

OPTIMIZING WASTE COLLECTION IN AN ORGANIZED INDUSTRIAL REGION: A CASE STUDY

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Abstract

In this paper we present a case study which involves the design of a supply chain network for industrial waste collection. The problem is to transport metal waste from 17 factories to containers and from containers to a disposal center (DC) at an organized region of automobile parts suppliers. We applied the classic mixed-integer programming (MIP) model for the two-stage supply chain to the solution of this problem. The visualization of the optimal solution provided us with several interesting insights that would not be easily discovered otherwise.

Keywords: Logistics of industrial waste, Supply chain network design, Waste collection, Waste management, Facility location, Organized industrial regions.

1. Introduction

The problem presented in this paper consists of planning the logistics of industrial waste collection from factories located in an organized industrial region, to suitable intermediate points which are possible container locations, and finally to disposal centers. The main process leading to solution of this waste collection problem is designing a network model according to the cost analysis, and determining waste container locations based on their capacities and locations. The problem can be treated as a transshipment problem aiming to select the best intermediate points for waste transfer while minimizing transportation costs in the waste collection network (Section 2). After building the model and reaching the optimal solution minimizing the total cost, a Java program that can read input files was coded in order to visualize the solution (Section 3). At the visualization stage, the values of the parameters and variables were mapped to the sizes of the nodes and thickness of the arcs.

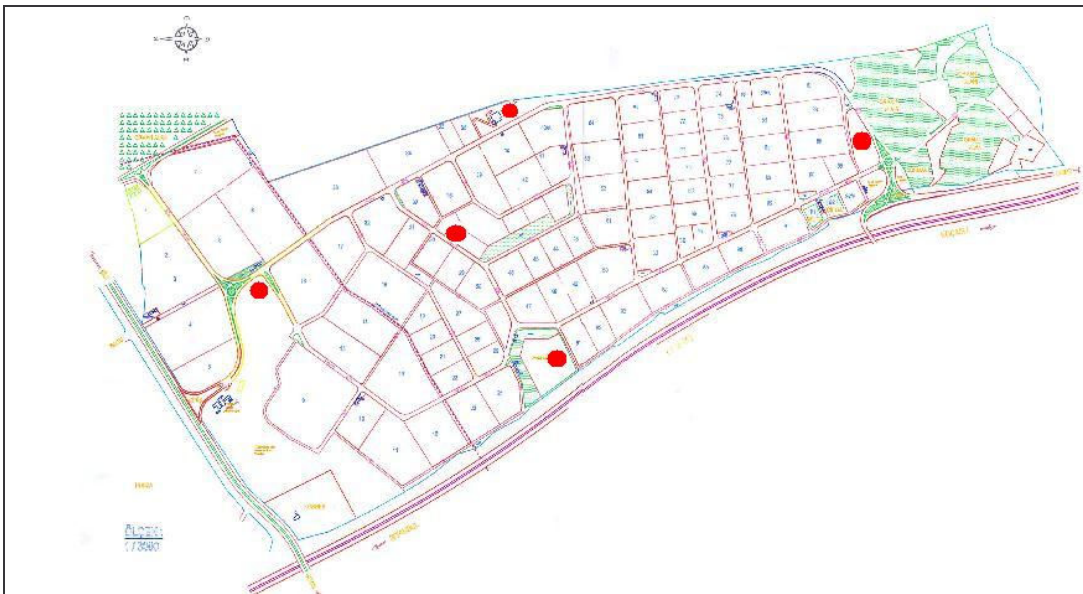


Figure 1. The candidate container locations displayed on a map of TOSB.

The industrial waste collection problem discussed in this paper was done as a graduation project at Sabancı University in 2005-2006 academic year. Distinguishing aspects of this study are that the problem is an example of

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environmental operations research is based on an estimate of real world data and that visualization is carried out. The used method and obtained solution have practical aspects which make them be easily adoptable to the one of the problems of organized industrial regions. This has also environmental contributions because of the fact that collected industrial waste such as metals are recycled. Furthermore, network visualization obtained by Java in the final phase leads to a better understanding of the solution and assessment of the designed supply chain network.

In the model, data from TOSB (TAYSAD Organize Sanayi Bölgesi - TAYSAD Organized Industrial Region) was used. The reasons for selecting to develop a model with TOSB (TOSB) data were as follows:

- TAYSAD (Taşıt Araçları Yan Sanayicileri Derneği, Association of Automotive Parts & Components Manufacturers), founded in 1978, is the most powerful association in the automobile parts supplier industry with %65 market share in Turkey. TAYSAD companies operate especially in Istanbul, Kocaeli and Bursa. TAYSAD is also a member of CLEPA, European Association of Automotive Suppliers.
- TOSB consists of 59 of 170 members of TAYSAD. Founded on a 625 acre (2.53 km²) of land, TOSB is one of the most important industrial regions chosen by Turkish and as well as foreign automotive parts manufacturers. Additionally, Turkish automotive parts supplier industry has approximately 700 firms operating with latest technology and makes %70 of its exports to European Union countries. This industry has a considerable contribution to the Turkish economy: In 2003, \$2.4 billion of exports were achieved by Turkish automotive parts suppliers.
- The fact that TOSB is located in Gebze, within close proximity of Sabancı University has highly motivated us as the project team, since we would have a chance to suggest a solution to a practical real-world problem in our neighbourhood. Meanwhile, Sabancı University has close ties with TAYSAD thanks to common projects between The Competitiveness Forum (Competitiveness Forum) of Sabancı University and TAYSAD.

2. The Model

In TOSB, 17 factories, 5 candidate container locations and one disposal center (DC) where total waste will be sent are available (Figure 1). Different amounts of waste from each factory are sent to suitable container locations from where they will be than transferred to the DC. The objective is to minimize total transportation cost under capacity constraints for the containers. This supply chain network design problem contains three sets of nodes (factories, containers and DC) and two sets of arcs (from factories to containers and from containers to the DC), hence the name two-stage supply chain. The set I represents factories which are the source nodes producing w_i tons of waste monthly. Intermediate nodes representing candidate container locations constitute the set J . In these sites indexed by j , container location decisions are reflected by binary variables z_j . There are three sets of decision variables: z_j , x_{ij} , y_j representing location and flow decisions. Since binary variables are present in the model together with continuous variables, the problem can be classified as a mixed integer programming (MIP) problem. The model is given bellow:

SETS

I : set of factories, $i = 1, \dots, n$

J : set of candidate container locations, $j = 1, \dots, m$

PARAMETERS

a_{ij} : cost of sending one ton of waste from factory i to container location j

b_j : cost of sending one ton of waste from container location j to DC

w_i : monthly waste amount of factory i

C : maximum monthly capacity of each container

f_j : monthly fixed cost of operating a container at container location j

VARIABLES

z_j : 1, if a container is located at container location j ; 0 otherwise

x_{ij} : amount of monthly flow of waste from factory i to container location j

y_j : amount of monthly flow of waste from container location j to disposal center (DC)

$$\begin{aligned} \text{Min } & \sum_{i \in I} \sum_{j \in J} a_{ij} x_{ij} + \sum_{j \in J} f_j z_j + \sum_{j \in J} b_j y_j \\ \text{s.t. } & \\ & y_j \leq C z_j \quad \forall j \in J \quad (1) \text{ Capacity and Linking constraints} \\ & \sum_{i \in I} x_{ij} = y_j \quad \forall j \in J \quad (2) \text{ Flow balance constraints: Containers} \\ & \sum_{j \in J} x_{ij} = w_i \quad \forall i \in I \quad (3) \text{ Flow balance constraints: Factories} \\ & z_j \text{ binary; } x_{ij}, y_j \geq 0 \quad (4) \text{ Binary } z_j \text{ and Nonnegativity} \end{aligned}$$

In the objective function, the total cost in the supply chain is to be minimized: The first summation represents the total cost of transferring waste from factories to container locations; the second summation represents the total fixed cost of opened containers (assuming that each container has a lifetime of one year); and the last summation represents the total cost of transferring waste from containers to the DC.

The constraints are as follows:

1. The first constraint set representing capacity constraints assures that monthly flow of waste from container location j does not exceed the maximum monthly capacity. As can be observed, the capacity of every container is assumed to be identical, namely C . This constraint set also links the selection of container location j to the monthly waste flow from that container to DC. There can be a monthly flow from container location j to DC only if a container is located at a container location j .
2. The second constraint set assures that the total amount of waste coming from different factories to a container j is the same as the total amount of waste transferred from that container j to the DC.
3. The third constraint set ensures that outgoing waste from a factory i is equal to its monthly amount of waste.
4. The fourth constraint set specifies that the z_j are binary and that the other variables are nonnegative

In order to solve the model presented above, we have decided to use GAMS (General Algebraic Modelling Systems), a high-level modeling system for mathematical programming and optimization (GAMS). We have decided to use CPLEX (ILOG) as the MIP solver. The model is built based on the TOSB data, which contains 17 factories, 5 candidate container locations and one DC. The complete GAMS model is given in Appendix A. We would like to remark that the real world values are distorted and thus hidden in the given GAMS model due to confidentiality issues. However the magnitude of costs are of the same scale. Construction of the model required the declaration of sets I and J and their elements as $I = \{f1, f2, f3, \dots, f16, f17\}$ and $J = \{c1, c2, c3, c4, c5\}$, respectively. The maximum monthly capacity C of each container is taken as 600 tons. Distances are calculated based on the actual road structure of TOSB for each arc and then the costs on the arcs are determined by taking fuel costs and staff expenses into account. All of the costs are monthly and in terms of YTL (new Turkish lira).

In the optimal solution, minimum monthly cost of the waste transfer from factories to container locations and then to the DC is 70,338 YTL (approximately \$48,000). Three container locations (c1, c3, c4) out of the five candidates were selected to be opened by the solver.

3. Network Visualization

Following the development of the mathematical model and the GAMS model, we have carried out a visualization of the solution that was found by CPLEX. Visualization can dramatically enhance one's understanding of the optimization results and enable perception of useful and interesting insights. Some supply chain design/optimization software (CIMPEL, HKUST, Llamasoft, LogisticTools, Logistics Simulation, The Logistics Institute) are known to visually represent supply chain networks. Meanwhile, the paper by Camm et al. (1997) is a supply chain classic from the operations research / industrial engineering literature. In their paper, the authors describe an optimization based information system that is supported by GIS (Geographical Information System) visualization. The system they describe is reported to save more than \$200 million for the consumer products giant Procter & Gamble.

The visualization in our study (Figure 2) was carried out through a simple Java program that reads two input files, namely `problem.txt` and `solution.txt` (given in Appendix B with distorted parameter values, ex: factory coordinates and flows). In this visualization only the containers that appear in the optimal solution are displayed. Each factory is represented by a circle filled with blue. The magnitudes of the flows between nodes are

reflected in the thickness of the arcs. Flows in the first stage (factories and containers) of the supply chain are represented by red arcs and flows in the second stage (containers and DC) are represented by black arcs. The arc labels denote the amount of flows on the arcs in tons.

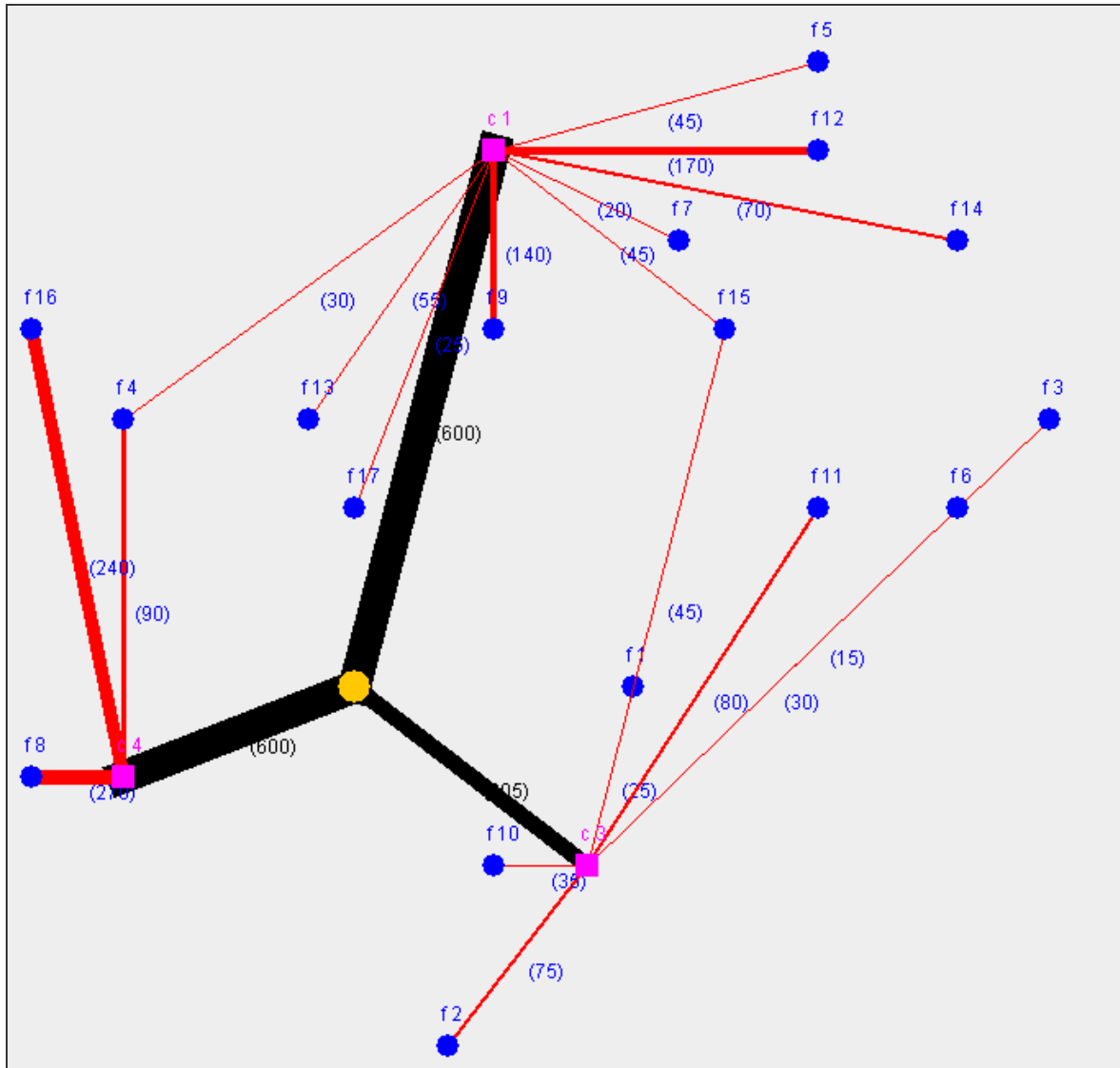


Figure 2. The Java visualization of the optimal supply chain network.

From Figure 2 one can observe that there exists a significant amount of flow from factories 8 and 16 (f8, f16) to container 4 (c4). Meanwhile there exist relatively significant amounts of flow from factories 4, 9, 12 (f4, f9, f12) to container 1 (c1). By observing the thickness of the black arcs from containers 1 and 4 to the DC, one can conclude that these two containers are utilized to full capacity. On the other hand, container 3 is not utilized to full capacity, since the arc from that container to the DC is approximately half as thick as the other black arcs. All the factories send their waste to a single container (single-sink), except factories 4 and 15 (f4, f15).

The visualization of the network allowed us to make the above observations, which would be very hard to make by looking at the text output of the GAMS solution. Thus we believe that the extra effort spent for the visualization is highly justified.

4. Related Literature

Amponsah and Salhi (2004) argue that waste collection problem is one of the most crucial problems for large cities and local authorities. Waste collection and solid waste management pose importance since some wastes contain toxic and hazardous ingredients, where some others are recycled. Literature contains studies focusing on efficient waste collection, supply chain network designs leading to operational cost savings. There are many related problems, including Vehicle Routing Problem (VRP), where the main aim is to incur the minimum total cost while routing multiple numbers of vehicles, going out from a depot, visiting intermediate nodes and returning back to the depot. (Tung, D. V., Pinnoi, A., 1999). Minimizing number of vehicles can be another objective in VRP. Vehicle

Scheduling and Routing Problem (VSRP) can be considered as an extension of VRP with time periods and place requirements constraints (Johansson, O. M., 2005). Additionally, Vehicle Routing Problem with Time Windows (VRPTW) includes time windows between which the nodes have to be visited (Kim, B. I. et al., 2005). Other problem variants include Periodic Vehicle Routing Problem (PVRP) (Teixeira et al., 2004) and Capacitated Arc Routing Problem (CARP) (Chu, et al., 2004).

The model which is most related to the network design problem in this paper is presented by Rahman et al. (1995). The authors refer to the problem as the Solid Waste Transfer Stations (SWTS) location problem and solve it for the City of Phoenix, Arizona. Their model aims to select the most suitable intermediate nodes to transfer materials with the objective of minimizing transportation costs. In their paper, they also develop an additional approach to SWTS by minimizing public opposition.

It is also possible to find out several works about waste management in Turkey. For example, Koçer et al. (2003) investigated waste collection, waste transfer costs and waste disposal areas in Elazığ, Turkey. In their research, they considered criteria such as location of the waste area, population, daily amount of waste, container capacities, weight of waste, costs, time, and productivity in waste management. They conclude that first of all, records for waste quantities and costs should be kept and secondly the number of workers, distances of transportation, capacities of the containers and their technical capabilities affect productivity. Another research is done by Karagüzel and Mutlutürk (2005), who considered geological, hydro geological, topographical criteria and observed environmental protection areas, land sliding and flooding in order to select the most suitable waste area in Isparta, Turkey. Demir et al. (2001) studied the design of waste transportation and waste collection in Yenimahalle, Ankara, Turkey. They have developed a long-term and short-term plan for waste collection and logistics and selected the transfer stations. They have developed a mathematical model similar to the one presented in our paper but additionally, they also considered allocation of trucks to collection areas, frequency of the collections and definition of the optimal roads. Their study also includes financial analysis.

5. Conclusions

We have presented the application of optimization to a real-world industrial waste collection problem. Two distinguishing aspects of our study are the following:

1. The model was built using real-world data provided by the management of the industrial region and estimated values which we believe are close enough to the real values (however, the values given in the paper for the model and its solution are distorted due to confidentiality agreements).
2. The optimal solution was visualized, enabling the observation of several interesting issues.

Mathematical programming, specifically mixed integer programming (MIP) is an essential tool to model and solve strategic and tactical managerial problems of industrial regions. Industrial regions in developing countries such as Turkey can highly benefit from this approach, as illustrated in our study. Meanwhile, visualization can contribute greatly to the usability and thus acceptance of optimization models in industry.

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Appendix A. The GAMS Model

```

SETS
    I   Factories      / f1*f17 /
    J   Container Locations / c1*c5 /
    DC  Disposal Center /d1/ ;

PARAMETERS

    F(J)  fixed monthly cost
          /   c1   626
            c2   626
            c3  1252
            c4   750
            c5   750
          /

    W(I)  average monthly waste amount of factory i
          /
f1  25
f2  75
f3  15
f4  120
f5  45
f6  30
f7  20
f8  270
f9  140
f10 35
f11 80
f12 170
f13 55
f14 70
f15 90
f16 240
f17 25
          /

    B(J)  unit cost per ton from location j to dc
          /   c1   36
            c2   40
            c3   36
            c4   32
            c5   44
          / ;

    TABLE A(I,J) unit cost per ton from factory i to location j
          c1   c2   c3   c4   c5
f1    26   16    6   32   24
f2    32   16   10   20   34
f3    30   32   22   46    6
f4    18   14   28    4   46
f5    14   24   24   34   16
f6    28   30   18   44   10
f7     8   14   20   30   28
f8    26   22   32    4   54
f9     4    6   20   20   30
f10   24   12    6   22   32
f11   26   24   14   40   14
f12   16   30   26   38   16
f13   12    6   18   12   38
f14   22   34   24   44   10

```

```

f15      14      20      16      34      24
f16      26      20      34      12      52
f17      14       2      16      16      42

SCALAR capacity /600/;

VARIABLES obj ;

    POSITIVE VARIABLES
        X(I,J)
        Y(J) ;

    BINARY VARIABLES Z(J) ;

EQUATIONS

    COST          objective function
    CAPLINK(J)
    FLOW(J)
    FLOW2(I);

COST ..          OBJ =E=  SUM((I,J),A(I,J)*X(I,J)) + SUM(J, F(J)*Z(J))
                        + SUM(J, B(J)*Y(J));
CAPLINK(J)..    Y(J) =L= CAPACITY*Z(j) ;
FLOW(J)..       SUM(I, X(I,J)) =E= Y(J) ;
FLOW2(I)..      SUM(J, X(I,J)) =E= W(I) ;

MODEL TOSB_PROJECT /ALL/ ;

option lp=CPLEX;
SOLVE TOSB_PROJECT USING MIP MINIMIZING OBJ ;

```

Appendix B

problem.txt

```

PROBLEM_FILE
NO_OF_FACTORYS
17
NO_OF_CONTAINER_LOCATIONS
5
FACTORY_COORDINATES
16 10
12 14
...
10 8
CONTAINER_LOCATIONS
13 4
12 8
15 12
5 11
26 5
DISPOSAL_CENTER_LOCATION
10 10
a_ij
26 16 6 32 24
...
b_j
36 40 36 32 44
w_i
25 75 15 120 45 30 20 270 140 35 80 170 55 70 90 240 25
C
600
f_j

```



```
25 75 15 120 45 30 20 270 140 35 80 170 55 70 90 240 25
```

solution.txt

```
SOLUTION_FILE
```

```
x_ij
```

```
0 0 25 0 0 0 0 75 0 0 0 0 15 0 0 30 0 0 90 0 45 0 0 0 0 0 30 0 0 20 0 0 0 0  
0 0 0 270 0 140 0 0 0 0 0 0 35 0 0 0 0 80 0 0 170 0 0 0 0 55 0 0 0 0 70 0 0 0  
0 45 0 45 0 0 0 0 0 240 0 25 0 0 0 0
```

```
y_j
```

```
600 0 305 600 0
```

```
z_j
```

```
1 0 1 1 0
```