APPLICATION OF PRINCIPLES OF RELIABILITY ANALYSIS TO OPTIMIZATION PROBLEM IN TRANSPORTATION INDUSTRY

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Abstract:
A typical optimization problem emanating from the actual optimization that is conducted on a routine basis at a leading retail store, Staples, Inc. is used to illustrate the concepts of Simulation-optimization. This is done by solving a transportation problem of 10 cities (a subset of the actual 40-city problem) using optimization principles. The same problem is then solved using probabilistic principles using the total traveled distance between two cities as a random variable (depending upon the route taken). In a typical Simulation-optimization problem, Monte Carlo simulation is used for simulation of random paths. In this paper, an alternate but efficient method is prposed and used based on the probability principles. This is based on the concept of capturing uncertainities ranging from 68.3% to 99.7% in the physical system based on (μ +/- σ, μ +/- 3)σ concept. The results from probabilistic optimization and the corresponding deterministic optimization are the compared. It is found that sumulation-optimization results in savings of cost as compared to traditional optimization.

Keywords: Reliability, optimization, Simulation, Random, Transportation

1. Introduction

This paper deals with application of principles of simulation-optimization to problems related to transportation industry. In transportation industry, the main aim is to minimize the cost of transportating various comodities from several sources to several destinations with an with some practical constraints and associated cost for each of the path chosen. This is a typical LPP (Linear Programming problem) associated with transportation industry. The industry chosen for this study is Staples, Inc., a well known retail store with a good reputation. All this is related to deterministic optimization in which all the possible paths and the associated costs are fixed quantities. In a probabilistic analysis, each path is consideed as a Random variable (RV) as the outcome is uncertain. The solution of a probabilstic analysis problem typically involves use of smulation principles such as Monte Carlo simulation. When these two pinciples (optimization and probability are combined, it leads to what is known as Simulation-Optimization. This paper considers a typical transportation industry problem (a subset of the actual problem used at Staples, Inc.) and solves it as a traditional deterministic optimzation problem as well as simulation-optimization problem (it's probabilistic conterpart) and the results are compared. Essentially, this paper applies the concepts of reliability analysis to optimization problem with specific application to transportation industry (Putcha and Rao, 1991).

2. Details of JDA software used at Staples, Inc.

JDA Software Group, Inc is a leading global provider of supply chain management, merchandising and pricing solutions. Located in Scottsdale, Arizona, JDA empowers more than 6,000 companies of all sizes to make optimal decisions that improve profitability and achieve real results in the discrete and process manufacturing, wholesale distribution, transportation, retail and services industries. JDA Software has acquired many market leaders including i2 Technologies, Manugistics, E3, Intactix and Arthur (http://en.wikipedia.org/wiki/JDA Software)

At Staples, the Retail distribution team uses the Transportation optimization software provided by JDA. Transportation management and logistics management solutions from JDA Software effectively manage the entire closed-loop transportation process — from long-range strategies and operational planning to day-to-day execution (JDA User Manual, Transportation and LogisticsManagementRelease7.5.2.2, http://www.jda.com/company/display-collateral/pID/492/).

2.1 Key functions of a transportation management module can:

- Implement transportation plans driven by consumer demand and replenishment policies
- Control costs and streamline productivity
- Leverage logistics to support profitable growth
- Improve trading partner relationships with effective collaboration

The JDA will give us the least cost carrier assignment based on the information provided. It optimizes the complex transportation problem and give us the comprehensive solution. At Staples, Inc the required information from vendors, carriers, PC miller, inventory at warehouse and warehouse resources allocation for the transportation planning are integrated in the JDA system. Based on the constraints that we provied to the software, it creates optimal loads satisfying our constraints with stop sequence.

2.2 Capabilities of JDA that helps our transportation:

- Provides multi-modal, multi-echelon logistics network design
- Optimizes based on actual costs, distances and service levels
- Qualifies modal tradeoffs with service level requirements
- Honors private fleet and third-party carrier volume requirements
- Evaluates multiple business scenarios to determine optimal transportation policies
- Provides an optimization engine that is consistent with the daily planning engine to ensure realization of anticipated results
- Develops green network strategies
- Enables multi-site, inbound, outbound and backhaul load planning
- Provides deep support for private fleet and third-party carrier environments
- Supports complex, multi-modal planning and optimization
- Provides advanced carrier selection and load optimization
- Leverages real business and operational constraints for load planning and optimization
- Includes optimization for load building and containerization, inventory-sensitive transportation and dock-sensitive routes
- Includes a robust, interactive planner workbench
- Provides robust rate management and cost allocation
- Delivers seamless planning-to-execution transition

Not only just building the loads, its also gives performance measures that enable us to evaluate the transportation cost in different senarios and also to find the progress. The report generated will have the detailed information of the loads and the optimization [3].(This information is taken from JDA website)

2.3 Problem Formulation of Optimization

The goal of our optimization is to reduce the transportation cost. Allocation of resources is the best way to get the optimization results. There are several constraints that will limit optimization. For exapmle, Some store are feasible with 48 footer trucks, some require lift gate, some stores need to be delivered in perticular time. Satisfying all the constraints JDA will give the results.

Objective: Minimization of outbound transportation cost for Staples.

$$\text{Min } Z = C1* X1 + C2* X2 + C3* X3 \ldots\ldots\ldots\ldots Cn*Xn$$

Where C1,C2,C3…Cn are the cost associated with the perticular store

And X1,X2,X3……Xn are the respective distances from the warehouse W to the store

2.3.1 Assumptions/Constraints:

1. A standard 53 footer truck can fit 30 pallets or 2600 cube
2. A standard 48 footer truck can fit 26 pallets
3. Depends on the geographical location of the store, they may require Lift gate at delivery
4. Total number of trucks available in a perticular day is limited and vary each day
5. A driver must take a layover of minimun 10 hours after eleven hours of drive
6. Delivery must be done in the store hours only and they vary from store to store
7. Some stores are have special requirement/equipment
8. No delivery on Sunday
9. Wearhouse is open 24x7
10. Orders are available at 2 am in the morning at wearhouse each day
11. Some stores require delivery at Crossdock
12. Special orders for the stores should also be routed with the existing orders
13. No order should left unrouted at any cost
14. Distance between points/stores is calcuated by PC Miller

2.3.2 Actual Example problem :

A typical transportation problem encountered on a particular day (depending on the demand) resulted in the following optimization table (Table 1) using JDA software.

Table 1 Actual results for 40 cities obtained using JDA optimization software

Load	stops	PltDL	Miles	Manu Cost
00005537826M	4	10	357	$755
00005537830M	3	10	417	$806
00005537833M	4	7	406	$745
00005537837M	4	14	435	$846
00005537841M	4	9	407	$804
00005537845M	4	0	278	$521
00005537847M	4	10	428	$886
00005537851M	5	11	901	$1,697
00005537855M	7	8	780	$1,655
00005537861M	5	6	574	$1,104
00005537866M	4	7	368	$808
00005537870M	5	7	391	$856
00005537875M	4	8	418	$872
00005537879M	5	7	949	$1,801
00005537883M	9	10	1324	$2,444

00005537888M	4	10	445	$917
00005537892M	4	10	362	$656
00005537979M	4	12	251	$801
00005537987M	5	9	249	$822
00005537992M	7	8	408	$858
00005537997M	4	9	188	$672
00005538001M	5	12	396	$862
00005538005M	4	13	195	$684
00005538009M	4	8	247	$761
00005538013M	7	8	557	$1,130
00005538019M	3	15	180	$609
00005538022M	5	9	195	$447
00005538026M	3	11	256	$744
00005538029M	5	8	225	$506
00005538033M	5	9	149	$357
00005538037M	6	10	372	$814
00005538042M	4	11	214	$711
00005538046M	5	13	328	$706
00005538050M	8	8	409	$888
00005538056M	4	11	179	$669
00005538060M	3	11	196	$625
Total		348		$32539

The total cost for this transportation of various commodities from various sources to required destinations is $32539.

2.3.3 Example Problem (with Manual Adjustments)

For some practical reasons we have to do manual adjustments for the optimization. As is well known, it is difficult to attain global optima. Making changes in the software based on the constraints of the actual problem resulted in getting a better optima. The corresponding results are shown in Table 2 below.

Table 2 Results for 40 cities obtained after making (manual adjustments) using JDA optimization software

Load	Stops	Pallets	Miles	Total Cost
00005537826M	4	10	357	$755
00005537837M	5	8	488	$1,048
00005537847M	4	10	428	$886
00005537855M	9	6	785	$1,476
00005537870M	4	6	391	$856
00005537892M	4	13	354	$758
00005537979M	4	12	251	$801
00005537987M	5	9	249	$822
00005538009M	4	8	247	$761
00005538013M	5	7	557	$1,130
00005538026M	3	11	256	$744

00005538840M	4	15	180	$669
00005538850M	7	10	383	$814
00005539332M	4	10	504	$1,022
00005539336M	5	11	960	$1,798
00005539341M	5	9	393	$891
00005539346M	5	12	803	$1,507
00005539350M	4	7	407	$745
00005539355M	4	6	538	$986
00005539359M	9	6	1028	$1,870
00005539364M	4	7	368	$808
00005539368M	4	10	445	$917
00005539378M	5	7	305	$661
00005539383M	8	6	400	$869
00005539389M	4	9	201	$689
00005539393M	4	9	346	$741
00005539398M	5	12	345	$716
00005539402M	4	13	184	$679
00005539408M	5	8	186	$429
00005539412M	4	8	194	$423
00005539415M	6	10	376	$822
00005539420M	5	9	149	$357
00005539424M	4	11	214	$711
00005539428M	4	11	190	$674
00005539432M	4	8	166	$662
Total		348		$30,497

As can be seen from Table 2, the optimum cost obtained now is lower than the previous optima.

3.1 Simulation Optimization Problem

For the purpose of this research to illustrate the concept of Simulation optimization, a problem of transporting material to 11 cities (a subset of the actual 40 city problem used at Staples, Inc.) is used here. First, traditional deterministic optimization is performed using JDA software followed by Probabilistic optimization.

3.1.1 Deterministic Optimization

For the ease research, we took a sample of 11 orders based in OH and WV. The order set shown and the necessary information for those orders is shown in table 3 below.

Table 3 Request of orders for the chosen cities for deterministic optimization

Source ID	Source City	State	Pallets	Cube	Destination ID	Destination	State
RDC00994	HAGERSTOWN	MD	8	696	STR01202	ATHENS	OH
RDC00994	HAGERSTOWN	MD	10	885	STR00851	FERMONT	OH
RDC00994	HAGERSTOWN	MD	10	873	STR00840	ELYRIA	OH
RDC00994	HAGERSTOWN	MD	9	782	STR00753	NEW PHILADALPHIA	OH
RDC00994	HAGERSTOWN	MD	10	829	STR00591	WOOSTER	OH
RDC00994	HAGERSTOWN	MD	8	680	STR00451	COLUMBUS	OH
RDC00994	HAGERSTOWN	MD	9	763	STR00403	COLUMBUS	OH
RDC00994	HAGERSTOWN	MD	10	877	STR00609	BECKLEY	WV
RDC00994	HAGERSTOWN	MD	10	879	STR00607	CHARLESBURG	WV
RDC00994	HAGERSTOWN	MD	10	847	STR00432	CHARLESTON	WV
RDC00994	HAGERSTOWN	MD	10	869	STR00352	CHARLESTON	WV

We took this order set and optimized using the JDA. These orders were grouped together and for the simplicity there is no return pallets included. All the loads are one way trips. This will help us to give variation in the cost. The results were tabulated and it shows the number of stops in each truck load, number of pallets included, miles and the total cost.
The results are tabulated as below in Table 4 below

Table 4 Results for Deterministic optimization using JDA

Load	Stops	Pallets	Miles	Total cost
00005258907M	4	29	492	$1060
00005258911M	3	20	426	$776
00005258914M	4	28	473	$792
00005258918M	4	27	402	$840
Total			**1301**	**$3468**

3.1.2 Probabilistic optimization (Simulation Optimization)

The procedure used is as follows:

1. Calculate the statistical parameters of the random varaible (Td) which can be considered a Random Variable (RV). These statistical parameters are - Mean value -μ and standard deviation -σ).
2. Calculate μ - σ, μ + σ, μ - 2 σ, μ + 2 σ, μ - 3 σ, μ + 3 σ values of Td. There are total of 6 values but there are 3 sets [μ - σ, μ + σ], [μ - 2 σ, μ + 2 σ,], [μ - 3 σ, μ + 3 σ].

   The reason for choosing these three is because each of these three sets because these capture uncertainties of 68.3%, 95.4% and 99.7% respectively which cover almost all practical ranges. Hence results obtained using these ranges, are practical and correspond to a realistic situation.

3. Pick the cities corresponding to each of these 6 values.
4. Pick those cities and run the software which will give us the optimal path.

Using the above detailed procedure, the following steps are performed as solution of probabilistic optimization (simulation –optimization).

It is to be noted that, the suggested method is used instead of traditional Simulation method such as – Monte Carlo Simulation (Ang and Tang, 2007), and the method used elsewhere (Putcha and Rao1991; Putcha and Tadi, 2010) is because this is a large number of random samples is required for Monte Carlo Simulation for it to be realistic. Further, the method proposed in this paper captures most of the uncertainties up to 99.7%.

For the same data set, we are now calculating the distances between the cities. The stores were arranged in the order of their zip codes.

Table 5 Request of orders for the chosen cities for probabilistic optimization

S.no	City	ID	STATE	ZIP	Distance in miles from W
1	ATHENS	L1	OH	45701	291
2	FREMONT	L2	OH	43420	365
3	ELYRIA	L3	OH	44035	321
4	NEW PHILADELPHIA	L4	OH	44663	262
5	WOOSTER	L5	OH	44691	305
6	COLUMBUS	L6	OH	43212	333
7	COLUMBUS	L7	OH	43235	350
8	BECKLEY	L8	WV	25801	294
9	CHARKSBURG	L9	WV	26301	185
10	CHARLESTON	L10	WV	25313	303
11	CHARLESTON	L11	WV	25309	304

For the purpose of research, let’s assume store L11 is the mandatory delivery store. Now we need to find the optimal path that is feasible to make a delivery to that store. Let us call the warehouse location as “W” and the final destination as “D”. There are different paths that a truck can go to this destination.

The Distance from the W to D is a random variable and let’s say it “Td”. Consider different random paths between these two points. These order numbers were obtained by random number generator.

Table 6 Distances for cities for Probabilistic optimization using JDA

Source "W"	L	L	L	L	L	L	L	L	L	L	"D" L11	Total Distance Td
W	4	3	10	7	1	5	9	8	2	6	D	2091
W	8	3	7	10	6	5	2	4	1	9	D	1849
W	1	5	4	7	10	8	9	3	2	6	D	1671
W	9	3	1	7	6	8	5	10	4	2	D	2222
W	6	2	9	4	5	7	10	1	8	3	D	2183
W	5	10	7	8	6	3	2	9	4	1	D	2158
W	7	3	9	2	6	8	4	5	10	1	D	2104
W	10	7	4	2	9	1	5	6	8	3	D	2392

Calculating the Mean $\mu = \sum Td/8$

$= 2083.75$

Standard Deviation SD = $\sqrt{(\sum(xi - \mu)2)/((N-1))}$

$= 225.33$

Table 7 Range of Distances corresponding to the random variable of total distance between initial and final city (based on probability theory)

	μ - s	μ + s	μ - 2s	μ + 2s	μ - 3s	μ + 3s
	1858.42	2339.08	1633.09	2534.41	1407.76	2759.74

Consider the μ - σ, the nearest Td value to this number is 1849. In this path, consider stores that make the solution feasible. In other words, using these points obtain a solution that is feasible with the real time constraints. By applying this method to all the μ and Sigma combinations we got the following results:

Table 8 Results for Probabilistic Optimization

Combination	Feasibility	Total Cost in $
μ - σ	Y	1440
μ + σ	Y	1562
μ - 2σ	Y	1292
μ + 2 σ	Y	1562
μ - 3σ	Y	1440
μ + 3σ	Y	1562

4.0 Discussion of Results and Conclusions

As can be seen from Table 4 and Table 8, the total optimal cost for deterministic optimization is $3468 while the range of optimal cost for probabilistic optimization is from $1292 to $1562 for the whole spectrum of uncertainties. This shows the efficacy of probabilistic optimization or what is known as simulation-optimization. While the procedure for simulation-optimization is little bit involved as it uses the concept of probability and statistics, it does result in saving of cost. Hence it is recommended that simulation-optimization be used for solving transportation problems.

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