TRAVELLING SALESMAN PROBLEM IN PROVIDING LOGISTIC SOLUTIONS

Gurpreet Singh Virdi

Himani Narain

Isha Agrawal

I. ABSTRACT

The first part of the paper deals with various methods to solve Traveling Salesman Problem. The second part deals with the applications of Traveling Salesman Problem in logistic practice and the third part highlights various limitations observed and how they can be resolved.

II. INTRODUCTION

With the rise in online shopping and e-commerce customers, it is important for companies to implement an efficient logistic system. After an order is placed, a worker retrieves items from the warehouse, and these items have to be delivered to their respective delivery addresses in minimum time and cost. Several variations of this problem, where time, cost and capacity constraints are combined, are common in many other real world applications. These problems are solvable as Traveling Salesman Problems.

III. TRAVELING SALESMAN PROBLEM

Given a set of cities and the distance between each pair of cities, the problem is to find the shortest possible route that visits each city exactly once, and returns to the origin city. It is a NP-Hard problem in which the solution cannot be found in reasonable time. However, it can be efficiently verified by deterministic computations that can be performed in polynomial time.

The applications of TSP are numerous and range from computer wiring and drilling of Printed Circuit Boards to X-ray crystallography to design of global navigation satellite system surveying networks.(4)

In the logistics problem, the delivery locations of the items correspond to the nodes of the graph. The distance between two nodes is given by distance between the cities. The problem of finding a shortest route for the vehicle with minimum pickup time can now be solved as a Traveling Salesman Problem.

IV. METHODS OF SOLVING TRAVELING SALESMAN PROBLEM

There have been many approaches to solve the Traveling Salesman Problem which range from a simple heuristic algorithm to algorithms based on the real life like ant colony optimization.

Following is a brief description of some common approaches:

1. **NAÏVE -** This is a brute force approach where all the possible routes are checked and the shortest one is taken as the answer. This method always gives the best solution. However, as the number of cities increase, the number of routes grows exponentially, and the method becomes infeasible. The time complexity of this method if O(n!).(1)

2. **Branch and Bound** – The term branch and bound refers to all state space search methods in which all the children of the root node are generated before any other node becomes the root node. We expand the node which is most promising, which means the one which promises that expanding or choosing it will give optimum solutions. Other candidate nodes are discarded by using upper and lower estimated bounds of the quantity being optimized.(2)

3. **Dynamic Programming** – It is a method for solving the problem by breaking it down into a collection of simpler sub-problems, solving each of these sub-problems just once, and storing their solutions. The next time the same sub-problem occurs, instead of re-computing its solution, the previously computed solutions are used, thereby saving computation. The time complexity of this algorithm is $O(n^2*2^n)$.(1)

4. **Ant Colony Optimization** - Ant Colony Optimizations is based on the natural searching system found in an ant colony. Similar to ants forming a line to a food source, programmed ants are used to form a line through the shortest path of the TSP. The ants leave behind some amount of pheromone wherever they go. When another ant needs to decide which path to take, the pheromone on the trail influences it to take the same path as the previous ant.(3)

V. LOGISTICS AND SUPPLY CHAIN MANAGEMENT

Logistics is one of the most important basic industries for any economic growth as it is the management of the flow of products from the place of their origin to the place of their consumption, thus the industry also involves the integration of material handling, warehousing, packaging, transportation, shipping security, inventory management, supply chain management, procurement, and customs service.

With about 87.6% of Indian population in the middle and upper class range, current Indian scenario demands an efficient and optimized logistics and supply chain management such that it meets the needs of the people satisfactorily. This has made the logistics sector in India a priority. One of the contributing factors is the growth in the Indian economy in the past years which has resulted in the rise in the volume of the freight traffic moved. This growth in transportation has created a broad scope of growth in otherwise dormant sectors such as warehousing, freight forwarding, express cargo delivery, container services, shipping services etc.(5)

The market size of logistics sector in India is estimated to be about USD 90-125 Billion. Considering the growth in Indian economy to be in trillions in the past years, the importance of the contribution of logistics and supply chain management in the Indian economy. Despite of many attempts in improving the transportation and supply chain facilities , India has always lagged behind other developed countries in the same. These includes significant inefficiencies in transportation, poor condition of storage infrastructure, complex tax structure, low rate of technology adoption, and poor skills of logistics professionals.Some of the challenges faced by logistics in India due to the dominance of road transportation over other means such as rail, air, coastal shipways, inland waterways and pipeline. Though there are many benefits of road transportation over other types, road suffers from some of the serious drawbacks which include issues like poor road network coverage , poor road quality , inefficient and unreasonable delays in the construction of expressways and better facilities, high level of fragmentation in the trucking industry, and the multiple checkpoints the trucks and other vehicles have to pass through.

All these problems contribute in delay of the product delivery and an overall decline in the logistics system of the country. Many of these problems are being dealt with by various big logistic companies and by far, many companies have been able to establish themselves successfully in this field. Some of the top 10 companies include Aegis Logistics Ltd. , Agarwal

Packers and Movers Ltd., Allargo Logistics Ltd. , BlueDart Logistics Ltd. , Container Corporation of India Ltd., DHL Express India Pvt. Ltd., FedEx Express TSCS India Pvt. Ltd., First Flight Courses Ltd., Gati Ltd., Globe Express Services Pvt. Ltd., Transport Corporation of India Ltd., etc .(6)

V.A Case Scenario and Its Solution

Now, consider a case scenario of a salesman who is supposed to deliver items to their respective recipients. These recipients reside in different cities and the salesman is travelling with a truck which is loaded with luggage. Now , the salesman has a deadline for each of the item to be delivered. Also, the constraints on the vehicle capacity and weather conditions are to be kept into consideration. While the delivery of the goods to the respective customers , the salesman encounters several problems which he needs to deal with during his journey. He has to come up with solutions which optimize the profit gained by the logistic company with minimum efficient use of resources like fuel , pay of the drivers, maintenance and servicing of the vehicles etc.

First of all, let us consider a scenario of 16 cities where goods have to be delivered. The first solution he needs to work upon is to come up with such an optimized route to be followed which minimizes the total distance to be followed . This results in the minimum expenditure on fuel and maintenance of vehicle during the journey.

Lets us assume that while travelling on the optimized path, he notices a cancel in the delivery of the product in one of the cities. This may also happen before the salesman starts his journey. Another scenario for the same case may include a bad weather condition in any of the cities or a blockage of the transport medium due to natural calamities like landslides, earthquakes etc. All the cases involve the removal of that city from the target list and the optimization of the rest of the path. Thus, the driver has to come up with a dynamic decision for the same without wastage of time.

It may also happen that a customer requests for the return of the product (because of any of the possible reasons which may include the delivery of damaged product, unsatisfactory product etc.), or the driver notices a damaged product in the luggage and has to move to the closest inventory so as to replace the item. In all of these cases, an addition of an extra checkpoint is involved. Thus, the driver is burdened with another decision of dynamically deciding how to formulate a path which results in maximum profit by travelling all the cities covering minimum distance.

Both of these problems are a topic of research and some solutions to it have also been provided

by logisticians.

V.B EXISTING SOLUTIONS

1. Almost all of these problems involve dynamic calculation of an optimized path which covers all the cities in minimum distance and time and returns to the original starting point which was the inventory. This is nothing but an application of TRAVELLING SALESMAN PROBLEM which involves the same logic of optimization. There are many algorithms of solving a travelling salesman problem namely naïve algorithm, dynamic algorithm, branch and bound algorithm , ant colony optimization , genetic algorithm, heuristic algorithm , memetic algorithm, etc.

2. Solution to the capacity/luggage constraints on the vehicle has been provided using GENERALISED TRAVELLING SALESMAN PROBLEM. The GTSP makes use of the divide and conquer technique. It divides the cities into groups or clusters(the clustering logically done on the basis of either delivery date of the item or geographical positions of the target city. Now , it is the responsibility of the salesman to choose one city in each cluster and deliver the item . This minimizes the number of stoppage points in one round. In the next round, he again chooses one city in each cluster an deliver the item . This continues till all the cities are served.

3. The other solutions provided by companies involve a greater use of resources like increase in the number of vehicles. Thus, now there are more number of salesman to serve the same number of cities and therefore the work is very well distributed among them. To reduce the extra distance to be travelled in case of the recovery a damaged product from an inventory, companies make sure that their inventories are constructed at regular intervals and therefore lie close to the current location of salesman irrespective of his geographical position. In case of unpredictable and unavoidable weather conditions, companies inform their customers about the possible delayed arrival of goods due to the current situations. They try to find alternative ways to deliver the item. In case of a return of the product, the pick up of the good is rarely performed by the same salesman . There are always extra salespeople hired for this purpose.

All of the above algorithms provide a feasible and workable solution to the salesman (driver) for carrying out his job of delivering goods.

V.C. MORE SOLUTIONS POSSIBLE

Treating these logistic decisions as a potential application for the Travelling Salesman

Problem, it could be solved using any of the efficiently working algorithms by formulating them into real-life situational coding applications. This has been done using four of the algorithms which include the Naïve algorithm, Dynamic programming , Branch and Bound algorithm and the Ant Colony optimization. A brief mention of each of these algorithms has already been stated above. Though a number of available algorithms can work better than those mentioned above, it very much depends upon the application sphere and the data set chosen that decides algorithm which will suit the best. Upon evaluating some of the other algorithms , these four algorithms provided with the most convenient and least time taking decisions for the driver.

The data set chosen here shows the inter – city distance between 14 cities . This is represented in the form of 14 X 14 matrix each row of which denotes the source city and destination city.

The diagonal elements are taken to be zero to agree with the fact that the distance between two points in the same cities will always be much less than the distance between two cities. Also, the inter-city matrix is a symmetric one according to the assumption made that the distance between two cities will always remain the same irrespective of which city is considered as the source and which city is considered as the destination. The important point to note here is that the values in the data set are not done on scale. They are the assumed values which can vary according to the logisticians' convenience. All entries are in kilometers(kms).

V.D. Inter- City Distance(7)

```
  0 633 257  91 412 150  80 134 259 505 353 324  70 211
633   0 390 661 227 488 572 530 555 289 282 638 567 466
257 390   0 228 169 112 196 154 372 262 110 437 191  74
91 661 228   0 383 120  77 105 175 476 324 240  27 182
412 227 169 383   0 267 351 309 338 196  61 421 346 243
150 488 112 120 267   0  63  34 264 360 208 329  83 105
80 572 196  77 351  63   0  29 232 444 292 297  47 150
134 530 154 105 309  34  29   0 249 402 250 314  68 108
259 555 372 175 338 264 232 249   0 495 352  95 189 326
505 289 262 476 196 360 444 402 495   0 154 578 439 336
353 282 110 324  61 208 292 250 352 154   0 435 287 184
324 638 437 240 421 329 297 314  95 578 435   0 254 391
70 567 191  27 346  83  47  68 189 439 287 254   0 145
211 466  74 182 243 105 150 108 326 336 184 391 145   0
```

V.E. RESULT

ALGORITHM USED	COST (in kms)	PATH
Dynamic Programming	2743	1-13-7-8-6-14-3-11-10-5-4-9-12-2-1
Branch And Bound	1872	1-7-8-6-14-3-11-10-2-5-9-12-4-13-1
Ant Colony	3803	7-9-14-8-5-10-3-2-13-6-1-12-4-11-7

V.F ANALYSIS

On analysing the results obtained for the optimized path that traverses all the cities in minimum travelled distance, the Branch and Bound algorithm was found to give best results with the required travelling distance to be minimum of 1872 km. On the other hand, the Ant colony algorithm supplied the worst results with the maximum required distance of 3803 to be travelled.

This clearly states the fact that the logistic company would incur maximum profit by spending the least amount on travelling expenditure if the salesman chooses his path based on the optimization obtained on applying the branch and bound algorithm.

V.G. PROBLEMS FACED BY THE SALESMAN

So far , the following cases have turned out to be potential limitations for the salesman while delivering goods .

1. In case of the cancellation of a delivery of an item which is informed to the salesman while his path on the delivery of other items. It may also happen that the delivery of an item in a particular city has to be dropped owing to some unavoidable conditions like unfriendly weather situations, inaccessibility of the city etc.
2. In case of the return of a product or replacement of a damaged product, the salesman has to span an extra city or warehouse so as to collect the item to be returned or to reload the truck with a fresh product respectively.

All of the above cases require the salesman to decide the optimized path dynamically in the mid of his journey. There may be some sub-cases for each of the above two cases :

1. The salesman comes to know about another city to be spanned or a city to be skipped even before he starts his journey. In such cases, he will optimize the entire path accordingly and return to the starting position which might be an inventory or a factory.
2. The salesman comes to know about it in the mid of the journey in which case, he has to add or remove the city to or from his yet-to-be-travelled path and then optimize the resulting path (so as to travel minimum distance in minimum time thus maximizing the profit incurred by the company) .

V.H. OVERCOMING THESE LIMITATIONS

These limitations can be solved using the same algorithms. The logic for adding or deleting a node in the beginning or at a specified location can build up the solutions for the above problems. The below mentioned results are obtained on applying the Dynamic programming logic for addition or deletion of a node in the beginning or prior to any other node.

1. **Addition of another 15th city in the data set (Now, the data set becomes):-**

```
 0 633 257  91 412 150  80 134 259 505 353 324  70 211 268
633   0 390 661 227 488 572 530 555 289 282 638 567 466 420
257 390   0 228 169 112 196 154 372 262 110 437 191  74  53
91 661 228   0 383 120  77 105 175 476 324 240  27 182 239
412 227 169 383   0 267 351 309 338 196  61 421 346 243 199
150 488 112 120 267   0  63  34 264 360 208 329  83 105 123
80 572 196  77 351  63   0  29 232 444 292 297  47 150 207
134 530 154 105 309  34  29   0 249 402 250 314  68 108 165
259 555 372 175 338 264 232 249   0 495 352  95 189 326 383
505 289 262 476 196 360 444 402 495   0 154 578 439 336 240
353 282 110 324  61 208 292 250 352 154   0 435 287 184 140
324 638 437 240 421 329 297 314  95 578 435   0 254 391 448
```

70 567 191 27 346 83 47 68 189 439 287 254   0 145 202 289

211 466 74 182 243 105 150 108 326 336 184 391 145   0 57

268 420 53 239 199 123 207 165 383 240 140 448 202 57   0

On applying Dynamic Programming ,

the following new path is obtained with cost = 2701

Path>>>1--->13--->7--->8--->6--->4--->15--->14--->9--->12--->3--->11--->10--->5--->2--->1

2. **Removal of a city from the data set of 14 cities (Now , the data set becomes) :-**

0 633 257 91 412 150 80 134 259 505 353 324 70

633   0 390 661 227 488 572 530 555 289 282 638 567

257 390   0 228 169 112 196 154 372 262 110 437 191

91 661 228   0 383 120 77 105 175 476 324 240 27

412 227 169 383   0 267 351 309 338 196 61 421 346

150 488 112 120 267   0 63 34 264 360 208 329 83

80 572 196 77 351 63   0 29 232 444 292 297 47

134 530 154 105 309 34 29   0 249 402 250 314 68

259 555 372 175 338 264 232 249   0 495 352 95 189

505 289 262 476 196 360 444 402 495   0 154 578 439

353 282 110 324 61 208 292 250 352 154   0 435 287

324 638 437 240 421 329 297 314 95 578 435   0 254

70 567 191 27 346 83 47 68 189 439 287 254   0

On applying Dynamic Programming ,

the following new path is obtained with cost = 2327

Path>>>1--->13--->7--->8--->6--->4--->9--->12--->3--->11--->10--->5--->2--->1

VI. DISCUSSIONS

In the entire research , the usefulness of the Travelling Salesman Problem in the Logistics practice has been made evident through algorithms which yield their respective results depending on the number of cities that have to be traversed. The core objective of the application of TSP in the logistics solution is to minimize the time of travel (by minimizing the distance of journey) and maximize the profit earned by the company (which is incurred once the expenditures on resources is minimized). Several logisticians use different types of shortest path algorithms to achieve the same. It very much depends on the capability of the salesman as to how efficiently he is able to make dynamic decisions.

Also, an attempt has been made to simplify various problems faced by the salesman or driver during his journey for the delivery of goods. Dynamic algorithm appears to provide the best solutions for issues like return of a product , blockage of path for a city , reloading a product , etc. A sincere attention towards path planning according to the topology and dynamic situations can help reduce the travelling distance and maximize profit significantly.

VII. REFERENCES

1. https://www.geeksforgeeks.org/travelling-salesman-problem-set-1/
2. http://www.techiedelight.com/travelling-salesman-problem-using-branch-and-bound/
3. https://www.cs.nmsu.edu/~dcook/thesis/paper2.html
4. https://www.intechopen.com/books/traveling-salesman-problem-theory-and-applications/traveling-salesman-problem-an-overview-of-applications-formulations-and-solution-approaches
5. http://inpressco.com/wp-content/uploads/2014/04/Paper90946-9531.pdf
6. http://globalbizresearch.org/files/6029_irrem_s-ramachandran-mayur-s-nakhava-kumar-pratik-141856.pdf
7. https://people.sc.fsu.edu/~jburkardt/datasets/tsp/gr17_d.txt