supply node 4 is supplying 20000 kgs to demand node 2 and 15000 kgs to demand node 4. Supply node 5 is supplying 10000 kgs to demand node 5. Supply node 6 is supplying 20000 kgs to demand node 3.

Inventory of refrigerated commodity is 5000 kgs at demand node 1 and 15000 kgs at demand node 4. Also, there is unsatisfied demand of 10000 kgs at demand node 3 and 5 and of 5000 kgs at demand node 6.

For Deep-frozen commodity –

Supply node 1 is supplying 29000 kgs to demand node 6. Supply node 2 is supplying 24000 kgs to demand node 1. Supply node 3 is supplying 4000 kgs at demand node 2 and 36000 kgs to demand node 4. Supply node 4 is supplying 30000 kgs to demand node 2. Supply node 5 is supplying 29000 kgs to demand node 5. Supply node 6 is supplying 33000 kgs to demand node 3.

Inventory of deep-frozen commodity is 16000 kgs at demand node 4. Also, there is unsatisfied demand of 2000 kgs at demand node 1, 4000 kgs at demand node 5 and of 11000 kgs at demand node 6.

3.2 Time taken by CPLEX to compute the program

```
Root node processing (before b&c):
  Real time             =    0.02 sec. (1.29 ticks)
Parallel b&c, 4 threads:
  Real time             =    0.00 sec. (0.00 ticks)
  Sync time (average)   =    0.00 sec.
  Wait time (average)   =    0.00 sec.
                          ------------
Total (root+branch&cut) =    0.02 sec. (1.29 ticks)
```

Chapter 4 Conclusion

Our goal in this study is to coordinate CSC's logistics while minimizing transportation, penalties, and storage costs. To achieve this goal, a comprehensive optimization model is proposed for coordinating a set of supply and demand nodes. Refrigerated and frozen products are picked up from supply nodes and delivered to demand nodes. Since frozen and chilled products require different degrees of cooling, the cooling costs are also different. We proposed a mixed-integer model that considers detailed vehicle routes, considers inventory costs as storage costs and penalty costs for unmet demand, and solves the cold product distribution problem. CPLEX offers the best solution with an average computation time of 0.02 seconds (1.29 ticks). Ultimately, many future research opportunities could be achieved. For example, uncertainties in some parameters can be included in the model, and stochastic or robust operational research techniques can be used to solve such modified models. Additionally, you can use multiple targets to provide a Pareto front for your users. This includes many solutions with different target values related to transportation, penalties, or holding costs. Furthermore, some assumptions can be relaxed such as incorporating the fixed cost of using the vehicles in the objective function. Finally, different heuristics can be explored to find better solutions and/ or shorter computational times, such as Lagrangian Relaxation or Branch-and-Price.

Furthermore, some assumptions, such as including the fixed cost of using the vehicles in the objective function, can be relaxed. Finally, different heuristics, such as Lagrangian Relaxation or Branch-and-Price, can be investigated to find better solutions and/or shorter computational times.

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