Assigning Lanes to Dedicated Fleet in a White Goods Distribution Network

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1 Introduction

This paper presents an optimization problem regarding the assignment of truckload lanes to a private or dedicated fleet to minimize transportation costs in a distribution network formed by single-product plants, distribution (consolidation) centers and clients. These lanes are aggregated in such a way as to form closed cycles (tours) to guarantee a higher probability of efficient and continuous moving to a dedicated fleet. The method is applied to the design of a distribution network of a white goods manufacturer in Brazil.

An efficient tour can be defined in this context as the aggregation of origin-destination arcs (lanes) "using the same transportation equipment in a closed cycle of freight movement" (Tacla, 2003).

This combination of transportation arcs and flows has a positive influence in equipment costs, as it reduces deadhead movements and dwell times to look for backhaul freight, thus increasing equipment availability.

The methodology is shown in Figure 1. Two pre-processing steps generate possible arc aggregations to find out potentially efficient tours and then calculate their associated transportation costs. These tours define the decision variables of an IP model, which are the number of loads which flows through them. Thus, the model solution will result in the optimized flow of origin-destination pairs in direct (one way, open) path or combined (closed) tours.

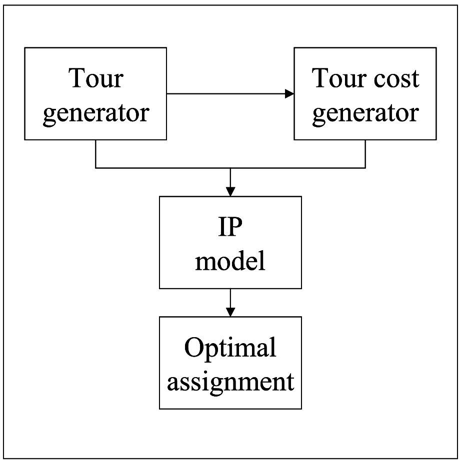

Figure 1 – Methodology to solve the problem

Tour generator

The tour generator has been developed in *VBA* and used as a basis the indexes of origin nodes (O_i) and destination nodes (D_j) to combine arcs or lanes *ij* into tour or paths (P_k), forming a matrix of 0-1 numbers, with arcs *ij* in the rows and paths *p* at columns, as shown in Table 1.

Table 1 – Matrix from the Tour Generator

Arcs	**Paths (P_k)**								
(OiDj) (DjOi)	**P_1**	**P_2**	**....**	**P_5**	**P_6**	**....**	**P_{10}**	**P_{11}**	**P_k**
O_1D_1	**1**	0		**1**	0		**1**	**1**	0
O_1D_2	0	**1**		0	0		0	0	**1**
O_2D_1	0	0		0	0		0	0	**1**
O_2D_2	0	0		0	**1**		**1**	**1**	0
....									
D_1O_1	0	0		**1**	0		0	0	0
D_1O_2	0	0		0	0		**1**	**1**	**1**
D_2O_1	0	0		0	0		**1**	**1**	0
D_2O_2	0	0		0	**1**		0	0	0
.....									
D_iO_j	0	0		0	**1**		0	0	**1**

The matrix in Table 1 shows all possible aggregations and, thus, a large number of generated paths are not economically attractive. The generator algorithm then has a filter that throws out any path which has total transportation cost bigger than the equivalent sum of spot freight of its component arcs.

The different types of paths that can be generated are presented in Figure 2.

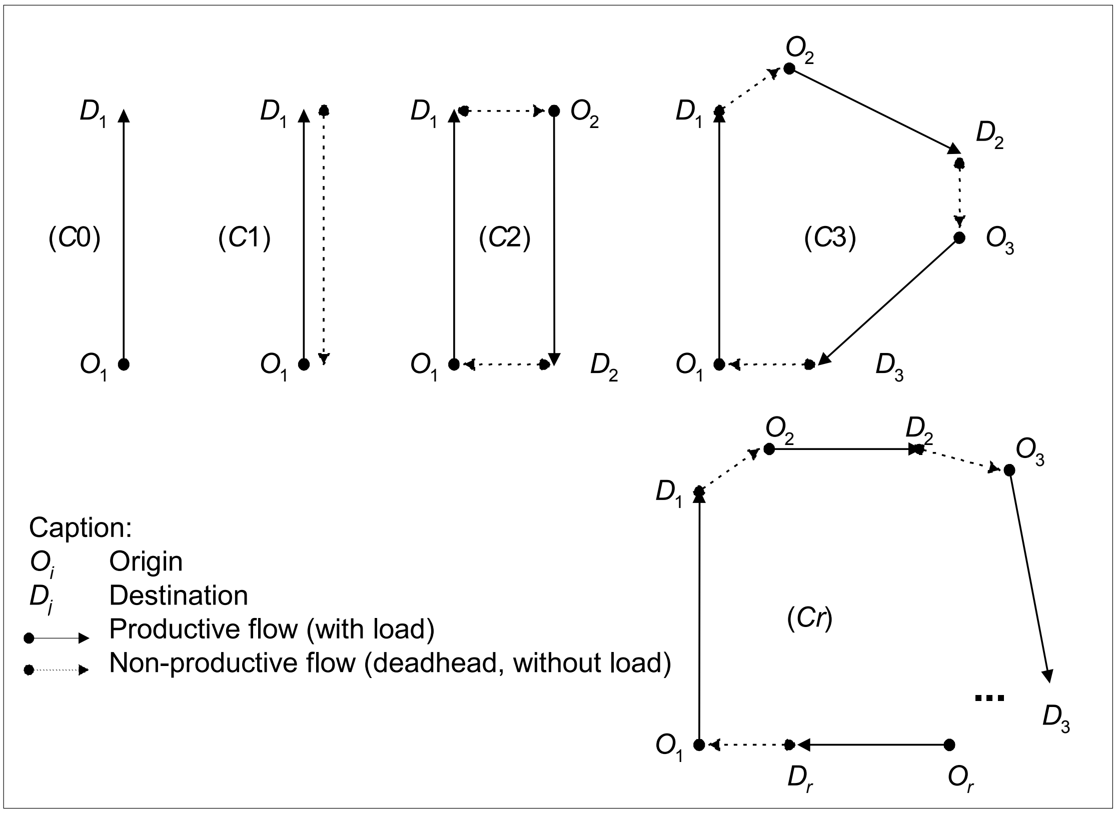

Figure 2 – Types of paths generated by the algorithm (see text)

In the generator, there are the following types of tours or paths:
(C0) Path with a direct arc (single load), only one origin and one destination; spot freight;
(C1) Path with a single headhaul arc with empty return; dedicated fleet;
(C2) Path with a combination of two loads and two deadheads; dedicated fleet;
(C*r*) Path with a combination of *r* arcs (loads and deadheads); dedicated fleet.

The following hypothesis are considered: homogeneous fleet compatible with all products in the same path, deterministic parameters. The measure unity of flow is the number of loads in a single lane *ij*.

Tour cost calculator

The tour cost calculator is based on an economic model of truckload operation, where the tour or path cost C_p function is proportional (linear) to the total traveled distance and inversely proportional to the cycle time.

The total path transportation cost (equation 1) is the sum of a fixed cost and a variable component, which is the variable cost ($/km) times the total traveled distance of the path.

$$C_P = CF_P + CV * DT_P \quad (1)$$

The fixed cost of the path p (equation 2) is the parcel of the fixed monthly cost of a piece of equipment for a complete cycle in path p.

$$CF_P = CF_{month} / Q_{cycle} \quad (2)$$

The amount of cycles in a month Q_{cycle} (equation 3) is the division of the Total Available Time for the equipment in a month by the Cycle Time of path p.

$$Q_{cycle} = TT_{month} / TC_P \quad (3)$$

The cycle time of path p (equation 4) is the sum of the traveling (productive) times and the dwell or idle time (non-productive).

$$TC_P = TR_P + TP_P \quad (4)$$

The Traveling Time of path p (equation 5) is the division of the total traveled distance of the path by the mean speed of the equipment.

$$TR_P = DT_P / VM \quad (5)$$

The dwell time of the path p (equation 6) is the sum of loading and unloading times (includes waiting times) plus time spent to find a follow-on load.

$$TP_P = T_{load,\,P} + T_{unloadP} + T_{follow\text{-}onP} \quad (6)$$

In the tour cost generator, VM, TT, DT, DM, and times $T_{load,\,P}$, $T_{unload,\,P}$, $T_{follow\text{-}on,\,P}$ are given parameters.

2 IP Model

The IP model has to minimize the total transportation cost of the distribution network.

$$Min\ CT = \sum_p C_p * X_p \quad (7)$$

Subject to:
(a) Complete fulfillment of load demand for each arc *ij*.

$$\sum_p \delta_p^{ij} * X_p = DM_{ij}, \forall ij \quad (8)$$

(b) The number of loads in a path *p* has to be a positive integer:

$$X_p \in N \quad (9)$$

Where:
i : origin node
j : destination node
p: path formed by arcs *ij* e *ji*
Xp : quantity of loads assigned to path *p* (decision variable)
δ_p^{ij} : auxiliary variable; = 1 if arc O_iD_j belongs to path *p*, 0 otherwise.

$$\delta_p^{ij} = [0,1], \forall ij \quad (10)$$

Cp : Unit cost of a load in path *p* (parameter calculated by the path cost generator).
DM_{ij} : Demand of monthly loads in arc/lane *ij*.

3 Application and Results

The model was applied to the distribution of a white goods manufacturer with 4 single-product plants (origins) and 185 aggregated destinations, as in Figure 3. The total number of type (8) constraints is only 224, which is less than 4 x 185 = 740 lanes, as many potentially productive lanes have no truckload demand (less than truckload lanes are out of scope). Table 2 shows the dramatic decrease in the total number of paths (columns) in the model (6.85 billion to 160.333) due to the application of the cost filter, which eliminates inefficient *r*-level paths.

The model was implemented in GAMS/CPLEX 7.0 and run in a regular Pentium IV computer, where it took about 11 hours to process. Results showed a 1.98% reduction in transportation costs, or more than R$ 1.2 million in savings per year.

This economic result needs new operational processes to guarantee the maximum use of the dedicated fleet.

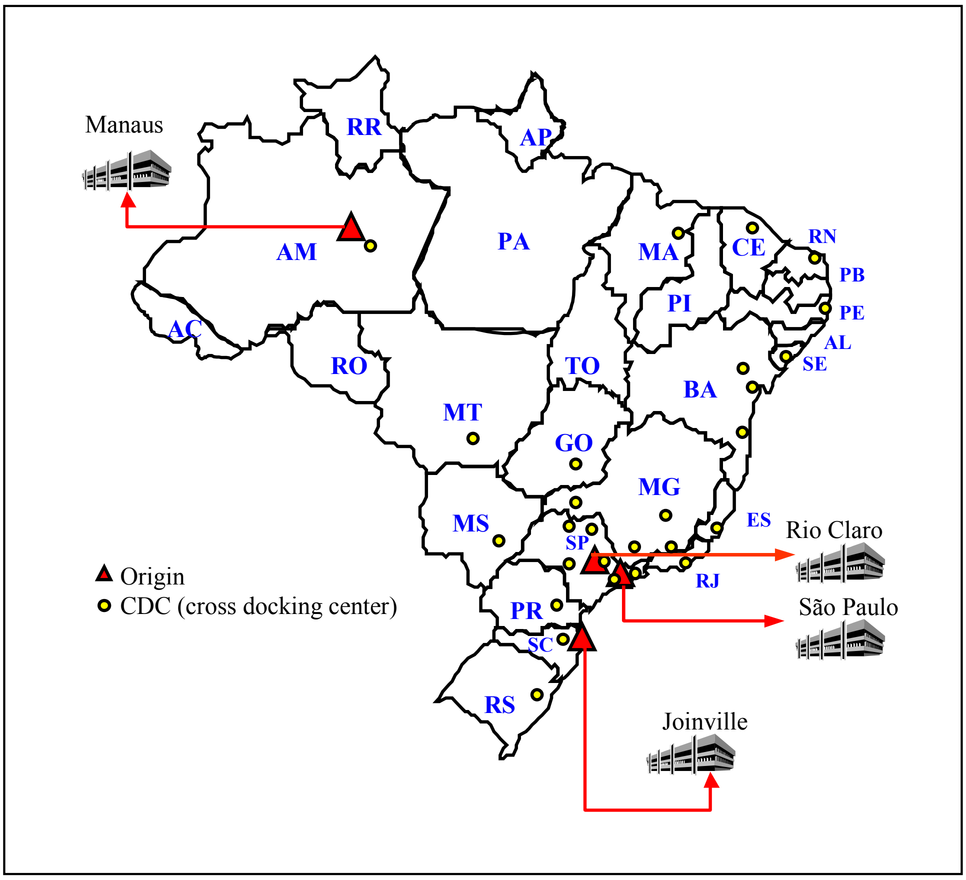

Figure 3 – White Goods Network Distribution Map (see text)

Table 2 –Number of Paths and Results of the Model

Results:	Qt. Total (unit)	Qt. less C0 cost (unit)	Qt. Optimal Solution (unit)	Qt. Optimal Solution (trips/year)
paths C0	740	740	182	15,740
paths C1	740	740	16	2,884
paths C2	204,240	977	14	620
paths C3	49,834,560	19,120	11	498
paths C4	6,802,417,440	138,756	0	0
Total	**6,852,457,720**	**160,333**	**223**	**19,742**

Table 2 shows the results of the tour generator, listing the number of each type of path; of the tour cost filter, with the quantity of paths cheaper than their C0 equivalents; and, finally, the number of each type of path for the optimal integer solution, with respective number of trips (loads) per year.

Analyzing each kind of path (Table 3), it is easy to notice that the biggest impact is due to C1 paths (more than 72%). However, the C2 and C3 paths are important too, as they contribute to significant economies when compared to the transportation costs of their C0 equivalents.

It is easy to check that economies of scope (Caplice, Sheffi, 2003) are influencing the result. The baseline case (only C0) has a fleet fixed cost of R$ 40,752 million, and a variable (km) cost of R$ 22,984 million. The optimal solution (with higher level *r*-paths) has a fixed vehicle cost of R$ 39,007 million, and a variable cost of R$ 23,467 million. Thus, deadhead arcs are incorporated in the dedicated fleet routes to guarantee better vehicle utilization and to form a closed cycle.

Table 3 – Economic Results per Paths of the Model

Kinds of Paths	Actual Transportation Costs (R$/year) (A)	Model Transportation Cost (R$/year) (B)	Result (R$/year) (C)	Result (%) (C)/(A)	Total Impact (%) (C)/ Total (A)
paths C0	57,099,450	57,099,450	0	0.00%	0.00%
paths C1	3,125,880	2,214,160	-911,720	-29.17%	-1.43%
paths C2	943,890	741,240	-202,650	-21.47%	-0.32%
paths C3	2,566,956	2,419,242	-147,714	-5.75%	-0.23%
paths C4	0	0	0	0.00%	0.00%
Total	**63,736,176**	**62,474,092**	**-1,262,084**	**-1.98%**	**-1.98%**

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