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ANALYSIS OF THE EFFECTS OF A COOPERATIVE DELIVERY SYSTEM IN BANGKOK

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ABSTRACT

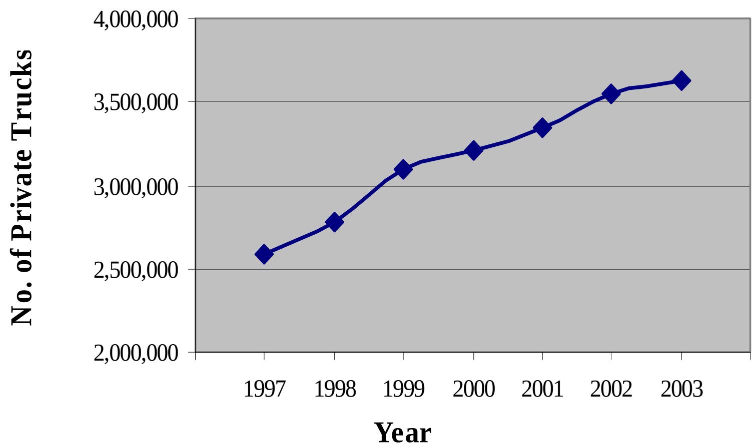
Freight companies, particularly small companies, may fear losing their identity if they participate in cooperative delivery systems (CDS), which use third party distribution, once the goods are collected at common stock points for their cooperative distribution. This study introduces a CDS, which consists of a common stock point for goods consolidation and use the trucks of participating companies for distribution instead of third party or neutral carriers. Objectives of the study also include the development of Truck Assigning Module to assign the consolidated routes of CDS to the trucks of participating companies. In the case study in Bangkok, the results estimated a considerable reduction in delivery costs that may be used in evaluating future implementation of CDS.

INTRODUCTION

With the increase in the economic and industrial activities, large cities are attracting more and more population due to better opportunities for jobs, education, health facilities and entertainment. All this is coupled with simultaneous increase in transportation requirements both in terms of passengers and freight. A high proportion of total goods movement occurs within cities (Taniguchi, et al., 2001). Most of this movement is based on road transport. Traffic congestion, noise, vibrations, generation of NOx, CO_2 and other environmental problems, accidents, loading and unloading on streets are common problems caused by the road based freight transport in urban areas.

Public logistics terminals, load factor controls, underground freight transport systems and cooperative delivery systems (CDS) are some city logistics schemes to improve the urban freight transport. CDS is a city logistics technique aimed at solving the urban freight transport problems by seeking the cooperation in delivery and/or collection of the goods between many logistics firms in order to increase the load factor and reduce the number of trucks required to deliver/collect goods. Cooperative use of information and cooperation in building and operating a common depot are other parts of cooperative freight transport systems (Taniguchi, et al., 2001).

A growing number of private trucks are registered every year in Thailand (Figure1). The growing percentage of goods being transported by road in Thailand shows that Bangkok also suffers from the same problems, being the economic center of Thailand. Large numbers of the trucks have to enter and leave of Bangkok for collection and distribution of goods.



Source: MOT

Figure 1 Number of private trucks in Thailand

In response to the above mentioned city logistic problems, the Government of Thailand has introduced measures to reduce these negative impacts of urban freight movement such as the construction of public logistics terminals and a ban on large trucks in the central area of Bangkok. Along with improvement in environment, the Department of Land Transport, in Thailand described the benefits of these truck terminals including as “to reduce the loss by the non-full loaded trucks, since truck terminal is the place to combine and transfer goods and the truck companies can share the trucks with same destination”, so as the idea of cooperative delivery system was aimed (Sridurongkatum, 2002). A simulation study done by Takahashi and Srikupanichkul (2001) showed that these terminals will decrease the large truck traffic inside Bangkok but light truck traffic will increase.

This study aims to investigate the concept of a Cooperative Delivery System (CDS) in Bangkok to increase the load factor and reduce the number of trucks. Many stakeholders may get benefits such as reduced distribution costs for freight carriers, reduced traffic and environmental problems for residents and administrators coupled with better management of traffic. The study area is the Central Business District (CBD) of Bangkok, comprising a total area of 28.9 sq. km, and with a population of 0.45 million people (2001 figures) (Angkana, 2002). 84 UTDM (Urban Transport Database and Model Development project, Bangkok) (UTDM, 1998) zones of the CBD were used in this study.

There are many forms of CDS, including the CDS where third party logistic is used to distribute the goods to the clients, once the goods are delivered to common stock point by participating companies. Examples of this type of CDS are the one followed in Kassel, Germany (Kohler 2004); and the social experiment conducted in Marunouchi, Tokyo, Japan (Sinarimbo et al, 2004). A neutral carrier is employed to collect and distribute the bundled goods in the centre of Kassel. In Marunouchi, natural gas trucks were used to distribute the goods from the common stock point to the clients rather than the trucks of participating companies.

Freight companies, particularly small ones, may fear losing their identity, when they participate in such a type of CDS. Therefore, this study has considered a CDS, where the distribution of goods from the stock point to the clients would be undertaken by using trucks of participating companies. This type of CDS may restore the confidence of small companies in CDS as well as provide them the chance to advertise using their trucks.

Many researchers have modelled CDS (Ieda et al., 1992; Duin and Jagtman, 1999; Taniguchi, et al., 2001; Sinarimbo et al, 2004). Yamada and Taniguchi (2004) modelled CDS in urban settings but their study considered a third party cooperative organisation. There was no model for assigning the routes developed in a cooperative environment and a common stock point for the trucks of the companies taking part in CDS. Therefore this study also aims at development of Truck Assigning Module (TAM) that is able to develop and assign the most economic route to the company that has the greatest number of the clients and/or highest client demand on that particular route for that particular instance.

METHODOLOGY

General

Data required to model or simulate urban freight transportation systems includes, the number of carrier firms, number of clients for each firm, their location, location of depots or common stock point, number and capacity of the trucks available for delivering the goods at each company, the frequency and size (weight) of the deliveries and specified time windows by the clients to receive the goods. Unfortunately this data is not available for the present non-cooperative delivery system of freight movement in Bangkok. For that reason the above mentioned data was randomly generated for each firm whereas actual road network data of Bangkok's CBD area was used from the UTDM report. Vehicle running cost, waiting time penalties and late arrival penalties were based on the vehicle operating cost (VOC) as calculated in another traffic study in Bangkok (MOT, 2004).

The objective of this study is to compare the relative advantages and potential of CDS over the present non-cooperative system used for the intra city movement of goods. Therefore the general approach of the methodology is to compare the effects of both the systems in terms of number of trucks required to deliver the goods and the cost of delivery. This was done by running the vehicle routing and scheduling problem with time windows (VRP-TW) model both in non-cooperative and cooperative environment and comparing the output from both of them.

Data Generation

Five hypothetical companies A-E were used to represent freight carriers participating in the CDS. The number of the clients for each company was restricted from 10 to 50, where as zone one was set as common stock point, and the remaining 83 zones were designated as client zones. Medium size trucks with capacity 2000 kg (MOT, 2004) were used as delivery vehicles. Two hours time window for each client was randomly generated within 0800 (8 AM) to 2000 (8 PM). The delivery time (service time) was set as 10 minutes plus 0.05 minutes per kg of demand. The vehicle operating cost for medium sized truck is 6.774 Baht/Vehicle-Kilometre (MOT, 2004). This was converted to 3.474 Baht/minute ($5.21/min.) by multiplying the ratio of total kilometres to the total working hours of the vehicle over its life. The waiting time cost is mostly taken as truck running cost where as late arrival cost varies from 4 to 5 times the truck running cost. The fixed cost of trucks was not available for Bangkok but it was estimated on the basis of the ratio of VOC to fixed cost used in Taniguchi et al. (2000).

VRP-TW Model

The VRP-TW model was developed inspired from the one presented by Taniguchi and Thompson (2002), which minimises the total cost of delivering the goods with truck capacity and designated time windows constraints. The objective function of the model is as:

$$Minimize[C_f \times k + \sum_{1}^{k} \sum_{i=1}^{n} C_d] \qquad (1)$$

Where

$$C_d \begin{cases} voc \text{ x } (t_{i,i+1} + td_i) & \text{if } e_i < ta_i < l_i \\ voc \text{ x } (t_{i,i+1} + td_i + (e_i - ta_i)) & \text{if } ta_i < e_i \\ voc \text{ x } (t_{i,i+1} + td_i) + Pl \text{ x } voc \text{ x } (l_i - ta_i) & \text{if } l_i < ta_i \end{cases}$$

i: *client*
C_f : *fixed cost of the vehicle utilisation*
k : *number of the routes in solution*
n : *total number of the clients in the route*
C_d : *delivery cost*
voc : *vehicle operating cost*
$t_{i,i+1}$: *travel time from client i to i+1*
td_i : *delivery time (service time) at client i*
ta_i : *arrival time at client i*
e_i : *start of time window of client i*
l_i : *end of time window of client i*
Pl: *late arrival penalty factor*

Usual VRP constraints such as each client can only be visited once and total demand along a route must be less than the capacity of delivery vehicle, were incorporated in the model. The used VRP-TW model is simple since the idea is only to compare the relative advantages of CDS over non-cooperative environment. Nonetheless if more refined VRP-TW models as VRP-TW with probabilistic times (Taniguchi and Thompson, 2002), VRP-TW with spare time

(Thompson, 2004) would be used to compare the cooperative and non-cooperative delivery systems, the advantages of cooperative delivery systems could be more emphasised.

A Matlab program was developed to solve the VRP-TW model using a Genetic Algorithm (GA). Integer population with order based crossover and swap mutation was adopted. Stochastic universal selection method was used with fitness based reinsertion technique using Matlab Genetic Algorithm Tool Box developed by Chipperfield et al.

Non-Cooperative System

When applied to the non-cooperative environment, VRP-TW model searches for the most economical routes for the trucks of various companies depending upon their capacity, satisfying the time windows constraint set by clients. Route starting time (ie. departure times) from depot (assumed to be located in same zone as of common stock point) for each route of a particular company as well as the cost of the route is also calculated by the model.

Cooperative Delivery System

In a cooperative environment, the resources (trucks) and clients of all the companies taking part in CDS were pooled together to form another virtual firm “F”. Traffic zones themselves were considered as the clients in the model, so combining all the clients of various firms presented the problem of repeated client zones in two or more companies’ client lists. This problem was tackled by inserting dummy zones instead of the repeated client zones, for example if client zone “13” is repeated in the client lists of company “A” and company “B” then while listing the clients for virtual cooperative firm “F”, client zone “13” was listed once as being the part of client list of company “A” and it was renumbered as client zone “85” (as the original number of zones were “84”), while considering the client list of company “B”. This specially occurs due to the time windows as same client zone with changed time windows represents two clients. Inter zonal travel time matrix was also expanded accordingly.

As the number of clients for this virtual cooperative firm was sum of the number of clients of individual companies, comparatively greater optimisation effort was used while running the VRP-TW model in cooperative environment. This is consistent with the NP-hard nature of vehicle routing problems where the complexity increases as the number of nodes increases. Output of the VRP-TW model in cooperative environment is an ordered chain of clients from various companies participating in the CDS, grouped in many routes; cost of the complete solution and the start time of each route from common stock point.

Truck Assigning Module

As shown in the Figure 2, we have considered a CDS, where the distribution of goods from the stock point to the clients, using trucks of participating companies. The output of the cooperative application of VRP-TW model is a long chain of clients numbers grouped in routes and it does not specify which company’s truck has been assigned to what route. The Truck Assigning Module (TAM) was developed for handling this aspect. TAM assigns routes to the trucks of various companies based on the highest number of clients of an individual company, present in a particular route.

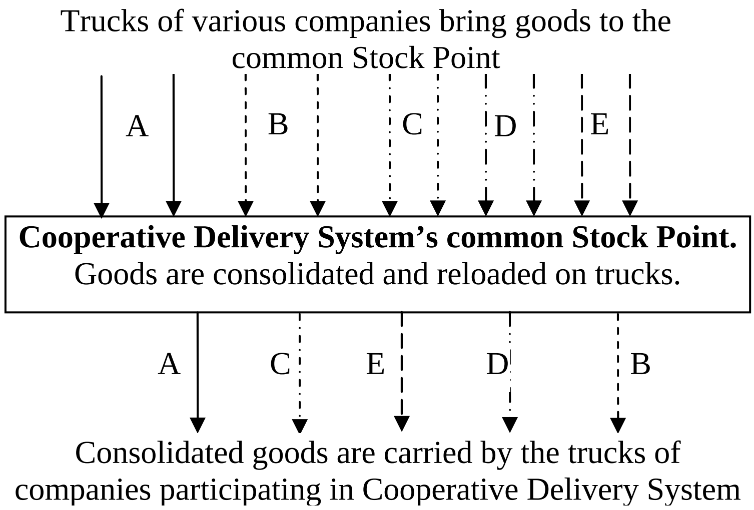


Figure 2 Proposed cooperative delivery system

As shown in the Figure 3, TAM takes the solution of cooperative application of VRP-TW model as well as the renumbered clients lists (due to repeated client zone numbers) of individual companies as its input. It then takes each route from the cooperative solution and sorts it by matching the client zone numbers to the renumbered client lists of individual companies. It then assigns the route to the truck of that participating firm which has the maximum numbers of clients on that route. In case of ties between two or more firms the demand (weight) to be delivered for each firm along with maximum number of clients is considered.

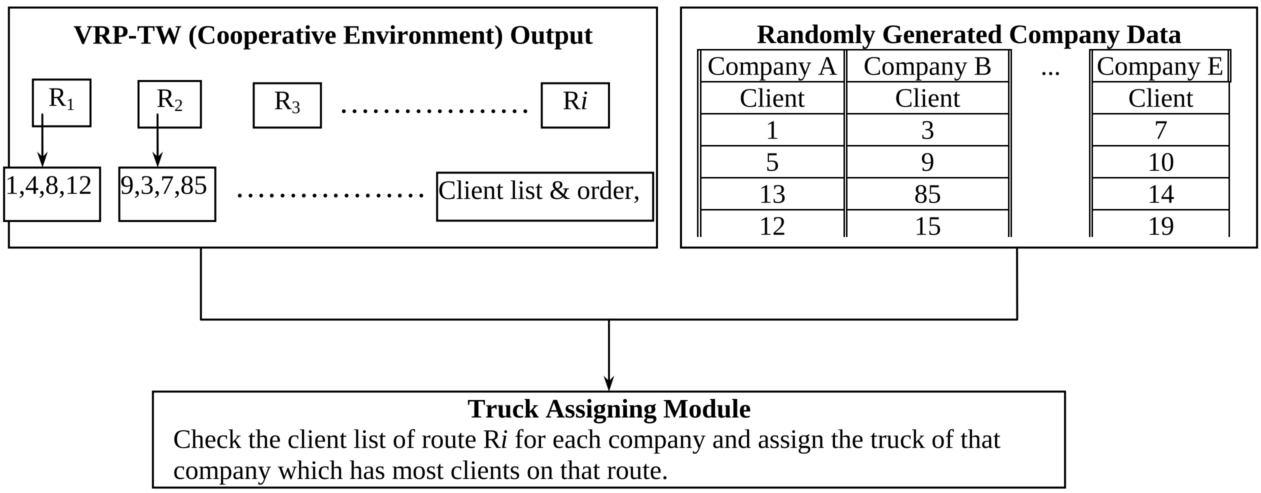


Figure 3 Flow chart of truck assigning module

TEST CASES

Three different cases are considered as follows:

I. Freight carriers put more emphasis on load factors (Base case)
II. Freight carriers put more emphasis on over all cost reduction.
III. Maximum demand at each client is reduced and penalty cost is increased.

Case I
The first case guides the models to find the best possible solutions where the load factors are maximised and the number of the routes kept to minimum. Clients were added to the route until the next insertion violates the capacity constraint of the delivery truck. The early arrival penalty cost and late arrival penalty cost are added to the cost of solution. The higher demand in this case may be mapped for the distribution systems where the goods to be delivered are bulk and massive.

Case II
In this case all other settings were kept same as case I, only with one change i.e. clients were added to a route until the next insertion either violates the capacity constraint or its penalty cost is more than the fixed cost of the truck used (cost of starting a new route). This case looks for an overall cost reduction and gives less emphasis on load factors.

Case III
In this case the penalty cost for late arrival was increased from four times to five times that of the VOC and the range of demand was also decreased. The minimum demand at each client zone was set as 50 kg and the maximum as one sixth of the truck capacity i.e. 333 kg. The client insertion condition in the route was kept same as in case II. This case was set by keeping in view the distribution of relatively small sized goods of more valuable nature thus the late arrival penalty was also increased.

Table 1 Parameters for different cases

Parameters	**Settings**		
	Case I	**Case II**	**Case III**
No. of client zones	83	83	83
Vehicle Capacity	2000 Kg	2000 Kg	2000 Kg
VOC	3.47 Baht/min	3.47 Baht/min	3.47 Baht/min
Min. demand at client	100 Kg	100 Kg	50 Kg
Max Demand	666 kg	666 kg	333 kg
Waiting penalty	3.47 Baht/min	3.47 Baht/min	3.47 Baht/min
Delay Penalty	13.9 Baht/min	13.9 Baht/min	17.3 Baht/min
Fixed Cost of Truck use	3500 Baht	3500 Baht	3500 Baht
Population Size For Individual Company	40	40	40
Population Size For cooperative mode	80	80	80
No. of Generations for individual company	100	100	100
No. of Generations for cooperative mode	1000	1000	1000
Max. no. of clients for individual company	50	50	50
Min no. of clients for individual company	10	10	10

RESULTS

Fifty random data sets were generated, 25 for case I and case II (same data settings) and 25 for case III, thus overall model was run 75 times for in both the cooperative as well as the non-cooperative environment. Figure 4 compares the average cost of non-cooperative and CDS solutions in all the cases and Figure 5 shows the percentage cost savings in the case of CDS over non-cooperative delivery system. Figures 6 and 7 show the distribution of costs due to routes (fixed cost), running time, early arrival penalty and late arrival penalty in non-cooperative system and CDS respectively. There was a consist decrease in average costs for both systems in all the cases. In non-cooperative system the reduction in cost in case II compared to case I was mainly due to the reduction in early and late arrival penalty costs owing to the new route start condition of case II where new route was started if the penalty cost was too excessive. Case III, where the demands at clients were kept low, has least cost among them all, basically due to less number of routes.

Similar traits were found with the CDS, as in the non-cooperative system, when performance of CDS was compared in different cases. Cost of CDS was less than non-cooperative delivery system in all three cases as shown in Figure 4. Compared to non-cooperative environment, CDS was found very efficient in reducing late arrival penalty costs as it almost eliminated late arrival penalty (Figures 6 and 7). There was a decrease in cost savings in CDS in case II compared to the savings in case I, even though the same datasets were used as input. This signifies the effectiveness of the optimisation condition used in case II, which focused on over all cost minimisation. The cost savings in CDS again rose to 12.93 % in case III; higher average load factors from the CDS was the main factor influencing these results.

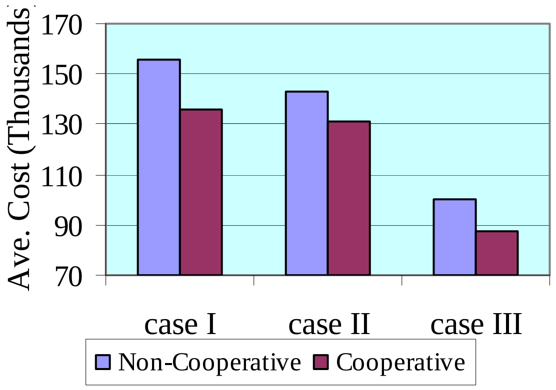


Figure 4 Average cost

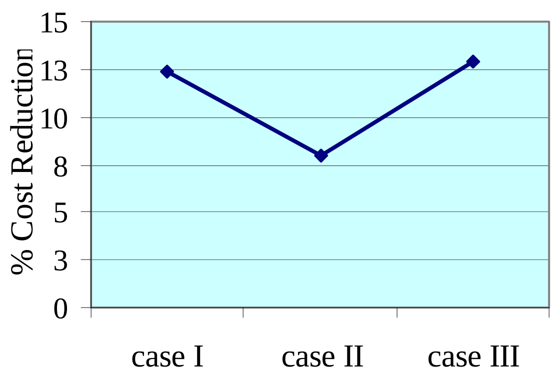


Figure 5 Percentage cost savings in CDS

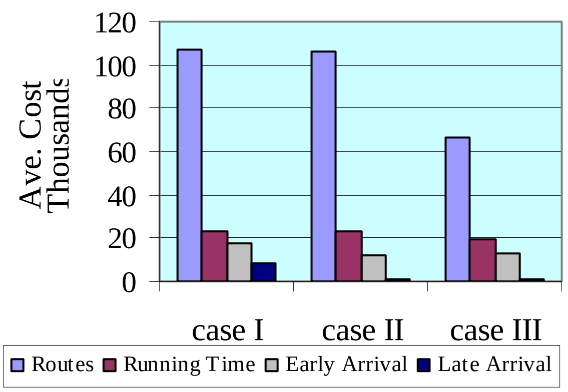


Figure 6 Shares in average cost of non-cooperation

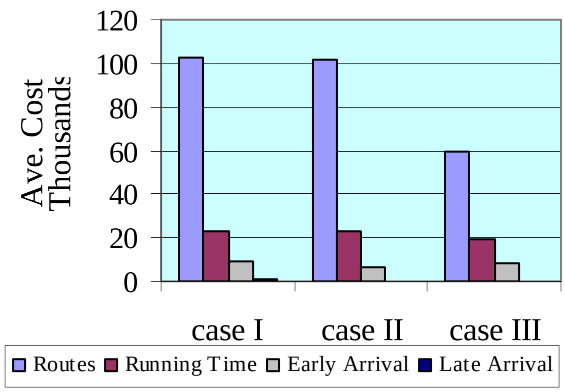


Figure 7 Shares in average cost of cooperation

Figures 8 and 9 show the load factors for the non-cooperative environment and CDS in all three cases. Initially it was perceived that load factor would decrease in case II compared to case I but the results showed that load factor has improved a little in case II compared to case I. The reason is that overall cost optimisation condition gives lower cost routes much earlier in the optimisation process as compared to the case in which load factor maximisation is the main objective and the penalties are just added to the cost. As Genetic Algorithm keeps the best solutions as the benchmarks, this guides the optimisation process in much batter way, which results in not only lower costs but also improved load factors. In case III, load factor went down as was perceived due to smaller delivery sizes (clients' demands). In the non-cooperative environment penalty costs are reduced and reliability is improved due to freight carriers often compromising load factors in order to satisfy the time windows.

CDS was able to increase the load factor by a little percentage in cases I and II (Figure 10), where the load factor of even non-cooperative environment was quite high above 0.85 (Figure 8), and little further increase was possible. It was in case III, where CDS showed its promise by considerably improving the load factors by more than 12 %. Improving load factor is considered to be an important evaluation measure for any city logistic scheme and the proposed CDS satisfies this well. The effect of increasing load factors in the CDS is also reflected in the improvement in proportion of savings due to lower number of routes in CDS compared to non-cooperative environment.

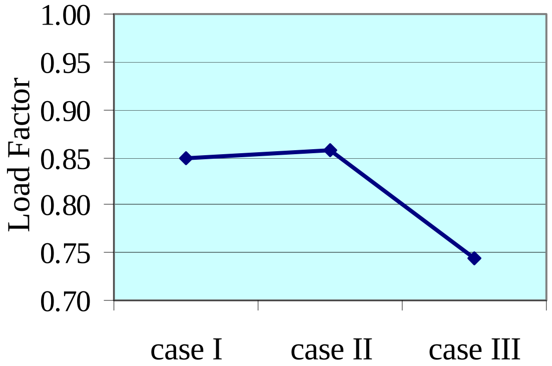


Figure 8 Load factor (non-cooperation)

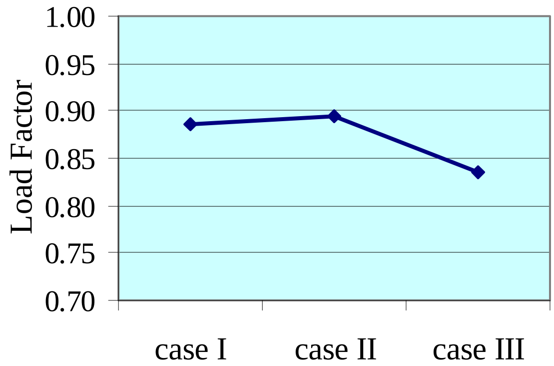


Figure 9 Load factor (cooperation)

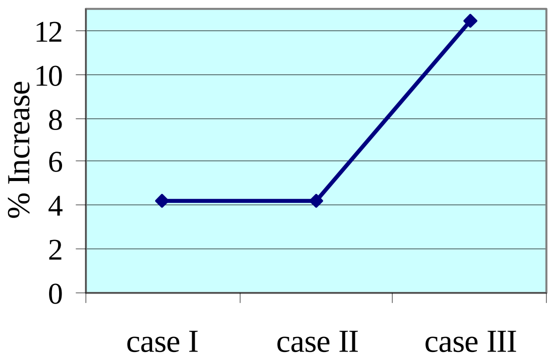


Figure 10 Percentage increase in load factors in CDS

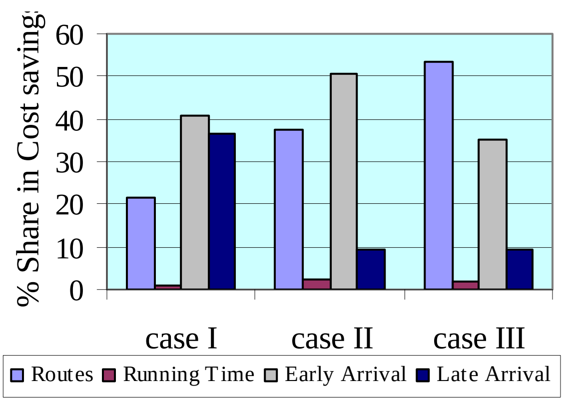


Figure 11 Shares of various elements in cost savings of CDS

As shown in Figure 11, the distribution in cost savings due to lesser running time in CDS was very small. It means that the VRP-TW model also optimised the distance travelled very efficiently in the non-cooperative environment. Figure 12 shows the distribution of cost savings due to lesser running time in all three cases. Percentage contribution in total savings of CDS, due to lesser running time was more than doubled in case II compared to case I, but again it declined in case III.

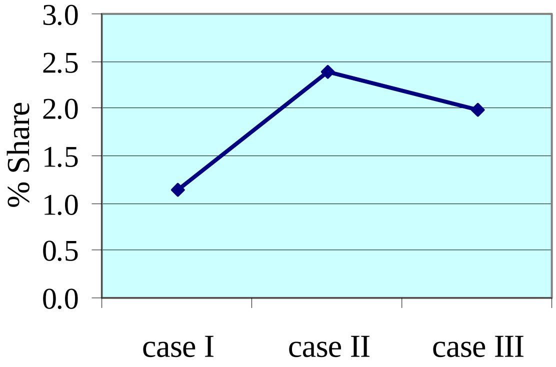


Figure 12 Share of less running time in cost savings of CDS

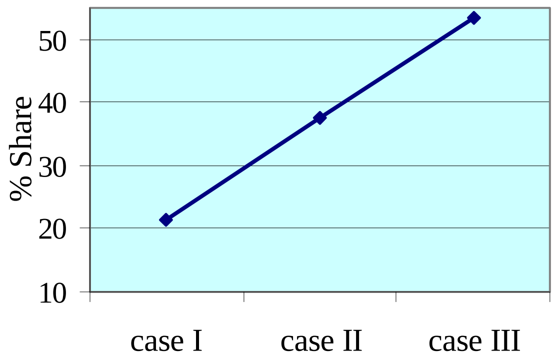


Figure 13 Share of fewer routes in cost savings of CDS

The proportion of cost savings increases due to the lower number of routes in cooperative environment (Figure 13). It started from a moderate value of 21.47 % in case I and eventually became the largest factor in cost savings in case III (Figure 11). This result signifies that the CDS can be very successful in distribution environments with lower demands and tighter time windows, by reducing number of routes. Reducing number of routes means reduced number of trucks on the roads, with corresponding improvement in traffic conditions and decrease in on street parking. This could be a very important factor considering the narrow roads of Bangkok.

While fewer routes were the major contributing factor in the cost savings of the CDS, the CDS was very efficient in reducing the penalties in all the cases, as well. Figure 11 shows that both the early and late arrival penalties reduction was the major source of cost savings for the CDS in case I. This was due to the fact that while non-cooperative system was unable to produce better penalty optimised solutions in case I (where major emphasis was only on load factor optimisation), CDS had a very large number of clients (as clients of all firms were added together) and the VRP-TW model was able to search less penalty prone solutions by trying many possible combinations to satisfy time windows of clients.

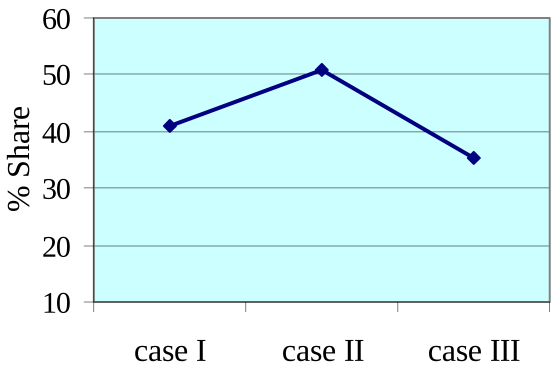


Figure 14 Share of less early arrival penalty in cost savings of CDS

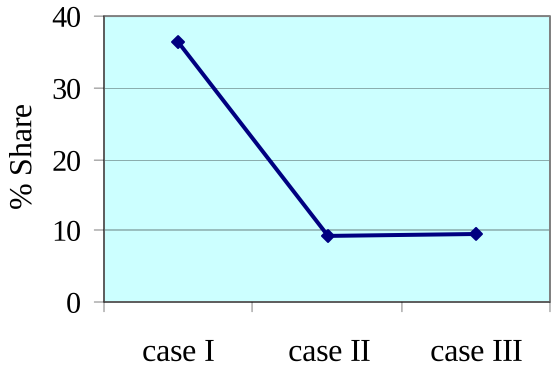


Figure 15 Share of less late arrival penalty in cost savings of CDS

Figures 14 and 15 show the percentage share of reduced penalty costs in savings obtained in CDS. Lower early arrival penalties have the maximum share (Figure 11) in CDS savings in case II, whereas it dropped slightly in case III (Figure 14). Both these cases were using the optimisation condition which prohibits excessive penalties. These results were due to lower penalty factor (equal to VOC) for early arrival penalty and hence a larger penalty could be tolerated rather than to start a new route. With the late arrival penalties the trend was reversed i.e. immediately after introducing the new optimisation condition, even non-cooperative environment reflected very good results as far as late arrival penalty was concerned and a considerable decrease was found in late arrival penalty costs for the non-cooperative environment in case II and III compared to that of case I (Figure 6). Higher penalty factors (4 times VOC in case II and 5 times VOC in case III) made even a moderate late arrival penalty time, a heavy cost and thus the optimisation process tried to minimise this cost as much as possible. This caused the share of cost savings in CDS due to reduction in late arrival penalty cost to decline considerably in case II and III as shown in Figure 15.

A high reduction in early and late arrival penalties in CDS compared to non-cooperative system does not only save cost but it also improves the reliability of the companies participating in the CDS. A lot of emphasis is given to improve the reliability and in doing so freight carriers even scarify their profits at some time by sending deliveries with lower load factors. As seen in above discussion the CDS was found to be very proficient in dealing with this problem of lower load factor at the same time improving reliability with savings in over all delivery costs as an added advantage.

Table 2 shows the effects of the CDS compared to the non-cooperative environment for all the scenarios.

Table 2 Effects of cooperative delivery system

Parameter	**Percentage Change due to CDS**		
	Case I	**Case II**	**Case III**
Average Cost	-12.56 %	-8.09 %	-12.81 %
Average Load Factor	+ 4.24 %	+4.22 %	+12.43 %
Average Fixed Cost (Routes)	-3.92 %	-4.08 %	-10.32 %
Average Running Time Cost	-0.96 %	-1.20 %	-1.32 %
Average Early Arrival Penalty Cost	-45.66 %	-48.64 %	-34.25 %
Average late Arrival Penalty Cost	-90.80 %	-79.91 %	-89.26 %

Truck Assigning Module's Performance

The Truck Assigning Module (TAM) results of case I are shown in Table 3. Almost in all cases except two, every company has at least one route allocated in cooperative environment. Companies C and D received at least one route 96 % of the times (in 24 out of 25 data sets) whereas corresponding results for companies A, B and E were 100 %. Also at some instances, a company in cooperative environment has to take more routes than in non-cooperative environment. But as the reduction in cost was in overall solution of the system, benefits to the company would always be more than what extra resources and cost a company has to bear in cooperative environment.

The overall performance of the TAM is shown in Figure 16 for all the three cases. It can be seen that in all the cases every company received a due share of the routes. This shows that proposed CDS, with the help of the TAM, can offset the fear of small participating companies that their identity as fright carriers will be lost if they join a CDS as well as giving them an opportunity to advertise through their trucks operating in the community.

Table 3 Truck assigning module results for case I

Data set No.	Non – Cooperative System					Cooperative System (TAM – Results)					
	Companies					Companies					Net reduction in routes
	A	B	C	D	E	A	B	C	D	E	
1	9	4	7	6	8	11	1	5	5	11	1
2	10	7	5	9	3	12	9	1	8	2	2
3	6	2	5	3	3	9	1	7	**0**	1	1
4	5	8	9	3	5	3	9	13	1	3	1
5	10	8	8	6	6	9	8	13	5	2	1
6	8	5	7	4	3	8	4	9	3	2	1
7	7	8	10	5	7	7	9	12	3	5	1
8	6	6	6	4	5	6	6	6	5	3	1
9	5	7	3	7	4	4	9	**0**	9	3	1
10	3	4	8	9	9	3	1	10	8	10	1
11	3	7	4	3	4	3	10	1	2	3	2
12	9	7	9	4	8	11	7	6	5	7	1
13	4	3	6	4	6	3	4	6	2	7	1
14	9	7	8	8	5	11	7	7	7	3	2
15	8	5	8	7	5	10	6	8	3	5	1
16	5	3	5	6	5	6	2	4	7	4	1
17	7	8	8	9	8	8	8	7	6	10	1
18	3	5	7	8	8	2	5	8	9	7	0
19	9	9	5	4	6	12	7	4	3	6	1
20	7	4	3	7	5	4	5	1	9	5	2
21	3	10	6	4	7	1	12	5	4	7	1
22	7	5	8	7	8	5	2	10	9	7	2
23	3	8	7	5	9	2	6	7	6	10	1
24	3	6	8	6	10	2	5	8	3	14	1
25	4	3	6	3	9	2	3	6	3	9	2

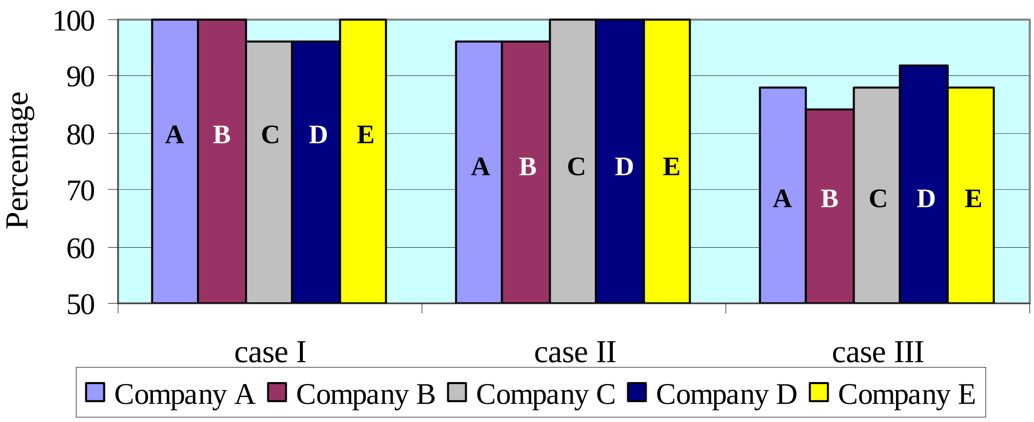


Figure 16 Performance of truck assigning module

CONCLUSION

Like every project starts by first making its plans and drawings, this study was aimed at introduction of a CDS system and its probable effects in Bangkok. The results obtained show that a considerable reduction in delivery cost may be realised by implementing CDS in Bangkok. As Bangkok has already three truck terminals, its implementation would be also not difficult.

Results of case III showed that CDS was very successful in the delivery environment where the sizes of deliveries were small. In this case, the non-cooperative environment forced a compromise on load factors to maintain a certain level of reliability. The CDS thrived in this situation not only by increasing the load factor and reliability by a considerable amount, it also saved delivery costs which can boost the profits of participating firms. As well, the CDS was able to significantly reduce number of routes compared with the non-cooperative environment. Reducing number of routes not only reduces distribution cost but also reduced the number of trucks on roads, with corresponding improvement in traffic conditions and decrease in on-street parking. This could be a very important factor considering the narrow roads of Bangkok.

Overall the TAM was able to assign the consolidated routes back to the participating companies quite competently. It showed that it could offset the fears of small participating freight companies of being side lined in the CDS, and of losing their identity if they join the CDS. Assigning routes back to the trucks of participating companies means they can also use their own trucks for their advertisement and publicity within the community.

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