Consolidation of Forward and Reverse logistics in an automobile industry: Case of SAZEHGOSTAR-SAIPA

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Abstract

This paper address the devising an integral logistics network for a real life case of a car industry in Iran called SAIPA group by consolidating the transportations involved its forward and reverse logistics activities. Currently, delivery dates are offered by SAZEHGOSTAR-SAIPA to suppliers and each supplier separately should execute their transpotations (sending parts and returning reusable empty pallets required for packaging of parts) by their vehicles. By using the vehicle-routing problem (VRP) approach, we integrate the gathering parts and subassemblies from suppliers and carry them to the plant of SAIPA, meanwhile deliver the empty pallets to them in order to minimize the transportation costs. Due to finite capacity of vehicles, we consider capacitated VRP (CVRP) and offer a rapid and near optimum solution using Tabu Search meta-heuristic and analysis the setting of its parameters.

Keywords: capacitated VRP (CVRP), transportions, Tabu Search, logistics network

1- Introduction

This paper is a case study of development a CVRP in an automotive part supplier company, called SAZEHGOSTARE of SAIPA company (S.G.S. Co.) which is a key partner of trading part for SAIPA group and has the responsibility of the supplying the all parts and subassembly parts to the plants of SAIPA. SAIPA company has started his activities in automotive production industry since 1975 by cooperation with CIROEN company. By 44 years experience, it becomes one of the two largest car manufacturers in Iran and after many years of development, now it is a group of corporations that involve 4 main plants in different areas for cars assembly lines that makes different class of cars (SUV, pick up, saloon, hatchback …) in 13 models, minibuses in 2 models and buses in 2 models. In the 2010, SAIPA as a group of car manufacturers could turn out these product approximately at the rate of 60000 cars per year. The S.G.S., a sub-company that completely affiliated to SAIPA group, started its activities in 1991 in the fields of designing, manufacturing management, supplying and distributing of the automotive parts and subassemblies to the SAIPA's plants. Because of the diversity of parts which is supplied by S.G.S., about 4500 parts and sub-assemblies, this company has outsourced all production activities to the sub-manufacturers that it involves about 500 large, medium and small different producers. These activities also contain supplying some special raw materials that are mainly sold in large bulk to some producers-for example, steel iron sheet, some polymers and etc. This large

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number of suppliers which are geographically widespread thorough the country of Iran and also enormous range of different pars which must be delivered to the SAIPA's plants needs a plethora of logistics activities and transportations.

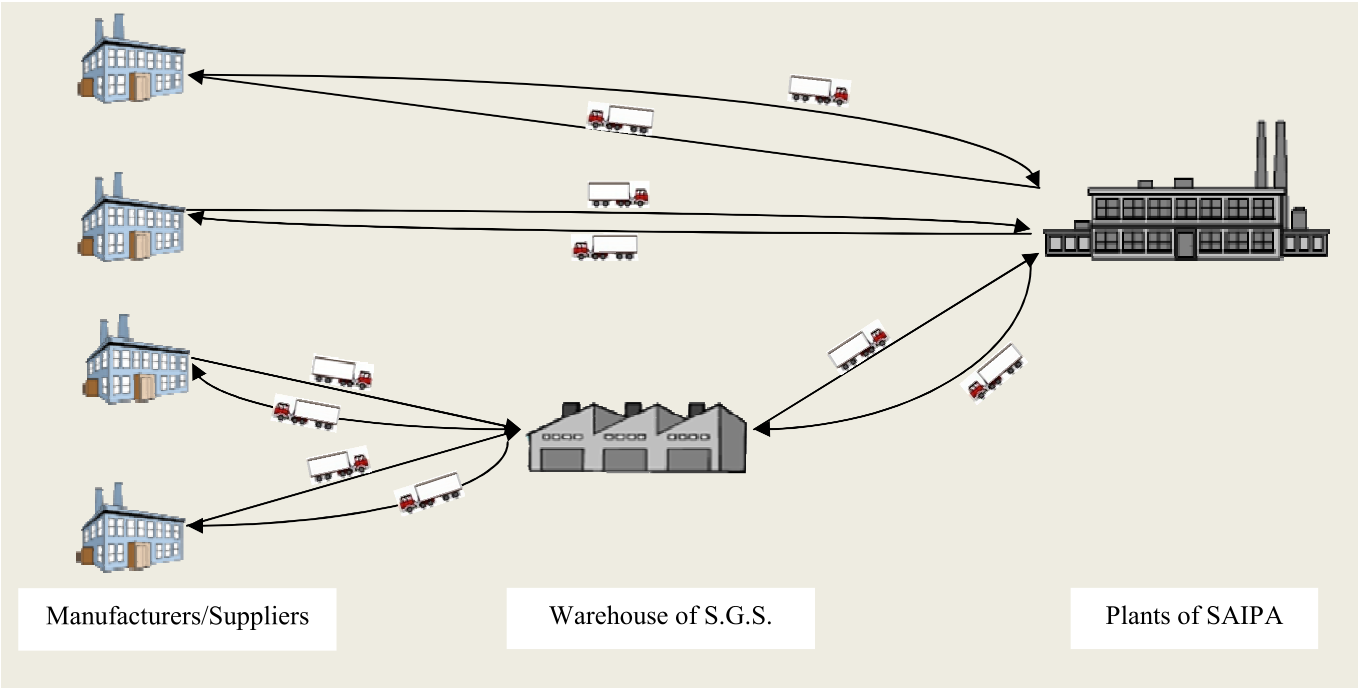

Figure 1.The current forward and reverse logistics network of SAIPA group

Currently, the responsibility of planning of supplier's delivery of parts to the point of uses is by the predetermined scheduling claimed by S.G.S. planning department. The suppliers should integrate their production planning and its transportation operations to ensure meeting the due dates. After delivery of parts to the plant, the supplier also has the responsibility of returning of the same number of delivered reusable empty pallets for using in the packaging of parts and subassemblies as well. The current logistics network of SAIPA group, including manufacturers/suppliers, S.G.S. Co., and plants of SAIPA can be seen figure 1. Thorough the current network not only parts shipped directly to the plant by suppliers but also the empty pallets returned back by the same vehicle for reusing it in the packaging of new parts.

Although operational costs of transportation are directly paid by the supplier, this sum would be added to the total cost of the final products. As there is a tendency for factories to decrease the batch sizes of receiving goods due to JIT strategies, this would lead to increase in transportation frequencies which likely cause to less economical transportation and non-full truck load. This is a good point for saving money if an integrated transportation done by a group of supplier to have full truck load transportation. Regarding this issue, the S.G.S. decided to devise a system to handle the situation. This was a stimulus for heading for vehicle-routing problem (VRP) that is a systematic approach to finding the best subset of customers and routes to optimize the related costs like distance and number of vehicles using for sending empty pallets and gathering the parts from different suppliers. The figure 2 shows the proposed logistics network between the manufacturers, S.G.S. and plants of SAIPA group based on the VRP approach. This is done by consolidating the transportations involved the forward and reverse logistics activities which contain the collecting of parts from suppliers and delivering to them the reusable empty pallets required for packaging of parts simontenously. Due to proposed logistics network, the current transportation strategy, which is currently done by offered schedulings of SAZEHGOSTAR-SAIPA and is separately done by the suppliers (sending parts and returning reusable empty pallets), can be transformed into this new and more efficient one.

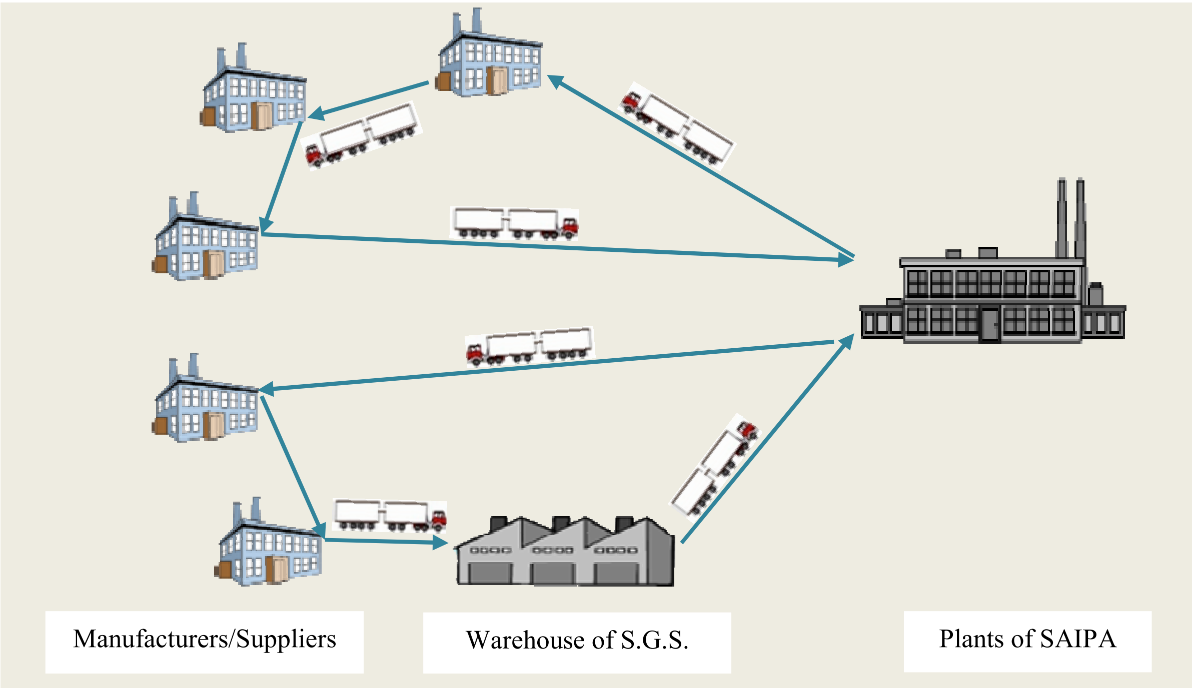

Figure2. The proposed consolidated forward and reverse logistics network of SAIPA group using VRP approach

2- Vehicle routing problem

The Vehicle Routing Problem is the one of the important practical issues in the logistics and distribution area of knowledge. It was first introduced by Dantzig and Ramser in 1959 [1], with formulating it as mathematical programming, then Clark and Wright [2] offered a better solution by introducing a heuristic. Since then, it has attracted the attention of many researchers due to its important applications and its solution complexity. Besides, many different versions of VRP have been created by imposing various constraints and premises on the basic model which has led to many other problems and different applications. A full range of definitions of VRP variants can be accessible in [3].

The basic definition of problem refers to the finding the minimum travel cost of a vehicle starts fleeting from a central depot, carrying some goods from there to some customers that have a determined demand. The vehicle must pass every customer just one time and should satisfy the customer demand then ends its travel in the depot. One of the main restrictions that seem to be reasonable to be entered to this problem to be more adaptable to the problem of the real word is when the capacity of the vehicles considers as being limited that is known in literature as Capacitated Vehicle Routing Problem (CVRP). By entering this limitation to VRP, the vehicle must returns to the depot more to carry the items to/from the customers to fulfill their needs/orders and this makes the problem of routing more complex. The complexity of problem is due to having different alternatives to choose from customers while the total distances can be optimized.VRP has many applications in real-world cases involve solid waste collection, street cleaning, school bus routing, routing of sales-people and maintenance units, transportation of handicapped people, and so forth [3].

3- Mathematical Model of CVRP

The integer linear programming formulation of CVRP proposed by Toth and Vigo [4] when the cost matrix is asymmetric is presented as following:

- **Model Assumptions:**
  - The demands are deterministic.
  - The demands may not be split.
  - The vehicles are identical.
  - The vehicles are based at a single central depot.
  - The capacity restrictions for the vehicles are imposed.
  - the cost matrix is asymmetric and the graph is directed
- **Model Inputs:**

  G = (V, A): A complete graph
  V = {0... n}: The vertex set
  A: The arc set
  d_j: The demand of each customer($d_0 = 0$)
  C_{ij}: The nonnegative travel cost spent to go from vertex i to vertex j
  $S \subseteq V$: The customer set
  $d(S) = \sum d_i$: The total demand of the set
  K: The number of identical vehicles
  C: The capacity of each vehicle,
  $K_{min}, r(s)$: The minimum number of vehicles needed to serve all customers.
- **Model Output:**

  $x_{ij} = 1$ if arc $(i, j) \in$ A belongs to the optimal solution and 0 otherwise.

Objective Function:

$$min \sum_{i \in V} \sum_{j \in V} C_{ij} X_{ij} \quad (1)$$

Constraints:

(2)

$$\sum_{j \in V} X_{ij} = 1 \quad \forall i \in \setminus \{0\} \quad (3)$$

$$\sum_{i \in V} X_{i0} = K \quad (4)$$

$$\sum_{j \in V} X_{0j} = K \quad (5)$$

$$\sum_{i \notin S} \sum_{j \in S} X_{ij} \geq r(s) \;\; \forall S \subseteq V \setminus \{0\} \quad , S \neq \phi \quad (6)$$

$$X_{ij} = \{0, 1\} \;\; \forall i, j \in V \quad (7)$$

Equations (2) and (3) are indegree and outdegree constraints that impose exactly one enter and one leave of each vertex respectively. Constraints (4) and (5) impose the degree requirement for the depot vertex. Inequalities (6) are called capacity cut constraints (CCCs), and they impose vehicle capacity requirements while ensuring the connectivity of the solution. In fact, they stipulate that each cut (V/S, S) defined by a customer set S is crossed by a number of arcs not smaller than $r(s)$.

4- Solution of CVRP

Because the VRP problems are nondeterministic polynomial-time hard (NP-hard) [5], solving them through mathematical modeling may takes a lot of times, especially when a large number of customers must be served. Therefore many heuristics and meta-heuristics have been proposed in order to an acceptable solution be met. For reviewing these algorithms one can refer to [3], [6] and [7]. The main meta-heuristics used for solving the VRP can be listed as Simulated Annealing (SA), Tabu Search (TS), Genetic Algorithms (GA), Ant colony (AS), Bee colony (BC) and Particle Swarm Optimization (PSO). We here for solving our problem use Tabu Search meta-heuristic. We introduce the TS in more detail with reviewing some literature focused on TS proposed for the CVRP in the following.

Moreno-diaz et al. [8] present three approaches to parallel multi-objective TS (TSMO) that applied to CVRPTW. First two approaches, called synchronous (TSMO-SYNC) and asynchronous (TSMO-ASYNC), focus on parallelized generation of neighborhood and parallelized evaluate functions. The third approach, which can be categorized as the multi-search parallel algorithms, uses a multiple point strategies. The former approaches only improve the running time, whereas the latter can improve solutions. Augerat et al. [9] suggested three algorithms for the identification and separation of the capacity constraints for the (CVRP): a constructive algorithm, a randomized greedy algorithm and a Tabu Search. While it is the first time that a meta-heuristic is used for identification problem, it has been proved that Tabu Search is useful to find a good number of capacity constraints violated in the Branch and Cut solving procedure. Tarantilis [10] combined TS with a heuristic to solve CVRP, called SEPAS. The heuristic part is based upon an adaptive memory programming framework that initially generates a population of diversified solution and stores them in the memory. Then merges route components stored in the memory. Finally, the solution is improved by using a Tabu Search approach.

5- Tabu Search algorithm

The standard steps of an Tabu Search algorithm for a CVRP can be seen in the table 1.

Table 1. the basic Tabu Search process for a CVRP

Step 1 (Initial solution): For J = 1 to K (K= the number of vehicles), construct K initial tours that cover all customers (based on the capacity constraint of vehicles).
Step 2: Construct all possible neighbor solutions by exchanging customers in/between routes by means of swap and 2-opt operators with regard to capacity constraints.
Step 3: Calculate cost function for each candidate solution found in *step 2*, and select one with least cost as the “best candidate solution”.
Step 4: For “best candidate solution” in *Step 3,* compare the position of exchanged customers in the initial solution of *Step1* with their new position (the place regarding to other customers and routes), Then, referring to Tabu list: If the new position of exchanged customers is forbidden, ignore this candidate solution and go to *Step 3*. If the new position of exchanged customers is not forbidden, chose it as “best solution” of this iteration and update the Tabu list to prevent the inverse exchange up to X* iteration.
Step 5: Repeat Steps 2-4 up to Y* iterations.
Step 6: STOP, If there is no improvement after Z* iteration, or no other exchange possible

The X*, Y*, Z* are predetermined parameters which must be set by user. The generation of a neighbor solution is described in following section.

5.1. Creation of neighbor solution:

To generate a neighbor solution there are some operators which has been proposed based on local search concept like swap, 2-opt, 3-opt, k-opt. We here use swap and 2-opt strategies to create a new neighbor solution for Tabu Search. Swap technique omits one customer from a route and insert it into another route while 2-opt exchanges two customers on the different routes, simultaneously (fig3).

"swap" operator:

"2-opt" operator:

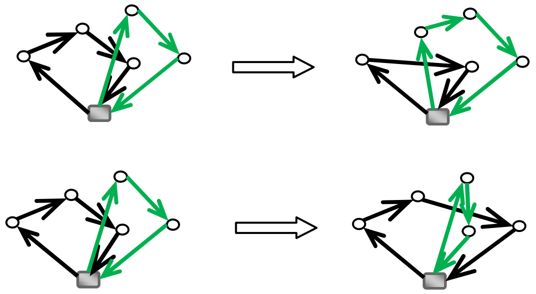

Figure 3. "swap" and "2-opt" operators

6- The Coding:

The algorithms of Tabu Search have been coded into "Visual Foxpro8" software and the sample VRP problems have been solved by it.To have a structure that can be easily intered into the software we need to code the CVRP structure include customers and vehicles and routes, here we define the sequential type of coding to creat a solution seed. A solution seed for CVRP can be like figure 4. In this sample, there are 18 customers which must be sereved by 3 vehicles. The zero number indicate the depot while the others shows the number of customers. A route is made by departing from any customers and returning back to depot when the zero is met. As regard the first route, first vehicle starts its journey by the customers number 18, then going to customers number 14, and 8, and 9 and after meeting the customers 10 the vehicle go back to the starting point (depot). Here, there are 3 different paths.

[18 5 14 8 9 10 0 7 12 15 4 3 6 0 13 2 11 6 1 17]

Figure 4. a sample solution seed for CVRP

7- The objective function:

The cost in CVRP is defined as the Euclidean distance between each two points (customer i and customer j) as C_{ij} which is calculated by formula 9.

$$C_{ij} = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2} \tag{9}$$

The objective function can be described as the total distances passed with the cost of C_{ij} by the vehicle or vehicles in every path (formula 10).

$$\sum\sum C_{ij}X_{ij} = \sum\sum \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2} * X_{ij} \tag{10}$$

8- The sample problem:

For examining the proposed network we take 50 customers, for instance, that located in the close area of the main plant of SAIPA in Tehran. The sample data and its approximate locations related to these 50 suppliers can be seen in the table 2.

Table 2- Customers locations and demands

No.	X	Y	Demand	No.	X	Y	Demand	No.	X	Y	Demand

0	30	40	0	**17**	27	23	3	**34**	61	33	26
1	37	52	7	**18**	17	33	41	**35**	62	63	17
2	49	49	30	**19**	13	13	9	**36**	63	69	6
3	52	64	16	**20**	57	58	28	**37**	32	22	9
4	20	26	9	**21**	62	42	8	**38**	45	35	15
5	40	30	21	**22**	42	57	8	**39**	59	15	14
6	21	47	15	**23**	16	57	16	**40**	5	6	7
7	17	63	19	**24**	8	52	10	**41**	10	17	27
8	31	62	23	**25**	7	38	28	**42**	21	10	13
9	52	33	11	**26**	27	68	7	**43**	5	64	11
10	51	21	5	**27**	30	48	15	**44**	30	15	16
11	42	41	19	**28**	43	67	14	**45**	39	10	10
12	31	32	29	**29**	58	48	6	**46**	32	39	5
13	5	25	23	**30**	58	27	19	**47**	25	32	25
14	12	42	21	**31**	37	69	11	**48**	25	55	17
15	36	16	10	**32**	38	46	12	**49**	48	28	18
16	52	41	15	**33**	46	10	23	**50**	56	37	10

We here consider some assumptions as following. The demands (orders to the suppliers) are deterministic as table 2. The number of vehicles is limited and for this sample we consider that there are just 5 vehicles (K=5). All vehicles used are identical with the same capacity. The capacity of these vehicles is 160 units (C=160). There is only one depot (SAIPA Plant) which is the starting point of any tour (D = 1). The matrix of distances (or costs), involve all C_{ij}, is calculate based on formula 9, which consider Euclidean distance between each two points (supplier and plant) can be seen in table 3.

9- Analysis and setting the parameters:

Because the Tabu Search algorithm is a meta-heuristic which find the solution based on the local search concept, for gaining the most desirable solution one should set some parameters like the tabu duration (the number of iteration that a forbidden move must not be done), the maximum iteration for stopping the algorithm, the number of non-improved iteration for stopping the algorithm. For setting these parameters, finding the most important parameters, and any possible interaction between them we used full factorial design of experiment method (DOE). The following section is describing how to set the parameter and its analysis based on reports from Minitab16 software.

In order to easily set the parameter, we here run the software with the same primitive feasible solution, which is obtained by a random choose algorithm that try to use the capacity of vehicle as far as possible to have a good reasonable primitive solution. The figures 5 and 6 are the different outputs of algorithm with different Tabu duration and with random choice when facing to two or more equivalent alternative movements with equal cost improvement that makes the same improvement in objective function. The figure 5 is all points passing by the algorithm and the figure 6 is the best improvement in each step. The table 4 shows the best result with minimum cost which aquired by different tabu duration to set the best tabu duration. In the figures TD is abbreviation for “tabu duration” and C means the minimum cost found in iterations. The TD = Taillard is a proposed tabu duration by Taillard [11] which means the tabu duration will offer good solutions if be chosen a number between [0.9*n] and [1.1*n+4] that n is the number of nodes of problem.

Table 3. matrix of distances between each supplier and SAIPA plant

nodes	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	0																																																		
1	14	0																																																	
2	21	12	0																																																
3	33	19	15	0																																															
4	17	31	37	50	0																																														
5	14	22	21	36	20	0																																													
6	11	17	28	35	21	25	0																																												
7	26	23	35	35	37	40	16	0																																											
8	22	12	22	21	38	33	18	14	0																																										
9	23	24	16	31	33	12	34	46	36	0																																									
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49	22	26	21	36	28	8	33	47	38	6	8	14	17	43	39	17	14	22	31	38	31	20	30	43	47	42	45	27	39	22	10	42	21	18	14	38	44	17	8	17	48	40	32	56	22	20	19	23	35	0	
50	26.2	24	14	27	38	17	36	47	35	6	17	15	25	52	44	29	6	32	39	49	21	8	24	45	50	49	42	28	33	11	10	37	20	29	6	27	33	28	11	22	60	50	44	58	34	32	24	31	36	12	0

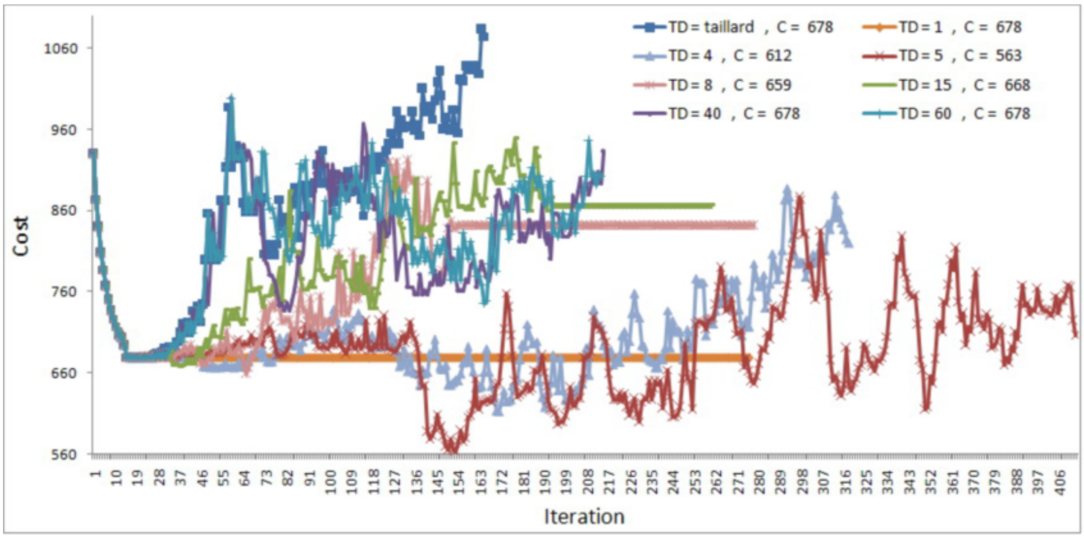

Figure 5 - All results gained in each step with different tabu duration

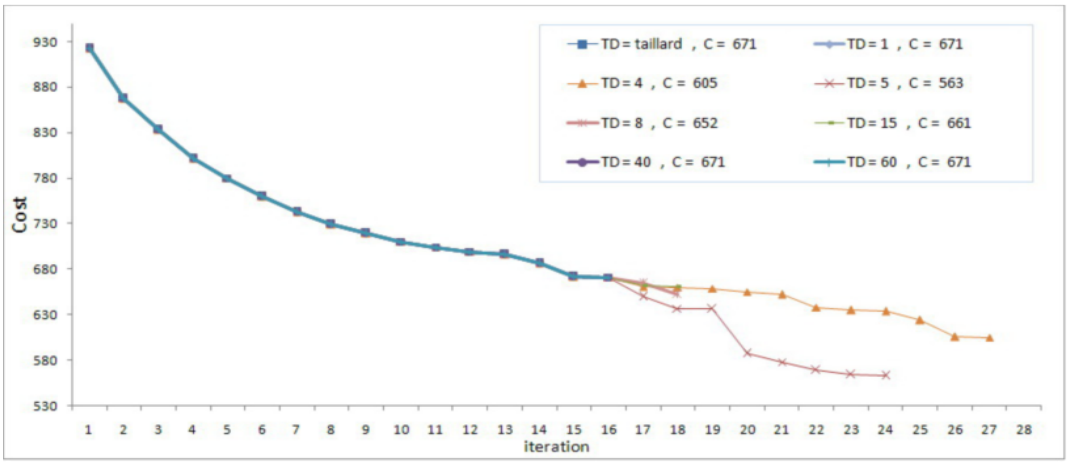

Figure 6 - The best results gained in each step with different tabu duration

Table 4 - Tabu duration and best solution

Tabu duration	Taillard	1	4	5	8	15	40	60
Cost	671	671	605	563	652	661	671	671
Min Cost				*				

To check that the best fitted tabu duration of 5 (equal to 5 forbidden iterations for the move that has resulted in improvement in previous steps) is valid, we run the algorithm with different random primitive solution as well. The figure 7 is the plot of average of different outputs of algorithm with different Tabu Search duration with a random primal solution. The table 5 summaries the results of figure 7 and shows the validity of Tabu duration of 5.

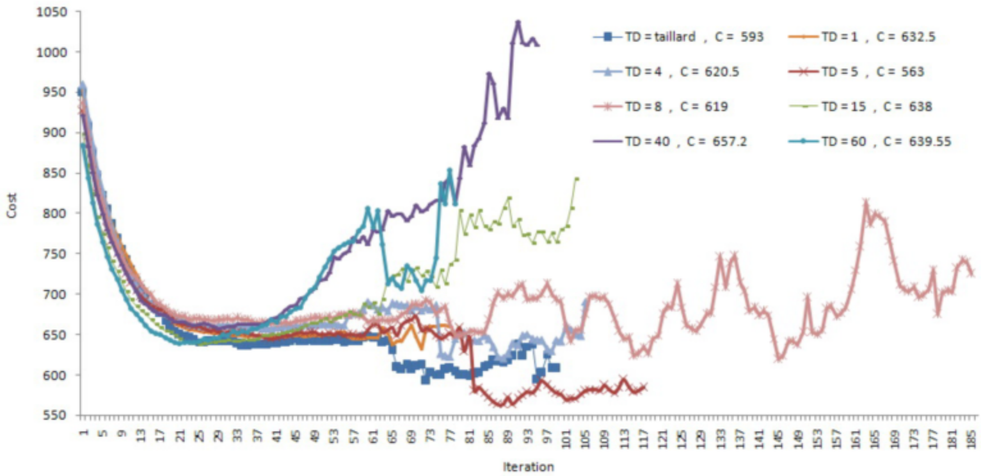

Figure 7. The average results gained in each step with different tabu duration

Table 5 - Tabu duration and best solution (of figure 7)

Tabu duration	**Taillard**	**1**	**4**	**5**	**8**	**15**	**40**	**60**
Cost	593	632	620.5	563	619	638	657.2	639.5
Min Cost				*				

In order to determine the main effective parameter and internal interaction between them (for two parameter of iteration and Tabu duration) we devise a full factorial design of experiment. The table 6 shows the data entry form of our DOE.

Table 6 - data entry form for full factorial design of experiment (DOE)

iteration	**Tabu duration**	**problem size**	**cost**
300	10	50 nodes – 5 vehicles	563
15	10	50 nodes – 5 vehicles	651
300	5	50 nodes – 5 vehicles	651
15	5	50 nodes – 5 vehicles	600

The figures 8, 9, and 10 are “Pareto chart of the effects”, “Interaction Plot for cost”, “Main Effects Plot for cost”, respectively. The Interpretation of the these figures is shown in table 7, which means that “Main Effective Factor” is the number of iteration of algorithms (the number of internal runs) and the iteration and Tabu duration both have interaction on each other so that as the number of iterations increase the cost of best solution decrease and as the tabu duration increase the cost increase as well.

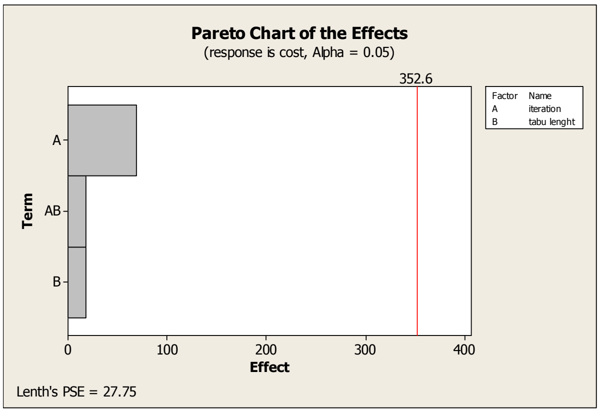

Figure 9.

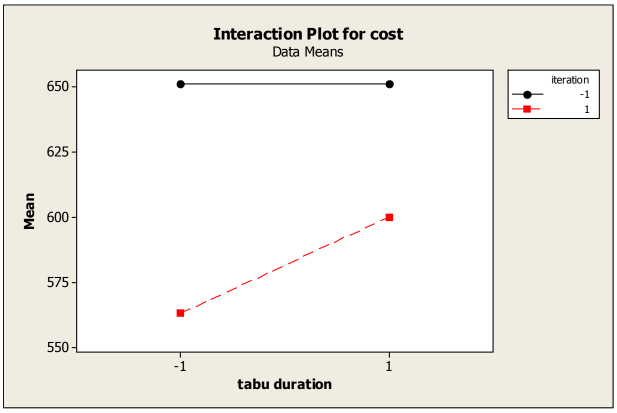

Figure 8.

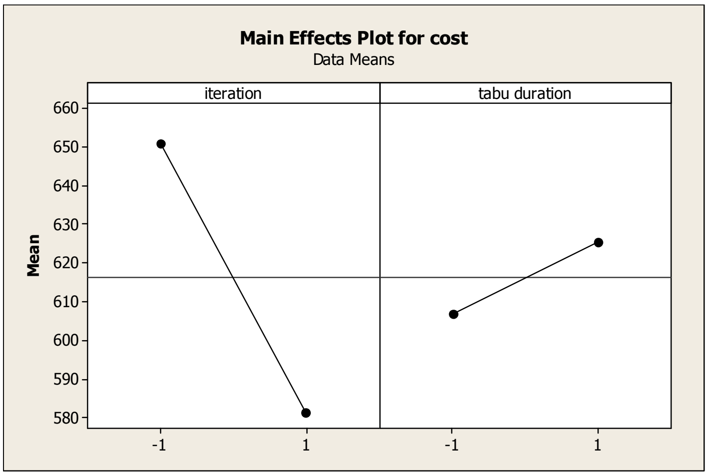

Figure 10.

Table 7 – Interpretation of DOE

Factors	**A = iteration**	**B = Tabu duration**
Main Effective Factor	Yes	-
Interaction	Yes	
Cost	↓as A ↑	↑as B ↑

10-The results

The details of best solution with the minimum cost (distance) can be seen in table 8. In the tables 9, 10, the current and proposed logistics network requirements (consolidated network), based on the required number and type of vehicle, distance and cost related to the tours, is shown respectively. The estimated improvement (savings) after consolidation of parts shipment and reverse logistics of empty pallets is shown in the table 11. Besides, the figures 11, 12 and illustrated the current and proposed logistics network respectively. The savings table shows that although the total distance for supplying parts with the planning period of one week have been increased, the total cost of the transportation have plummeted by 15% which show that here there is good opportunity for saving cost by consolidating of both direct and reverse logistics in SAIPA group.

Table 8. the details of best solution

Tour	ROUTE 1			ROUTE 2			ROUTE 3			ROUTE 4			ROUTE 5			total
	Sup.	Dem.	Dist.	Sup.	Dem.	Dist.	Sup.	Dem.	Dist.	Sup.	Dem.	Dist.	Sup.	Dem.	Dist.	
Tour details	1	0	28.16	1	0	17.26	1	0	8.00	1	0	22.02	1	0	9.43	
	27	7	10.05	18	3	5.10	28	15	8.25	9	23	9.22	48	25	7.81	
	32	11	6.32	38	9	7.28	33	12	6.40	49	17	9.22	5	9	16.03	
	29	14	9.49	45	16	6.08	12	19	10.00	24	16	6.08	43	13	8.54	
	4	16	12.08	16	10	6.71	17	15	5.66	8	19	12.04	20	9	10.63	
	37	6	6.08	46	10	7.00	51	10	5.66	44	11	12.37	41	7	12.08	
	36	17	7.07	34	23	13.93	10	11	6.40	25	10	14.04	42	27	9.43	
	21	28	10.05	40	14	10.00	50	18	8.25	26	28	6.40	14	23	14.42	
	30	6	9.06	11	5	9.22	6	21	9.22	15	21	10.30	19	41	14.76	
	3	30	10.63	31	19	6.71	13	29	7.07	7	15	11.40				
	23	8	7.07	35	26	9.06	47	5	2.24							
	2	7	13.89	22	8	18.38										
				39	15	15.81										
Capacity used	150.00			158.00			155.00			160.00			154.00			777
Total distance	129.96			132.54			77.14			113.09			103.15			556

Table 9. Current logistics network requiremts

Number of suppliers	**Plan-ning period**	**Parts shipment**				**Reverse logistics (returning of empty pallets)**				**Total**			
		Required vehicles (qty)		Total distance (km)	cost (million Rls)	Required vehicles (qty)		Total distance (km)	cost (million Rls)	Required vehicles (qty)		Total distance (km)	cost (million Rls)
		truck	trailer			truck	trailer			truck	trailer		
50	One week (5days)	32	38	1201	4300	32	38	1201	2150	32	38	2402	6450

Table 10. Proposed logistics network requiremts

Number of suppliers	**Plan-ning period**	**Parts shipment**				**Reverse logistics (returning of empty pallets)**				**Total**			
		Required vehicles (qty)		Total distance (km)	cost (million Rls)	Required vehicles (qty)		Total distance (km)	cost (million Rls)	Required vehicles (qty)		Total distance (km)	cost (million Rls)
		truck	trailer			truck	trailer			truck	trailer		
50	One week (5days)	-	25	2805	5610	0	0	0	0	-	25	2805	5610

Table 11. Savings in logistics network

Number of suppliers	**Plan-ning period**	**Current logistics network**				**Proposed logistics network**				**Savings**			
		Required vehicles (qty)		Total distance (km)	cost (million Rls)	Required vehicles (qty)		Total distance (km)	cost (million Rls)	Required vehicles (qty)		Total distance (km)	cost (million Rls)
		truck	trailer			truck	trailer			truck	trailer		
50	One week (5days)	32	38	2402	6450	-	25	2805	5610	32	13	-403	840

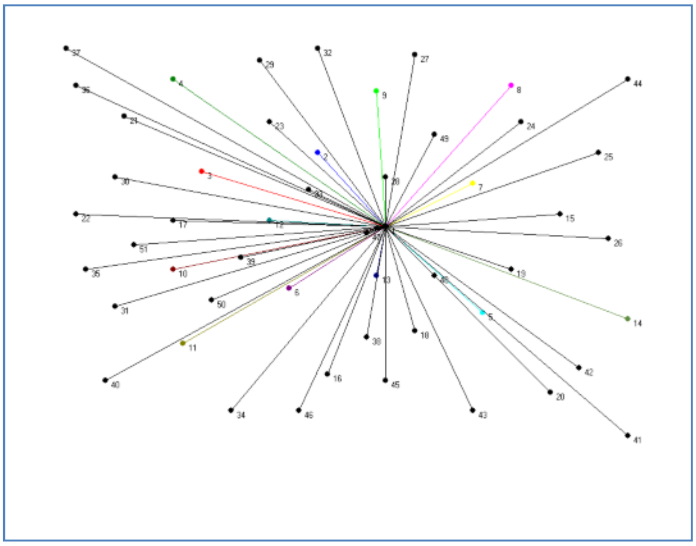

Figure 11. Current logistics network

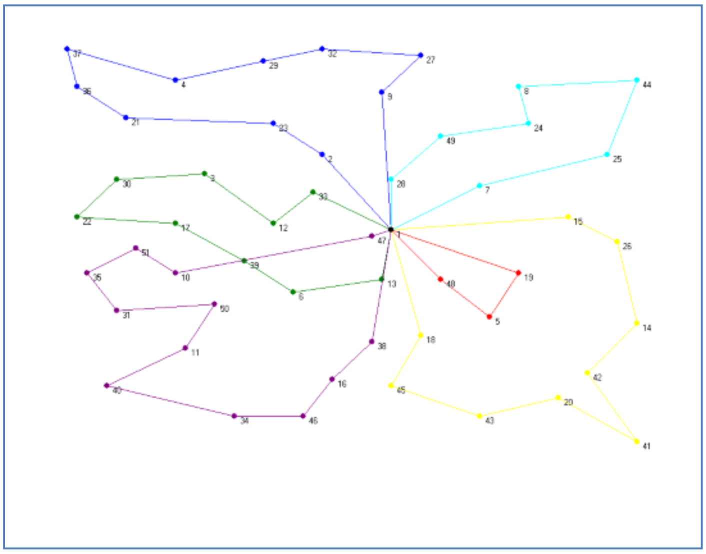

Figure 12. Proposed logistics network

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