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The Expansions of Vehicle Routing Problems: A Logistical Overview

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Abstract---*This paper provides an overview of the expansions ofVRP (vehicle routing problems) from a logistical point of view. The expansion includes the integration between VRP and inventory problems. That integration is known as IRP (inventory-routing problems). Another expansion is the integration of VRP with location problems which is then known as LRP (location-routing problems). The last expansion is known as LIRP (location-inventory-routing problems) which is the integration between VRP, inventory problems, and location problems. This paper also provides suggestions for future research related to the expansion of VRP.*

Keywords---*inventory-routing problems, location-routing problems, location-inventory-routing problem, overview, vehicle routing problems*

I. INTRODUCTION

An efficient distribution system requires an integrated approach to various logistical functions (Qu et al., 1999). This integration is particularly needed in the basic logistical functions, such as in the inventory system and transportation system. In the transportation system, customers are served by a fleet of vehicles where the locations are known in advance (Federgruen and Simchi-Levi, 1995). The aim is to find a set of routes that meet each of the constraint and to minimize the total distance. This problem is referred to as VRP (Vehicle Routing Problem).

VRP only focuses on determining the set of routes, while the quantity of goods to be delivered and when to deliver the goods are known in advance. This is because in VRP, customers themselves that order the goods according to their needs and customers also determine when the goods to be delivered (Custodio and Oliveira, 2006). The problem of determining the quantity of the goods to be delivered and when to delivered them is a problem related to inventory system. Therefore, however, inventory problem is interrelated with VRP (Moin and Salhi, 2007).

In determining which customers that will be served and the quantity of goods to be delivered to each customer, information of routing costsare needed so that the profit for each customer can be calculated accurately. On the other hand, the routing costs for each customer depend on the vehicle routes, which on the contrary it requires the information of customers to be served and the quantity of goods to be delivered. The reciprocal relationship between inventory problems and routing problems is an integrated problem that is known as IRP or inventory-routing problem (Moin and Salhi, 2007).

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The combination of these two problems can be seen as an expansion of VRP which in VRP, customers make the orders and suppliers served customers' demand and meanwhile minimizing the total cost of distribution. Whereas in IRP, orders are determined by suppliers based on input made by customers in the aim of minimizing the total cost of inventory costs and distribution costs. In other words, IRP is a medium-term problem while VRP is a short-term problem. In VRP, the question is to determine the vehicle routes, while in the IRP the question is not only to determine the vehicle routes, but also the quantity of the goods to be delivered and when to deliver the goods. IRP gives benefitto the customers in reducing inventory costs and avoiding customers from the complexity of inventory planning (Federgruen and Simchi-Levi, 1995). Meanwhile, the benefit to the suppliers is to be able to determine the quantity of the goods to be delivered and when to deliver the goods.

In addition to IRP, there is also another expansion of VRP, namely LRP (location-outing problems). LRP is allocation-location problems with considering routing problems simultaneously. Location-routing problems are related to the classic location problems and VRP. Both problems can be seen as special cases of location-routing problems. If customers are connected directly to a facility, the location-routing problems become location problems in general. Whereas if the location of the facility has been previously determined, the location-routing problems become vehicle routing problems in general (Nagy and Salhi, 2007).

Every customer is located in a facility that will supply that customer's demand. The delivery of that customer's demand is transported using a vehicle departing from the facility and the operation of the routes including more than one customer. The location of distribution facilities and the distribution of the goods from facilities to customers are two key components in a distribution system. In various circumstances, these two components are interdependent. Therefore, it is necessary to consider the location of facilities and the distribution decisions simultaneously (Tuzun and Burke, 1999 in Hassanzadeh et al., 2009).

The other expansion of VRP is known as LIRP (location-inventory-routing problems). The integrated LIRP model will simultaneously answer the problems related to the following decisions: 1) Location decisions: how to select facilities from potential facilities and how many must be selected?; 2) Allocation decisions: which customers should be allocated to the selected facilities?; 3) Routing decisions: what routes will be taken to meet customers's demand?; 4) Inventory decisions: how many products must be delivered from the facilities to customers? (Bo et al., 2011).

PAPERS IN THE EXPANSIONS OF VRP

The first integrated model of IRP was developed by Federgruen and Zipkin (1984) in Custodio and Oliveira (2006). The problem studied was related to distribution from a warehouse to several retailers and consisted of a limited number of products. Demand of each retailer was assumed to be random variable. On one particular day, inventory must be allocated to retailers, by minimizing transportation costs, inventory costs, and shortage costs. Dror and Ball (1987) in Custodio and Oliveira (2006) also conducted a research on a single period model but with an evaluation proposal to find out what happened after a short term planning period. The study started by calculating the optimal replenishment day for each customer which the calculation included the possibility of a shortage on a particular day in the planning horizon, the average costs of replenishment, and the costs of replenishment in anticipation of shortage.

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The unlimited planning horizon model appeared in the research of Anily and Federgruen (1990) in Custodio and Oliveira (2006). The study provideed a model with a single product, a warehouse and several retailers. Demands were considered deterministic and constant and retailers were interdependent. Inventories were stored in retailers and not in warehouses. The aim was to minimize the average transportation costs and average storage costs. Viswanathan and Mathur (1997) in Custodio and Oliveira (2006) developed the first integrated model with more than one product type. Assuming the demand was deterministic, the study used a heuristic approach to calculate a balanced joint replenishment policy in which all replenishment periods were the multiplication results of two known base periods.

Researcher that also developed IRP model was Qu et al. (1999) which developed IRP model with more than one type of product but stochastic demands and limited vehicle capacity. The study discussed a warehouse with several suppliers and implemented a periodic review policy in planning inventory in the warehouse. The aim is to meet demands with a minimum average cosat per unit of time. Gaur and Fisher (2004) developed IRP model in a supermarket retail chain in Albert Heijn, BV. The model developed was applied to problem with various time-dependent and heterogeneous vehicles with limited capacity. In this study, one retailer can be served several times during the planning horizon. The study also developed a software system that can be used by decision makers in resolving IRP. Custodio and Oliveira (2006) also developed an integrated model of IRP with more than one product type, stochastic demands and limited vehicle capacity. The model developed faced limited information relating to cost parameters and actual demands by retailers. The research provideda directionon how the current operation was carried out even though it did not provide a solution derived from optimization procedures.

Researcher discussing LRP included Lin et al. (2002) in Hassanzadeh et al. (2009). In this study, it was given a problem that integrated location facilities and distribution planning.In the problem there was no time window constraint and if more than one route could be assigned to a vehicle without exceeding daily working hours, then the cost reduction would be achieved. There are several constraints in this study relating to operational constraints, namely daily working hours, vehicle capacity, and potential depotscapacities. The aim was to minimize the cost of facilities, labor costs, rental costs and operational costs. Caballero et al. (2007) in Hassanzadeh et al. (2009) also developed LRP model. In this study, the model was developed to find the best location for burning trash from several potential locations in Andalusia (Spain). In determining the best location there were several different factors that must be developed. Therefore, the problem became a problem with more than one objective function. Five different objective functions were developed in this study by considering two main aspects, namely economic aspect and social aspect. Other researcher that also developed LRP model was Lin and Kwok (2006). This study discussed an integrated logistics system in which the location of the depot and vehicle routing were determined simultaneously. In addition, this study also contributed to estimating data unavailability by proposing the use of GIS (Geographic Information System)..

Researcher who developed LIRP model was Bo et al. (2008). In this study a LIRP model was developed with a stochastic demand and the product consisted of one type of product. This study did not considere the capacity of the facility, either depost or warehouse, as decision variables in the developed model. In addition, in this model the vehicle used was homogeneous so that the capacity of the vehicle was the same as each other. Javid and Azad (2010) also developed a LIRP model. The model developed in this study considered facility capacities as decision variables in addition to location, allocation, routing, replenishment, and safety stock. The product consisted of one type

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product, the demand was stochastic, and the vehicle was homogeneous. In addition, Hiassat and Diabat (2011) also developed a LIRP model with deterministic demand, the product consisted of one type product, and was a perishable product. The vehicle used in this study was also homogeneous one and the capacities of the facilities to be selected were also not considered in the development of the model. Guerrero et al., (2012) also developed the same model, with determistic demand and the products consisting of one type product. The vehicle used in this study was also homogeneous and the capacity of the selected facilities was not considered in the development of the model. Summary of previous studies can be seen in Table 1.

TABLE1:CLASSIFICATION OF PAPERS IN THE EXPANSIONS OF VRP

Papers	Number of Echelons		Number of Products		Scope of Problems				Decisions Making Levels			Transportati on policies		Expansions of VRP			
	Single	Multi	Single	Multi	Location	Allocation	Inventory	Routing	Strategic	Tactical	Operational	Direct delivery	Sharing delivery	IRP	LRP	LIRP	Others
Anily and Federgruen (1990)	√		√				√	√			√		√	√			
Bo et al. (2008)	√		√		√	√	√	√	√	√	√		√			√	
Caballero et al. (2007)	√		√		√	√		√	√	√	√		√		√		
Custodio andOliveira (2006)	√			√			√	√			√		√	√			
Dondo et al. (2011)		√		√				√			√	√	√				√
Dror and Ball (1987)	√		√				√	√			√		√	√			
Federgruen and Zipkin (1984)	√		√				√	√			√		√	√			
Gaur and Fisher (2004)	√			√			√	√			√		√	√			
Guerrero et al. (2012)	√		√		√	√	√	√	√	√	√		√			√	
Hiassat and	√		√		√	√	√	√	√	√	√		√			√	

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Diabat (2011)																	
Javid and Azad (2010)	√		√		√	√	√	√	√	√	√		√			√	
Lin and Kwok (2006)	√		√		√	√		√	√	√	√		√		√		
Lin et al. (2002)	√		√		√	√		√	√	√	√		√		√		
Qu et al. (1999)	√			√			√	√			√		√	√			
Viswanathan and Mathur (1997)	√			√			√	√			√		√	√			

II. THE DISCUSSION

From the previous chapter, it can be seen that VRP has expanded. This can be seen from the scope of the problems and the level of decisions produced. Classic VRP deals with routing problems which are problems at the operational level. The first expansion is IRP which deals with inventory and routing problems. Both of these problems are still at the operational level. The next expansion is LRP that answers the problems of location, allocation, and routing simultaneously. Location problems are problems at the strategic level, allocation problems are at the tactical level, and routing problems are at the operational level. The last expansion of VRP is LIRP which simultaneously answers the problems of location, allocation, inventory, and vehicle routing. Therefore LIRP is an approach that answers three levels of decision making at once. The expansions of VRP based on the level of decision making can be seen in Table 2.

TABLE 2: THE EXPANSIONS OF VRP

VRP	IRP	LRP	LIRP
Operational level (Routing)	Operational level(Inventory and routing)	Strategic level (Location) Tactical Level (Allocation) Operational level (Routing)	Strategic level (Location) Tactical Level (Allocation) Operational level (Inventory and routing)
Late 50’s	Early 80’s	Late 80’s	Late 90’s

III. SUGGESTIONS FOR FUTURE RESEARCH

From the discussion that has been done, some suggestions for future reasearch in the expansions of VRP are given. They are:

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1. Developing IRP models that consider inventory decisions for all entities involved.
2. Developing LRP models that consider sociocultural factors.
3. Developing effective and efficient heuristic methods for every expansion of VRP, for the problems itself are NP-hard problems.

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