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Alternate mode dispatching: the impact of cost minimisation

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When a shipper may use a variety of trucks to ship less-than-truckload shipments, shipping cost is the relevant criterion for evaluating alternate dispatches. This point is demonstrated by optimally solving 15 dispatching problems from industry in two ways, once minimising distance, and second time minimising costs, when a mixed private fleet and a common carrier are available. The distance minimising dispatches are, on the average, 35% more expensive than the corresponding cost minimising ones, but part of this difference stems from assumptions which are necessary to compare these two criteria.

Keywords: distribution; vehicle routing

Introduction

Numerous organisations around the world distribute goods by trucks. Very often trucks with different physical, operational and cost characteristics are available to distribute such goods, and the shipper has to decide which shipments to assign to each truck for delivery. Many manufacturers and distributors use regional distribution centers to deliver goods to their customers by a private fleet of trucks (which is not necessarily homogeneous) and they usually have the option to use other types of carriers to deliver their shipments, for example dedicated, contract and/or common carriers. Shippers who do not have a private fleet usually use a mix of such other carriers.

When less-than-truckload (LTL) shipments are assigned to trucks, usually more than one shipment is assigned to each truck, and the truck routing must be determined. The private fleet trucks are usually based at the distribution center (where the goods are stored) and return to it upon the completion of their assigned routes. This type of problem is known in the literature as a single source vehicle (or truck) routing problem. But other types of trucks (those of common or contract carriers) may not return to that origin, and are ignored by the vehicle routing problem. A vast body of literature has evolved concerning the vehicle routing problem[1,2] but it is almost exclusively concerned with minimising truck miles, hours, or number of trucks used. When the fleet is homogeneous these measures tend to minimise the shipping costs. However, when a mixed fleet of trucks is used, such measures of effectiveness are not appropriate, and shipping cost is the relevant measure of effectiveness. This is especially true when shipments may be assigned to a common carrier for delivery at a known cost, without being concerned with routing the common carrier's trucks (the common carrier routes his own trucks for delivery of shipments from multiple shippers). We deal here with both, a mixed fleet of trucks which may be dispatched and a common carrier who may be assigned LTL shipments for delivery. Relatively little work has been done in this area. Salhi and Rand[3] provide a summary of the work done in determining fleet size and composition for a mixed fleet of trucks, but they do not mention a common carrier alternative. Two papers[4,5] deal with fleet sizing when a common carrier alternative does exist, but they consider only a uniform fleet. However, the work mentioned above is focused on fleet size and composition, but we are concerned with dispatching trucks for actual delivery when a mixed fleet and a common carrier alternative are available. Another two papers addressed dispatching LTL shipments with a mixed fleet of trucks[6,7] and both considered only two types of trucks without a common carrier alternative, and employed heuristics. Surprisingly, only one work was found concerning dispatching LTL orders with multiple types of trucks and common carrier alternative,[8] which is fairly common situation in practice.

The focus of this work is on dispatching LTL shipments from a single source by a mixed fleet of trucks at minimal cost. This paper demonstrates the importance of shipping cost minimisation when the shipper may use a mixed fleet, and a common carrier alternative exists. We demonstrate the importance of cost minimisation using operational data from a real-life company. A set of 15 truck routing

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problems is solved twice, once minimising cost and second time minimising distance. Mathematically optimal solutions are achieved using an Elastic Set Partitioning (ESP) model, and the significant difference in costs for each pair of solutions is demonstrated. The distance minimising solutions are 18–44% more expensive than the corresponding cost minimising solutions.

The next section presents the methodology used for the analysis, and the following one presents the results and their analysis.

Methodology

An Elastic Set Partitioning (ESP) model is used to solve the single source mixed fleet truck routing problem with a common carrier alternative.

The formulation of the ESP model is as follows:

Indices:

$I = 1, \ldots, n$ trucks
$t = 1, \ldots, r$ truck types
$j =$ an alternate route
$j \in J(t) =$ feasible routes of truck type t
$k = 1, \ldots, m$ orders/shipments to be delivered
$j \in J(k) =$ routes that deliver order k

Data:

$C_j =$ cost of entire route j (a function of the truck type and the orders in that route)
$N_t =$ number of trucks of type t
$\underline{d}_t, \overline{d}_t =$ lower and upper constraint violation penalties for truck type t
$\underline{s}_k, \overline{s}_k =$ lower and upper constraint violation penalties for order k.

Decision variables:

$y_j = 1$ if route j is selected; 0 otherwise
$\underline{\delta}_t, \overline{\delta}_t =$ elastic (constraint violation) variables for truck type t
$\underline{\sigma}_k, \overline{\sigma}_k =$ elastic (constraint violation) variables for order k.

Model formulation (ESP):

$$\min \sum_j C_j y_j + \sum_{t=1}^{r} (\underline{d}_t \underline{\delta}_t + \overline{d}_t \overline{\delta t}) + \sum_{k=1}^{m} (\underline{s}_k \underline{\sigma}_k + \overline{s}_k \overline{\sigma}_k) \quad (1)$$

subject to:

$$\sum_{j \in J(t)} y_j + \underline{\delta}_t - \overline{\delta}_t = N_t; \quad \text{for each truck type } t \quad (2)$$

$$\sum_{j \in J(k)} y_j + \underline{\sigma}_k - \overline{\sigma}_k = 1; \quad \text{for each order } k \quad (3)$$

$$y_j \in \{0, 1\}; \quad \text{for each route } j \quad (4)$$

$$\underline{\delta}_t, \overline{\delta}_t \in \{0, 1\}; \quad \text{for each truck type } t \quad (5)$$

$$\underline{\sigma}_k, \overline{\sigma}_k \in \{0, 1\}; \quad \text{for each order } k. \quad (6)$$

Constraints (2) seek one route for each truck of type t, where a lower violation represents total idleness of such a truck (at a penalty representing the idleness cost) and an upper violation incurs a high schedule disruption penalty (use of a truck which is not available). Constraints (3) seek to deliver all orders; a lower violation represents a common carrier shipment, namely the order is not delivered by the private fleet, where permissible, at the appropriate cost, and an upper violation results in a high disruption penalty (an order is delivered more than once). The disruption penalties are assigned large numerical values in order to prevent such disruptions from occurring.

A column generator is used to generate all feasible routes (columns) for each truck type. When the problem size is large (over 10 000 columns) only good routes are generated (routes with geographically contiguous orders). For large problems the solution will not necessarily be the optimal one because not all feasible routes are considered. However, in our dataset the largest problem has only 7084 columns, thus the solutions we present here are optimal. The routes are generated by a modified sweep algorithm.[9] Each truck type is treated separately in the route generation process. All orders compatible with the specific type of truck are considered. (An order may be incompatible with a truck type if the truck is too small to carry the order, or the truck does not have the equipment necessary to deliver the order, or for other reasons.) The orders compatible with the truck type are sorted by their angle from the source and each one of these compatible orders is used as a seed point for a sweep. Each sweep generates a set of columns (routes): the first order in the sweep is retained as a column, then the first two orders, the first three orders, and so on, up to the limit on the number of orders in a column (route). For example, if we number the orders compatible with the specific type of truck $1, 2, 3, \ldots$, where 1 is the seed order for the sweep, 2 is the second order encountered by a ray from the source (sweeping either clockwise or counter clockwise, whichever direction is selected for the specific sweep), 3 is the third order encountered, and so on, then the first generated column (route) in this sweep will be: 1, the second column will be: $1 + 2$, the third column will be: $1 + 2 + 3$, and so on. These columns are retained only if they represent feasible routes. This process generates all feasible (sweep) contiguous routes (columns). The orders in each one of the resulting columns are then sequenced into their delivery sequence either by full enumeration or by a quadratic assignment algorithm. Travel time is determined by dividing the leg distance by an average speed, where the average speed is a step function of the leg distance. If delivery time windows are specified the sequencing assures that they are met. Delivery time windows reduce significantly the number of feasible routes (columns). In our dataset, delivery time windows were not present.

Data for fifteen dispatching days are used in the following analysis. The data were received from a major manufacturer for a major metropolitan area in the middle of the USA. Two types of private fleet trucks are considered for distributing the shipments, 10 m and 13 m trucks. The physical, operational and cost characteristics of these two types of trucks are provided in Table 1. The costs per hour are the cost of the driver, the cost per kilometer is the variable cost of operating the truck, and the set-up cost is the fixed cost of owning the truck. The cost of a route of a private fleet truck consists of all these cost components. The 13 m truck is a little more expensive to operate but its capacity is larger. In addition to these two types of trucks, each order may be assigned to a common carrier for delivery at a known cost. A common carrier usually collects his shipments from multiple shippers into a sorting facility where he sorts them and loads them on his delivery trucks. Thus, his delivery truck may deliver orders from multiple shippers to multiple customers in a single route (the common carrier himself routes his trucks). Common carrier rates are published and are a function of the order's origin, destination, weight, density (class) and special handling requirements. Therefore, the cost of shipping a specific order by a common carrier can be easily calculated.

The number of orders per dispatching day varied from 14–54. Almost all orders weighed less than 5000 kg, and there were no orders above 10 000 kg. All orders are within 320 km of the source, and are delivered on the same day.

Table 1 Truck characteristics

Type	*10 m*	*13 m*
Capacity (kg)	13,500	18,000
Cost per hour ($)	20.82	20.82
Overtime cost per hour ($)	20.45	20.45
Cost per km ($)	0.51	0.53
Set-up cost per day ($)	112.43	117.47
Maximum stops on a route	9	9
Operating radius (km)	320	320
Regular time per day[a] (h)	9	9
Maximum overtime per day (h)	3	3
Fixed time per stop (h)	0.25	0.25
Unloading rate (kg per h)	7,000	7,000

[a] Includes 1.5 h for loading the truck at the source, and for lunch.

The private fleet trucks are loaded overnight, but the common carrier picks up his orders on the former evening.

As stated above, each daily dispatch was solved twice: once minimising cost and second time minimising distance traveled. In both cases the same set of columns were used. The only difference was in the objective function coefficients. In the cost minimisation case, the orders assigned to a common carrier were charged their common carrier cost (in the objective function). In the distance minimisation case, the orders assigned to a common carrier were charged their one-way distance. Private fleet trucks which were used in the solutions were charged their cost or distance, respectively. In addition, for each solution the other measure (distance or cost) was also calculated.

Because the purpose of the analysis was to evaluate the required private fleet size and composition, a sufficient number of trucks of each type was provided, and the solution determined how many trucks of each type were necessary. For the same reason the set-up cost of the private fleet trucks was included. This also provides a level playing field with the common carrier rates (which include fixed cost recovery).

Results and analysis

The results are presented in Table 2. Summaries for each of the 15 days for the cost minimisation and the distance minimisation solutions are given. Each pair of solutions is also compared with regard to their minimisation criteria. The number of orders per dispatching day ranged from 14–54, and the number of columns (routes) in the corresponding ESP models ranged from 706–7084. Solution times ranged up to several minutes on a medium size mainframe computer.

In the minimal cost solutions the distance traveled is 1–46% higher than in the corresponding minimal distance solutions, with a (weighted) average of 22.5% longer distance driven.

The cost of the minimal distance solutions is 18–44% higher than the corresponding minimal cost solution, with a (weighted) average of 35.4% higher cost (weighted by the cost of the solutions).

The active constraints in generating the feasible routes for the trucks turned out to be the number of stops on their routes and the route hours, not truck capacity. Since the truck capacity was seldom reached, the 13 m trucks were barely used although their cost is only slightly higher than the 10 m trucks. When minimising distance 10 m and 13 m trucks are equally desirable because their distances are not weighted by the truck size.

The distance minimising solutions used more trucks than the cost minimising solutions and assigned less orders to common carriers. This phenomenon is affected by the mileage penalty used for assignment of orders to common carriers. Distance minimising solutions are sensitive to the

Table 2 Daily dispatches

Day	Orders	Columns	Min criterion[a]	Number of trucks 10 m	13 m	Common carrier Orders	Distance (km)	Cost ($)	Total distance (km)	Total cost ($)	% distance	% cost
1	40	4902	D	5	—	6	477	328	1957	2199	100	141
			C	1	—	31	2419	1088	2850	1565	146	100
2	33	3498	D	3	—	10	1112	461	1757	1494	100	137
			C	1	—	24	1746	741	1915	1093	109	100
3	47	6074	D	6	—	3	526	98	2200	2307	100	140
			C	2	—	29	2542	909	3016	1652	137	100
4	14	706	D	2	—	1	272	161	1104	1034	100	144
			C	1	—	5	714	256	1117	716	101	100
5	29	3002	D	3	—	9	962	586	1866	1706	100	136
			C	1	—	20	2206	826	2574	1255	138	100
6	35	4186	D	3	—	9	806	197	1742	1424	100	126
			C	2	—	18	1402	377	1880	1127	108	100
7	25	2240	D	2	—	11	1186	475	1992	1335	100	144
			C	—	—	25	2195	924	2195	924	110	100
8	25	2012	D	2	—	9	1309	629	2136	1530	100	144
			C	—	—	25	2331	1065	2331	1065	109	100
9	42	5002	D	3	2	6	730	604	2178	2511	100	134
			C	3	—	20	1653	507	2875	1878	132	100
10	35	3680	D	3	—	11	1213	563	1909	1654	100	136
			C	—	1	27	2150	857	2298	1212	120	100
11	36	4150	D	4	—	4	646	305	2198	2035	100	127
			C	2	—	20	1797	590	2821	1604	128	100
12	34	3362	D	4	—	10	790	600	2482	2387	100	138
			C	3	—	13	1704	383	2912	1734	117	100
13	33	3510	D	3	—	10	768	484	1654	1643	100	140
			C	1	1	17	1637	579	1821	1171	110	100
14	54	7084	D	6	—	11	949	320	3048	2791	100	134
			C	3	—	27	2869	869	3752	2085	123	100
15	23	1736	D	2	—	10	1242	628	1851	1399	100	118
			C	1	—	15	2275	829	2491	1188	135	100

[a] D = Distance, C = Cost.

distance charged for orders assigned to common carrier. One-way distance was charged for such orders because it seems the natural thing to do (routing of the common carrier trucks is up to their operator and out of the shipper's control). Reducing that charge would have reduced the relative advantage of cost minimisation, because more orders would have been assigned to the common carrier and the total distance would have been lower. However, this dilemma demonstrates the point of this paper: when one has a mixed fleet, transportation cost minimisation is the relevant measure of effectiveness (assuming customer service requirements are met).

Unfortunately, one cannot tell in advance which orders will be assigned to common carriers. That assignment depends on the specific mix of orders being dispatched.

Conclusions

Using industrial data a set of 15 single source mixed fleet truck routing problems with common carrier alternative was solved twice, once minimising costs and the second time minimising distance. Distance minimising dispatches were found to be, on the average, 35% more expensive than the corresponding cost minimising dispatches.

The analysis of the results also indicates that, for the specific operation from which the data were taken, the smaller trucks are the preferred ones. This preference is due to operational limits on the truck routes (hours and number of stops). Knowing this, the management may wish to reconsider these limits and investigate the impact of changing them, using the same dispatching model.

When alternate modes (types of trucks) are involved, minimising travel distance of the trucks is misleading because it does not take into account size and cost differences among truck types. This is especially true when a common carrier alternative exists, because the shipper does not have any control over routing the common carrier's trucks, but his dispatching decisions must incorporate such an alternative. Therefore, cost is the appropriate measure of effectiveness of alternate dispatching decisions under such circumstances.

We have demonstrated here, with data from a real-life operation, that when one dispatches orders from a single source with a mixed fleet and a common carrier alternative, minimising distance is misleading and expensive. The common denominator of the various types of trucks which may be used for dispatching is cost, and therefore the dispatch cost should be minimised, and not any other proxy (such as distance or number of trucks). Numerous organisations face daily the dispatching problem discussed here and still try to minimise distance, because it is more convenient to handle. We hope that this work will open their eyes and make them look more closely at their dispatch costs.

We used here a mathematical optimisation model to find the mathematically optimal dispatch in each case, rather than using heuristics which usually provide solutions with unknown quality. Therefore, the comparison between the cost minimising and distance minimising solutions is reliable and indicative of the potential benefits of our approach. However, inclusion of distance of common carrier trucks is problematic and practically irrelevant, and dispatching cost should be minimised.

A major roadblock to implementation of solution methodology based on mathematical optimisation in a dynamic operational environment is its lack of robustness. A small change in the input data, for example addition or deletion of a single order, may result in a drastically different solution.[10] The ESP model facilitates establishing robustness of solutions through a penalty on changing former order-truck assignment. Such penalties may be included in the cost of the columns, and the size of the penalty can be fine-tuned to provide the desired degree of robustness. These penalties represent the disruption cost of changing a former order-truck assignment, and can be order-specific.

The concepts presented in this paper and the ESP model have been integrated into a commercial software package named SHIPCONS II, which is being used by several corporations for making tactical (fleet size and mix) as well as operational (dispatching) decisions.

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