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# Minimizing Safety Equipment Cost in Manufacturing Systems Using Transportation Simplex Method

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**Abstract**

This paper takes a deep look at the costs related to process safety. It is not confined to the costs of trips and alarms, compliance with regulations and worker training, but also takes into consideration many aspects considered standard process design practice. Factors that affect the cost due to the hazardous nature of operation have been listed. While the exact cost would vary from one plant to another, this cost could, according to our thinking, amount up to one-third to one-half, or even more, of the capital and operating costs of the new plant handling the hazardous operations. The vision of the process industry globally is zero hazards and zero accidents. The costs of running the hazardous process mentioned in this paper would hopefully drive the industry to consider inherently safer systems, green chemistry, process intensification, and the like.

**Keywords:** Cost analysis; Transportation simplex method; Fuzzy multi-objective linear programming; Supply chain

## Introduction

It was never an easy task to ensure safety for all the employees and contractors' employees of the Company. However, with determination, hard work and the engagement of everyone, from top management to the grass root level, the company has made it possible to reduce the number of accidents per year. Now, there are several problems which still pressurize the management. An optimization can be really useful if the fire and other necessary anti-hazard equipment can be distributed cost-effectively throughout different factories in the world. There are lots of different equipment used to prevent accidents like quarrying, crushing, filtering, fire hazards, clinker piling, mixing hazards, machine hazards, fuel storage activities, hazardous materials etc. We were also delivered some data. By using the data we started formulating our simple linear problem [1,2]. During formulation we realize that our problem is actually a combination of transportation (for distribution of parts) and linear programming (for the minimization of total cost).

Risky decisions can be complex. People can have great difficulty comprehending and performing well in complex situations. Yet such situations are common in organized, formal markets such as insurance and housing and in less formal settings involving individual health and safety [3]. The dominant economic paradigm for risky decisions has been the expected utility model, a model of rational behaviour. Whatever its position now, criticism of it is plentiful and research on anomalies associated with expected utility continues [4]. Even if traveling fully consider all the benefits and costs of their actions and are well informed, a problem may arise if individuals cannot properly process information about risks. The individual benefit-cost approach is appropriate for people who can evaluate the target level of safety that they have chosen. People who have the ability to do so compare their subjective estimates of risk being experienced to their target level and respond to any gap between the two. The criticism of safety decisions that is taken most seriously is the challenge to individual competency [5,6].

## Description of Optimization Methods Used

### Linear programming

Linear programming is all about allocating scare resources among competitive activities. An optimization problem will be linear if and only if it's all constraints function and objective function is linear. Linear programming problem can be of two types

1. Maximization problem

2. Minimization problem

The standard linear programming problem is given below

Minimize/Maximize $Z=c_1x_1+ c_2x_2 \cdots +c_nx_n=\Sigma c_jx_j$

subject to the constraints

$a_{11}x_1+a_{12}x_2+\cdots+a_{1n}x_n \le b_1$

$a_{21}x_1+a_{22}x_2+\cdots+a_{2n}x_n \le b_2$

….………………………

$a_{m1}x_1+a_{m2}x_2+\cdots+a_{mn}x_n \le b_n$

(or $Ax \le b$)

and

$x_1 \ge 0, x_2 \ge 0, \ldots, x_n \ge 0$ (or $\mathbf{x} \ge \mathbf{0}$).

Here $\mathbf{Z}=c_1x_1+\cdots+c_nx_n$ is the objective function, $\mathbf{Ax} \le \mathbf{b}$ the functional constraint and $\mathbf{x} \ge \mathbf{0}$ is the non-negativity constraint.

To apply linear programming to a problem, the problem has to follow some assumptions. The assumptions are illustrated below:

**Proportionality assumption:** The contribution of each activity to the value of the objective function Z is proportional to the level of the activity $x_j$ as represented by the $c_jx_j$ term in the objective function. Similarly, the contribution of each activity to the left-hand side of

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each functional constraint is proportional to the level of the activity $x_j$ as represented by the $a_{ij}x_j$ term in the constraint. Consequently, this assumption rules out any exponent other than 1 for any variable in any term of any function (whether the objective functions or the function on the left-hand side of a functional constraint) in a linear programming model. If the exponent is greater than 1, it can be solved using quadratic programming (QP) and thus it becomes non-linear in nature. Considering these, the assumption can also be termed as direct proportionality assumption [7,8].

**Additivity assumption:** Every function in a linear programming model (whether the objective functions or the function on the left hand side of a functional constraint) is the sum of the individual contributions of the respective activities. It actually means the total incorporation of the level of activities with demand in an objective function. The incorporation will be done using the addition (+) operator.

**Divisibility assumption:** Decision variables in a linear programming model are allowed to have any values, including non-integer values that satisfy the functional and non-negativity constraints. Thus, these variables are not restricted to just integer values. Since each decision variable represents the level of some activity, it is being assumed that the activities can be run at fractional levels. For an integer restriction on decision variables leads us to integer (IP) and mixed integer (MIP) programming.

**Certainty assumption:** The value assigned to each parameter of a linear programming model is assumed to be a known (certain) constant. But in real cases, it is typically violated. The values assigned to the different parameters generally follow a probability distribution. It becomes very important for sensitivity analysis and re-optimization of a valid model. Our problem seems quite simple at first with this assumption of certainty but eventually we come to know that the parameters (cost per unit) assigned for the objective function for different equipment are not valid and thus cannot be used directly in our solution to the linear programming model of cost minimization. Here comes the utilization of transportation simplex and formulation of a transportation (distribution) problem.

### Transportation problem (Transportation simplex)

In particular, the general transportation problem is concerned (literally or figuratively) with distributing any commodity from any group of supply centers, called sources, to any group of receiving centers, called destinations, in such a way as to minimize the total distribution cost. There could be many sources and their destinations. We also need to remember that the distribution is not limited to a single product from different sources. There could be more than one product for distribution [9]. In such cases the problem can be defined to be combination of two (or more) transportation problems. For transportation problem, a modified simplex is used which is termed as transportation simplex. There are many variations in different steps to this special form such as:

**North-west corner rule:** It basically determines the direction of a transportation simplex tableau. This rule allows us to begin the distribution of item from the north-west corner point and keep going until all the resources are allocated.

**Vogel's approximation method:** It is more concerned with the parametric table rather than the simplex tableau. It depends on the difference between smallest and next to the smallest values in parametric tableau for each iterative solution. Largest difference with smallest unit costs will be the direction for the distribution.

**Russell's approximation method:** It determines the largest unit cost and the multiplier of the basic variables are approximated to be the largest negative value in the transportation simplex tableau. The tie in the values for this method can be broken arbitrarily.

In a transportation problem, certain assumptions are followed or maintained (otherwise, it must be modeled with linear programming with lots of constraints that would be next to impossible in some cases to solve). The assumptions are illustrated below:

**The requirements assumption:** Each source has a fixed supply of units, where this entire supply must be distributed to the destinations. Similarly, each destination has a fixed demand for units, where this entire demand must be received from the sources. This assumption that there is no leeway in the amounts to be sent or received means that there needs to be a balance between the total supply from all sources and the total demand at all destinations.

**The feasible solutions property:** A transportation problem will have feasible solutions if and only if

$\sum_{i=1}^{m} S_i = \sum_{j=1}^{n} d_j$ , where s=supply and d=demand for i and j number of sources and destinations respectively.

In some real problems, the supplies actually represent maximum amounts (rather than fixed amounts) to be distributed. Similarly, in other cases, the demands represent maxi-mum amounts (rather than fixed amounts) to be received. Such problems do not quite fit the model for a transportation problem because they violate the requirements assumption.

However, it is possible to re-formulate the problem so that they then fit this model by introducing a dummy destination or a dummy source to take up the slack between the actual amounts and maximum amounts being distributed.

**The cost assumption:** The cost of distributing units from any particular source to any particular destination is directly proportional to the number of units distributed. Therefore, this cost is just the unit cost of distribution times the number of units distributed. (We let $c_{ij}$ denote this unit cost for source i and destination j.) It is more like a proportionality assumption in linear programming model.

**The model:** Any problem (whether involving transportation or not) fits the model for a transportation problem if it can be described completely in terms of a parameter table after satisfying both the requirements assumption and the cost assumption. The objective is to minimize the total cost of distributing the units from different sources to different destinations.

**Integer solution property:** For transportation problems where every $s_i$ and $d_j$ have an integer value, it is obvious that all the basic variables (allocations) in every basic feasible (BF) solution (including an optimal one) also have integer values. The integer solution property is automatically satisfied when setting up the table for demand and supply units.

## Problem Description

Lafarge Shurma Cement company is a leading company in cement production. It has a corporate office at Dhaka and three production plants located at Shreepur, Sylhet and Chittagong. They are going to buy some safety equipment, mainly helmets, gloves and $CO_2$ cylinders. These equipment are going to be imported from three different countries. These goods will enter into in to the country at three different points (Dhaka Airport, Chittagong Sea-port and Benapole Border) and from these ports they will be distributed among the production plants and the corporate house. Management is seeking a way of distribution so that they can minimize their distribution cost. The problem is illustrated with the following Figure 1.

The different costs associated with the transportation problem will be discussed in the numerical analysis of this report. The management wanted us to minimize their overall cost with some given constraints but we face a major problem in determining the optimum cost range for the transportation of different safety equipment. The problem begins with the carbon di-oxide cylinder having two different sources with four destinations. It was not possible for typical transportation simplex to solve the total problem at once for different sources of one single product. That is why we had to subdivide the total problem into a series of transportation problems for each of the equipment (namely helmets, $CO_2$ cylinders and gloves) and then find the optimum number of equipment required for cost minimization [10-14]. With those values and the minimized function values, we determine the average optimized cost for each of the 3 equipment units transported to factories. Finally we used this data in the total cost function (which is eventually a linear function of the three cost functions from three equipment) to minimize it with some given constraints. The solution steps are illustrated below with the help of a Figure 2.

## Numerical Calculation

### Data sets

We were given different scattered data sets from which we became able to construct the following parameter table for our analysis (Tables 1-3) and also we were told by the management to keep the total number of equipment bought to be at most 10,000 pieces and no way more than this for cost minimization.

### Numerical solutions

Software packages used: Microsoft Excel 2013 and Tora.

Microsoft Excel 15.0 Answer Report,

Worksheet: [Book1] Sheet 1,

Report Created: 19-Jun-19 7:42:53 PM,

Result: Solver found a solution. All Constraints and optimality conditions are satisfied.

### Solver engine

Engine: Simplex LP,

Solution Time: 0.015 Seconds.

Iterations: 10 Subproblems: 0.

### Solver options

Max Time Unlimited, Iterations Unlimited, Precision 0.000001, Use Automatic Scaling

Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 1%, Assume NonNegativ (Tables 4, 5, and Figures 3-5.

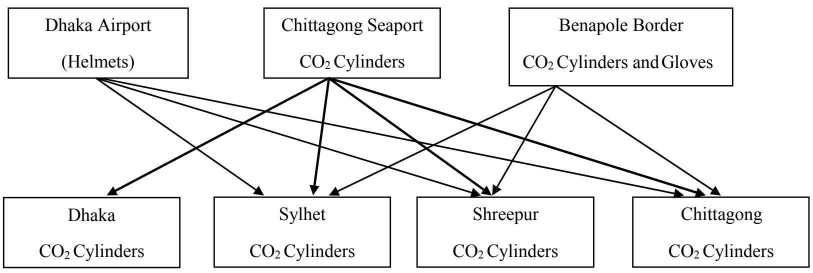


**Figure 1:** Illustration of the project problem.

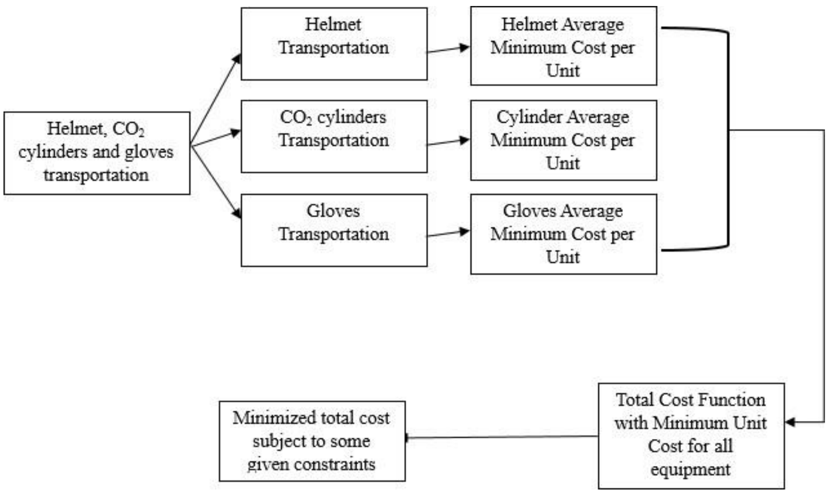


**Figure 2:** Flow chart for the solution steps for the project problem.

| To | Dhaka | Sylhet | Shreepur | Chittagong | Supply |
|---|---|---|---|---|---|
| From | | | | | |
| Chittagong Seaport | 30,000 | 17,500 | 4,000 | 5,000 | 1,280 |
| Benapole Border | 17,000 | 30,000 | 18,000 | 2,500 | 170 |
| Demand | 320 | 450 | 300 | 330 | |

**Table 1:** Parameter Table for $CO_2$ Cylinders.

| To | Dhaka | Sylhet | Shreepur | Chittagong | Supply |
|---|---|---|---|---|---|
| Dhaka Airport | 0 | 20,000 | 15,000 | 30,000 | 4000 |
| Demand | 0 | 1400 | 1430 | 1500 | |

**Table 2:** Parameter Table for Helmets.

| To | Dhaka | Sylhet | Shreepur | Chittagong | Supply |
|---|---|---|---|---|---|
| Dhaka Airport | 0 | 20,000 | 15,000 | 30,000 | 4000 |
| Demand | 0 | 1200 | 1000 | 900 | |

**Table 3:** Parameter Table for Helmets.

| Objective Cell (Min) | | | | |
|---|---|---|---|---|
| **Cell** | **Name** | | **Original Value** | **Final Value** |
| $J$11 | DHAKA | | 0 | 18965000 |
| **Variable Cells** | | | | |
| **Cell** | **Name** | **Original Value** | **Final Value** | **Integer** |
| $J$5 | CTG DHAKA | 0 | 0 | Contin |
| $K$5 | CTG SYLHET | 0 | 450 | Contin |
| $L$5 | CTG SHREEPUR | 0 | 300 | Contin |
| $M$5 | CTG CTG | 0 | 530 | Contin |
| $J$6 | BENAPOL DHAKA | 0 | 320 | Contin |
| $K$6 | BENAPOL SYLHET | 0 | 0 | Contin |
| $L$6 | BENAPOL SHREEP | 0 | 0 | Contin |
| $M$6 | BENAPOL CTG | 0 | 0 | Contin |
| **Constraints** | | | | |
| **Cell Name** | **Cell Value** | **Formula** | **Status** | **Slack** |
| $J$9 total DHAKA | 320 | $J$9>=$J$8 | Binding | 0 |
| $K$9 total SYLHET | 450 | $K$9>=$K$8 | Binding | 0 |
| $L$9 total SHREEPUR | 300 | $L$9>=$L$8 | Binding | 0 |
| $M$9 total CTG | 530 | $M$9>=$M$8 | Not Binding | 200 |
| $P$5 CTG total | 1280 | $P$5>=$O$5 | Binding | 0 |
| $P$6 BENAPOL total | 320 | $P$6>=$O$6 | Not Binding | 150 |

**Table 4:** Answer sheet for $CO_2$ Cylinders.

| Variable Cells | | | | | | |
|---|---|---|---|---|---|---|
| **Cell** | **Name** | **Final Value** | **Reduced Cost** | **Objective Coefficient** | **Allowable Increase** | **Allowable Decrease** |
| $J$5 | CTG DHAKA | 0 | 8000 | 30000 | 1.00E+30 | 8000 |
| $K$5 | CTG SYLHET | 450 | 0 | 17500 | 17500 | 12500 |
| $L$5 | CTG SHREEPUR | 300 | 0 | 10000 | 13000 | 5000 |
| $M$5 | CTG CTG | 530 | 0 | 5000 | 5000 | 5000 |
| $J$6 | BENAPOL DHAKA | 320 | 0 | 17000 | 8000 | 17000 |
| $K$6 | BENAPOL SYLHET | 0 | 17500 | 30000 | 1.00E+30 | 17500 |
| $L$6 | BENAPOL SHREEPUR | 0 | 13000 | 18000 | 1.00E+30 | 13000 |
| $M$6 | BENAPOL CTG | 0 | 25000 | 25000 | 1.00E+30 | 25000 |
| **Constraints** | | | | | | |
| **Cell** | **Name** | **Final Value** | **Sadow Price** | **Constraint R.H. Side** | **Allowable Increase** | **Allowable Decrease** |
| $J$9 | total DHAKA | 320 | 17000 | 320 | 1.00E+30 | 150 |
| $K$9 | total SYLHET | 450 | 12500 | 450 | 200 | 450 |
| $L$9 | total SHREEPUR | 300 | 5000 | 300 | 200 | 300 |
| $M$9 | total CTG | 530 | 0 | 330 | 200 | 1.00E+30 |
| $P$5 | CTG total | 1280 | 5000 | 1280 | 1.00E+30 | 200 |
| $P$6 | BENAPOL total | 320 | 0 | 170 | 150 | 1.00E+30 |

**Table 5:** Sensitivity Analysis for distributing $CO_2$ Cylinders.

```
Title: OR_PROJECT
Size:(2 x 5)
Final Iteration No: 3
Total cost =   19915000.0000


                                          DummyD
         D1        D2        D3        D4        D5
        |----------|----------|----------|----------|----------|
        |30000     |17500     |10000     |5000      |0         |
        |
S1      | 150      | 450      | 300      | 330      | 50       | 1280
        |    0.00|     0.00|     0.00|     0.00|     0.00|
        |----------|----------|----------|----------|----------|
        |17000     |30000     |18000     |25000     |0         |
        |          |          |          |          |
S2      | 170      |          |          |          |          | 170
        |    0.00| -25500.00| -21000.00| -33000.00| -13000.00|
        |----------|----------|----------|----------|----------|
Vj          30000.00  17500.00  10000.00   5000.00   V5=0.00
DEMAND          320       450       300       330        50

          Ui       SUPPLY
        |
        |      0.00
        |
S1      | 1280
        |
        |
        |   -13000.00
        |
S2      | 170
        |
        |
Vj
```

**Figure 3:** Tora software optimization with Northwest Corner Rule.

```
Title: OR_PROJECT
Size:(2 x 5)
Final iteration no: 1
Total cost =   19915000.0000

--------------------------------------------------------------------
From       To        Amount      Unit Cost      Route Cost
--------------------------------------------------------------------
S1         D1          150       30000.00     4500000.00
           D2          450       17500.00     7875000.00
           D3          300       10000.00     3000000.00
           D4          330        5000.00     1650000.00
           D5  DummyD       50         0.00          0.00

S2         D1          170       17000.00     2890000.00
           D2            0       30000.00          0.00
           D3            0       18000.00          0.00
           D4            0       25000.00          0.00
           D5  DummyD        0         0.00          0.00


Summary of Transportation Costs

--------------------------------------------------------------------
Node        Supply/Demand       Total Cost      Av. Cost/unit
--------------------------------------------------------------------
S1              1280          17025000.00         13300.78
S2               170           2890000.00         17000.00

D1               320           7390000.00         23093.75
D2               450           7875000.00         17500.00
D3               300           3000000.00         10000.00
D4               330           1650000.00          5000.00
D5 DummyD             50             0.00             0.00
```

**Figure 4:** Tora software optimization with Least Cost (Russell's Approximation) Method.

```
OPTIMUM TRANSPORTATION SOLUTION

Title: OR_PROJECT
Size:(2 x 5)
Final iteration no: 2
Total cost =   19915000.0000

--------------------------------------------------------------------
From       To        Amount      Unit Cost      Route Cost
--------------------------------------------------------------------
S1         D1          150       30000.00     4500000.00
           D2          450       17500.00     7875000.00
           D3          300       10000.00     3000000.00
           D4          330        5000.00     1650000.00
           D5  DummyD       50         0.00          0.00

S2         D1          170       17000.00     2890000.00
           D2            0       30000.00          0.00
           D3            0       18000.00          0.00
           D4            0       25000.00          0.00
           D5  DummyD        0         0.00          0.00


Summary of Transportation Costs

--------------------------------------------------------------------
Node        Supply/Demand       Total Cost      Av. Cost/unit
--------------------------------------------------------------------
S1              1280          17025000.00         13300.78
S2               170           2890000.00         17000.00

D1               320           7390000.00         23093.75
D2               450           7875000.00         17500.00
D3               300           3000000.00         10000.00
```

**Figure 5:** Tora software optimization with Vogel's Approximation Method.

For similar calculations, the steps for allocating helmets and gloves are skipped. We were able to create the necessary tableau with the following minimized average cost like the following (Table 6).

Now, the formulation for the linear programming can be stated like this:

Minimize Z=22000$x_1$+13500$x_2$+24a250$x_3$

Subject to,

$$
\begin{array}{lllll}
x_1 & & & \geq & 4300 \\
 & x_2 & & \geq & 1400 \\
 & & x_3 & \geq & 3100 \\
x_1 & +x_2 & +x_3 & \leq & 10000
\end{array}
$$

Where x1, x2 and x3 are the number of helmets, $CO_2$ cylinders and gloves.

From iterative simplex, we find the following optimum number of equipment to be transported via different routes to the factories located at 4 places in the country. Thus the aggregated supply (=demand) will be described as follows:

Number of helmets=5500 pieces,

Number of $CO_2$ cylinders=1400 pieces,

Number of gloves=3100 pieces,

And thus the optimized minimum cost will be 21, 50, 75000 taka.

| Equipment name | Minimized total cost (taka) | Minimized average cost (taka) | Optimized Demand (Units) |
|---|---|---|---|
| Helmet | 9,45,50,000 | 22,000 | 4300 |
| $CO_2$ Cylinder | 1,89,65,000 | 13,546 | 1400 |
| Gloves | 10,50,00,000 | 24,250 | 3100 |

**Table 6:** Minimized total cost and minimized average cost.

## Conclusion

In this project we have done mainly transportation problem along with linear problem. Here we apply the problem formulation to a renowned factory named Lafarge Surma Cement company. Our findings serve as a baseline for possible development of this company. The company actually gives much emphasis on the safety of the company worker and that's why they wanted to allocate the safety equipment to their different branches at minimum costs. At the time of solving, we found the problem a little bit complex. Going through our project we can see that Transportation Simplex method is efficient and essential model to deal with our project rather than other models. We used three methods for solving this problem. To make it easy we have used Simplex method for solving the linear problem. At the end of the day we actually minimize the transportation cost of those safety equipment and were able to provide an idea about the aggregated supply (=demand) for minimized cost.

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