Smart and Sustainable Delivery Operations for a Large Supermarket Chain

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Abstract
This paper reports the transformation of the delivery operations of a large supermarket chain from a traditional multi-layer distribution network to a smart cross-docking direct-to-store network. The sustainable effects due to the transformation are also assessed in this study.

Keywords: Supermarket chain, Smart delivery operations, Sustainable

Introduction

A retail cross-docking strategy is an advanced supply chain strategy which builds a virtual order management and operational execution system between geographically dispersed stores of a retail chain and its multiple suppliers. It is particularly critical to install supply chain collaborative/control scheduling system and sophisticated automatic material handling equipments for the carton or item-based orders to ensure the accurate and fast flow-through of store ordered products directly from the suppliers' warehouses to the cross-docking facilities and continue on to the retail stores (Su and Liao 2014).

In practice, the cross-docking set-up of a retail chain can create competitive advantages and value to the retail chain and its suppliers through supply chain inventory reduction, fast turnover of inventory at stores and supplier warehouses, reduced order cycle time, increased truck load factors and fleet utilization, streamlined information flow and better supply chain collaboration, et al. Several cross-docking literatures also validate the value mentioned here (Kulwiec 2004; Kumar 2008; Van Belle et. al. 2012).

The outbound delivery operations in Taiwan conventionally are controlled by experienced truck dispatchers using their "accumulated intelligence" and intuition (i.e. intuitive route planning). However, vehicle routing practices in more advanced economy such as U.S. have shown that delivery operations can be improved dramatically with the application of **vehicle routing analytics technology** (Partyka and Hall 2015; Toth 2015) (i.e. smart route planning). A research team was granted the task to help a large Taiwan supermarket chain recently transformed to a cross-docking supply chain to develop a vehicle routing system for its cross-dock store delivery operations applying vehicle routing analytics technology.

In this paper, a brief literature review will be first conducted. Next, the delivery requirements and demands will be described. Then, the original route planning approach will be explained, followed by the smart route planning approach. The smart route planning technology based on a VRP-based spreadsheet modeling system along with the related data management will be depicted. Finally, sustainable effects of the smart delivery operations will be assessed and discussed. The analysis in this study utilizes low, medium and high demands of three days in October, 2012 of the northern cross-dock distribution center servicing 274 stores.

Literature Review

The field of sustainable supply chain management (SSCM) has evolved from a perspective and investigation of standalone research in social and environmental areas; through a corporate social responsibility perspective; to the beginnings of the convergence of perspectives of sustainability as the triple bottom line (Elkington 1998) and the emergence of SSCM as a theoretical framework (Carter and Easton 2011). Sustainability drives efficiency – and this is particularly true in supply chain logistics. Profitability and sustainable logistics can go hand-in-hand (Waters 2013).

Market saturation, extreme competition and shifts in demographics, and the recent economic slump restrict players in the supermarket industry to limited external market growth. Supermarket retailers are forced to customize various operating strategies – expanding the array of services and products, increasing loyalty of profitable customers, generating profits through private labeling, and reaching customers through new delivery methods like cross-docking, internet shopping and home delivery (Kumar 2008).

A cross-docking business model is a collaborative supply chain system that attempts to optimize the upstream and downstream supply chain business processes to speed up movement of products from source to consumption, reduce the supply chain inventory and warehouse facilities, and increase supply chain transportation efficiency (Vogt 2010). The outbound delivery operation is a key process in the cross-docking operations. It is a classical and well-known operations research subject, that is, vehicle routing problem (VRP) (Toth 2015). There are many studies in VRP to design algorithms to obtain better solutions in shorter computing time. However, most of these studies are more theoretical than practical (Agustina et al. 2010; Van Belle et al. 2012). Therefore, practical algorithms with smart heuristics are developed for business application and VRP software. According to the literature and industry practice, VRP is commonly solved by two types of heuristics: “cluster first, route second” vs. “route first, cluster second” (Cordeau 2002; Gillett and Miller 1974). The “cluster first, route second” heuristics is used more often in practice due to its decomposition design principle, that is, to decompose a large VRP problem into many much smaller travelling salesman problems (TRP).

In Asian business, most of VRPs are dealt with by some intuitive route planning methods. The research team believes VRP heuristics could be robust alternative to intuitive route planning methods and create much higher sustainable value. Based on the operational characteristics of the store delivery of a supermarket chain, “cluster first, route second" heuristics (Gillett and Miller 1974) is selected for the cross-docking distribution center to revamp its delivery operations.

Supply Chain Transformation of PxMart

In 1998, the tax-free stores run by co-ops were banned by Taiwan government due to many wrong and unfair conducts accused by the "normal" retail sector. The largest co-op was taken over by a local house developer with 68 stores to begin with. However, it is no longer tax-free. With the smart strategies to modernize the stores, collaborate with suppliers and stick to the consignment-based transactions, the new supermarket chain is run under the new name, PxMart, and has been growing in a very fast speed to become the largest supermarket chain in Taiwan in less than 10 years. At one time, Wal-Mart even benchmarked PxMart's store model for its China market development. For the dry goods, there were about 400 medium and small local distributors spread out in the country to distribute more than 10,000 product items from more than 600 suppliers to over 500 stores. The complexity of this decentralized and fragmented multi-layer distribution system had caused many delivery problems at the store level and in the distribution channel. The management felt great pressure from the inefficiency and instability of its traditional distribution channel.

In 2009, top management decided to thoroughly investigate the issue and find solution to release the pressure and gain capability for future growth. Due to its consignment-based nature and frequent transactions between the retail chain and its suppliers, a cross-docking strategy was recommended to redesign its supply chain network and operational model after a thorough one-year supply chain study (Su et al. 2010). In 2010, PxMart approved the research suggestions and has started its multiple-year supply chain transformation journey from the old business model to the cross-docking business model. Two locations were selected, one in north and one in south, as the cross-docking distribution campuses.

The transition from the traditional distribution model to the cross-dock distribution model started with the northern campus in March of 2012 in a small tested area. One month later, the southern campus joined with a small tested area. The full implementation was completed in June of 2012 for the southern and northern regions. The total investment for the business model transformation is estimated to be more than $3 million dollars (i.e. 90 million New Taiwan Dollars). Figure 1 presents the supply chain network after the business model transformation. Substantial values are created for PxMart.

Figure 1 PxMart distribution channel after business model transformation

Delivery Operations in the Cross-docking Distribution Center

According to the sales statistics, average annual store sales are 100 million NTD (around 3.3 million US$). The northern distribution center serves 274 stores with sales close to 27.4 billion NTD. In PxMart's distribution center, 95% items are cross-docked while 5% need to keep inventory and use the traditional pick-pack-ship method. In a typical order cycle, it will go through several stages in the supply chain with conversion of handling units between stages to gain distribution economy. The supply chain order cycle stages are illustrated in Figure 2.

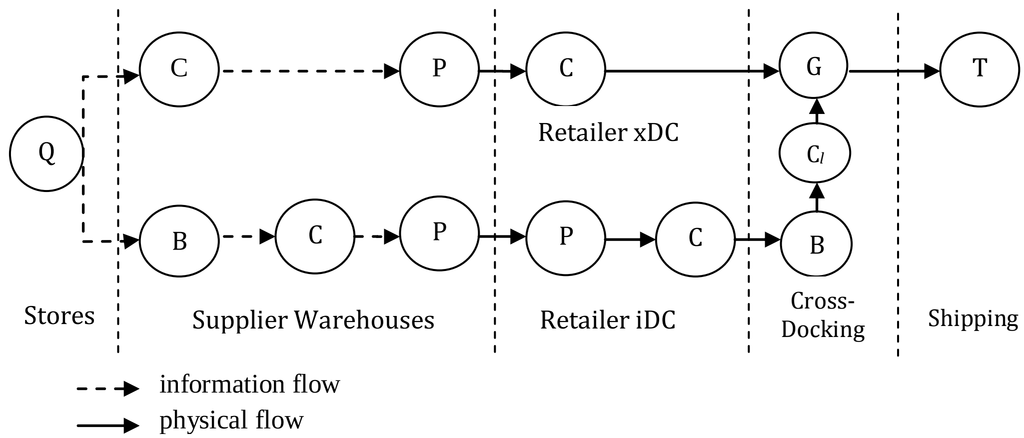


Figure 2 Conversion of the handling unit at different cross-docking distribution stages

The normal order cycle is 24 hours with 6 hours inside the cross-docking distribution center. In the order placing stage, Q is the demands of items ordered by stores. In the second stage, the suppliers will receive carton orders (C) for cross-docking items or piece orders (B) for inventory items. In the third stage, the retailer distribution center will receive pallet shipments of carton orders and feed those cartons directly into the cross-docking facility, i.e. xDC; on the other hand, the center will receive pallet or carton shipments of piece orders and move them to the storing facility, i.e. iDC, waiting to be picked and consolidated into logistics boxes (C_l). In the fourth stage, the cross-docking sorting system will receive cartons (C) from xDC and logistics boxes (C_l) from iDC. The cartons and boxes will be sorted to their store chutes and then transferred to store designated cages (G). In the final stage, the cages will be moved to temporary staging areas and then loaded into the delivery trucks (T) ready to be shipped to the stores.

Delivery Requirements and Demands

At the time of study, the northern cross-docking distribution center serves 274 stores. The geographic map is shown in Figure 3. The most densely area in the northeast is the Greater Taipei metropolis with around 7 million population. Moving away from the northeast towards the southwest, there are stores in the suburban and rural cities where population density is reducing gradually. Quadrant 4 is the Taiwan Strait and Quadrant 2 is the mountain area without populations and stores.

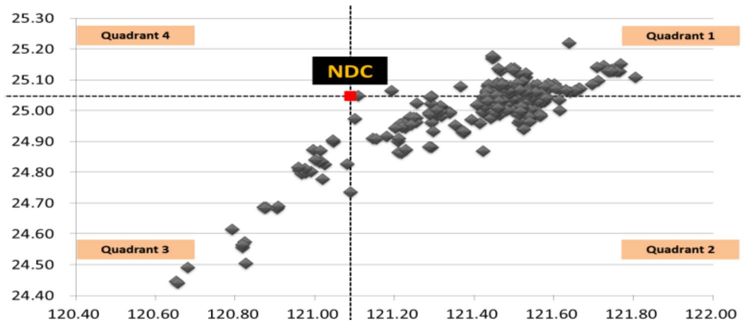


Figure 3 274 Store location map for northern cross-docking distribution center

Delivery operations utilize three types of trucks. The old town of Taipei and some areas have many narrow roads and Taipei City Transportation Authority allows only small truck to enter these areas. Small trucks with 3.5 ton capability serve 58 stores located in these areas shown in the left network in Figure 4. For the other stores with wider road conditions or rural areas, they are served by larger trucks including 6.5 ton fleet and 11 ton fleet shown in the middle and right networks in Figure 4. The carrying capacity of cages for 3.5, 6.5 and 11 ton trucks are 12, 17, and 27 cages respectively.

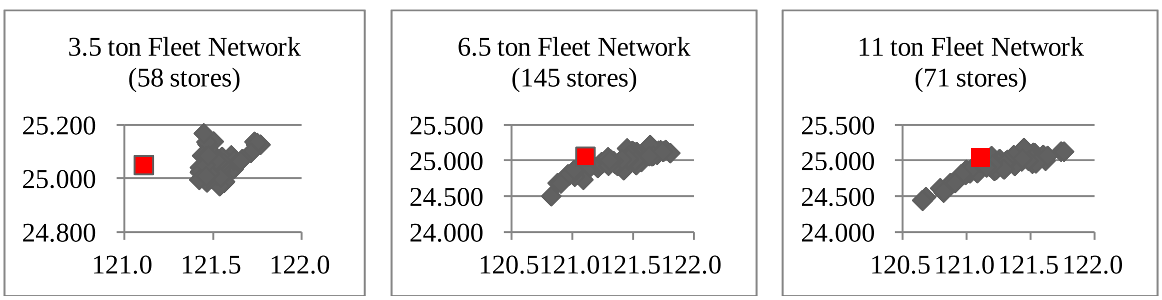


Figure 4 Fleet networks for three truck types: 3.5 ton, 6.5 ton and 11 ton

This study uses three daily demands to develop the smart delivery panning system. Table 1 shows the maximum, medium and minimum daily demands of cartons and cages in October, 2012. As it is shown the demands varies dramatically between peak and valley. In the cross-docking distribution center, the incoming cartons are handled by two work shifts: morning shift and afternoon shift. Normal sorting capacity of each shift is 40,000 cartons in a 4-hour operational period (i.e. 10,000 cartons per hour). Afternoon shift capacity plays the buffering role of daily demand processing and sorting. If there are more demands than 80,000 cartons, the cross-dock operations in the afternoon shift will continue until all cartons are processed. If the daily demand is near 40,000 cartons, the distribution center will open only for the morning work shift. To better utilize the fleet and drivers, PxMart Logistics set up a 240-minute soft delivery time window for all routes so that the trucks can be used for the morning shift first and afternoon shift later. For the minimum daily demand, it is only slightly higher than one shift processing capacity 40,000, therefore, it is treated only one shift in a day.

Table 1 Maximum, medium and minimum daily demands in October, 2012

	Daily Demands (October, 2012)			Demands per Shift (October, 2012)		
	Maximum	Medium	Minimum	Maximum (2 Shifts)	Medium (2 Shifts)	Minimum (1 Shift)
Carton	104,166	62,478	43,132	52,083	31,239	43,132
Cage	5,996	3,596	2,405	2,998	1,798	2,405

Intuitive Route Planning vs Smart Route Panning

The delivery operations for the stores of PxMart used to follow a conventional intuitive route planning approach using paper maps and experienced dispatchers to design fixed routes for drivers. However, because daily demands fluctuate quite large, the truck loading ratio (the ratio of loaded cages to load capacity) is often low at around 50% - 60%, at best 70%. In special instances, dispatchers need to hurriedly adjust routes to avoid very low loading ratio (less than 30%) truck routes. The situation has brought to the attention of management.

In the core of delivery operations, it can be modeled as a classical operations research problem, that is, vehicle routing problem widely studied since its first research in literature (Dantzig and Ramser 1959). A smart route planning approach based on the sweep algorithm is developed in this study. “Smart” is a relative term that implies VRP-based heuristics is smarter than the conventional intuitive planning approach.

Figure 5 illustrates the sweep algorithm used to design the delivery routes for the 3.5 ton fleet. The other two types of fleets are also using the same route planning approach. A sweep algorithm first studied by Gillett and Miller (1959) is a “cluster first, route second” VRP heuristics. The demand at some stores may exceed the capacity of the vehicles. The modification to the sweep algorithm is to add a preprocessing step. In general, if any store has demand greater than or equal to the capacity of the vehicle, then a vehicle is assigned to the store to form a single route and leaves the rest of the demand for the regular sweep steps.

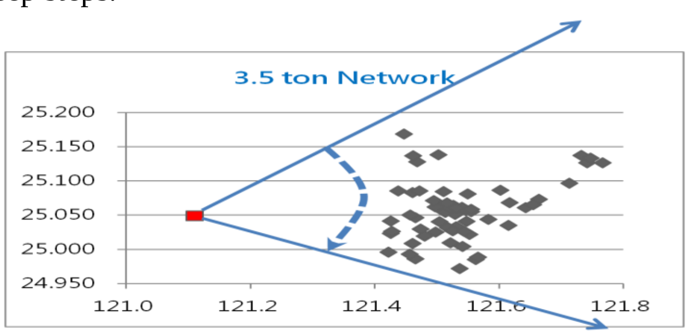


Figure 5 Sweep algorithm for 3.5 ton fleet illustrated

There are three stages in the VRP-based heuristics developed in this study:

1. Cage Loading: This is a modified sweep algorithm to find all routes in a delivery operational shift. A network with 7 stores and its route solution is illustrated in the left diagram of Figure 6 where 6 routes are found and 6 trucks are assigned to these routes.
2. Multiple Routes: Since there are routes with short delivery time (less than 120 minutes), it is possible to assign a truck to two routes and still obey the delivery time period limit, thus reduces the fleet size. In the middle diagram of Figure 6, the 7-store network now requires only 4 trucks since four routes can be grouped into two pairs with total delivery time of each pair less than 240 minutes.
3. Route Consolidation: Routes with very low loading ratio can be consolidated with other low or medium loading ratio routes. Any successful route consolidation can reduce the number of routes, thus, also reduce truck(s) in the fleet. The right diagram in Figure 6 shows three routes are consolidated to two routes, i.e. if the sum of the loading ratios of any three routes is less than 200%, they can be combined (or re-consolidated) into two routes.

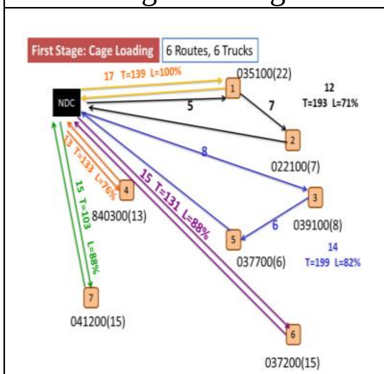
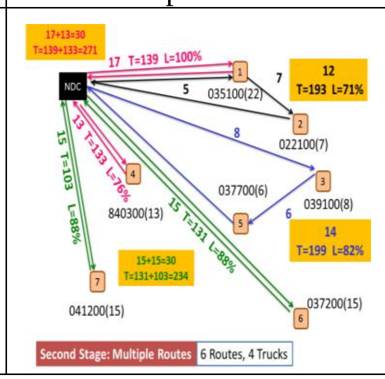
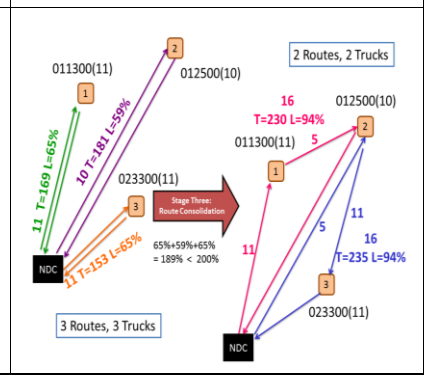
Cage Loading	Multiple Routes	Route Consolidation
		

Figure 6 VRP-based heuristics network illustration

Each route created in VRP-based heuristics represents a delivery route that may include one to several stores. If there is more than one store, a traveling salesman problem (TSP: Applegate 2007; Toth 2015) can be formulated to find the optimal or a good delivery sequence for the stores. Once the routes and their delivery sequences are determined, the trucks and drivers can be assigned to the routes and work schedules will be arranged and transmitted to the drivers.

Table 2 shows the smart route planning results of three days having different demands. It is clear that there are good improvements on all route performance measures for three days due to the three stages improvement heuristics. In specific, the loading ratios have reached above 85% and the higher the demand, the better the loading ratio is. Similarly, total routes, total trucks, and total delivery distances are all improved.

A spreadsheet modeling system is developed for planning the delivery routes. The kernel of the system is a VRP-based heuristics introduced in the previous section. Personal computer and Excel 2010 are used to develop the spreadsheet models for three days, two shifts, and three truck types. After the routes are found for a day, a shift, and a truck type, they will be combined with the routes of the other two truck types on the same day and shift. According to the modeling experience of this study, when all data elements for the spreadsheet models are ready, it takes about 2.5 hours to plan the routes for a delivery operational shift.

Table 2 Smart route planning results for daily demands of three days in October, 2012

	Max-Morning Shift				Min-One Shift				Medium-Morning Shift			
Total stores	268				272				267			
Total cages	2,998				2,405				1,798			
Heuristics Rule:	1-CL	2-MR	3-RC	sum	1-CL	2-MR	3-RC	sum	1-CL	2-MR	3-RC	sum
Total routes	198	198	188		164	164	160		125	125	123	
Improvement			-10	-10			-4	-4			-2	-2
Total trucks	198	155	145		164	147	143		125	120	118	
Improvement		-43	-10	-53		-17	-4	-21		-5	-2	-7
Average load ratio	83%	83%	88%		84%	84%	86%		82%	82%	85%	
Improvement			5%	5%			2%	2%			3%	3%

Sustainable Performance Assessment

In PxMart case, its transformation from a multi-layer distribution model to a cross-docking supply chain logistics model has created many operational benefits (Su and Liao 2014). It is believed that large sustainable benefits have also come with the huge operational change in the supply chain (Waters 2013). Through an in-depth study on the sustainable performance of the delivery operations before and after PxMart’s transformation, sustainable performances can be identified and will be discussed below.

Economic benefits are mainly derived from the dramatic reduction of the fleet size from 1,035 to 151, a reduction of more than 85%. Substantial cost savings, i.e. > 24 billion NTD, are generated from fleet purchase, annual depreciation, and annual driver salaries as shown in Table 3 (Lin 2014).

Table 3 Fleet size reduction and cost savings

Operational model	Multi-layer (Old)	Cross-dock (New)
Fleet size	1,035	151
Reduction of fleet size	884	
Savings in fleet purchase	1,591,200,000 NTD	
Savings in annual depreciation	286,416,000 NTD	
Savings in annual driver salary	530,400,000 NTD	

The total delivery distances are also reduced by more than 48% incurring greater than 22 million NTD fuel expense savings as seen in Table 4.

Table 4 Delivery distance reduction and fuel expense savings

Operational Model	Multi-layer	Cross-dock
Total delivery distances	17,260,385 KM	8,948,044 KM
Savings in distances	8,312,341 KM	
Savings in fuel expenses	22,537,226 NTD	

Annual CO_2e reduction is assessed for the operational model change. In Table 5, it is estimated that 1,843 tons of CO_2e, a 48% savings from the past, can be reduced due to the reduction of delivery distances travelled by trucks (Lin 2014).

Table 5 Annual CO_2e reduction

Operational Model	Average daily delivery distances (KM)	Average Daily CO_2e (KG)	Annual CO_2e (KG)
Cross-dock	28,588	6,340	1,984,420
Multi-layer	55,145	12,229	3,827,677
Annual reduction of CO_2e			-1,843,257

For the **social benefits**, they are assessed qualitatively over the driver and store effects. As shown in Table 6 (Lin 2014), there are many benefits created by the new operational model for the drivers and stores. We believe there are also social benefits for DC and suppliers' employees not yet assessed in this paper.

Table 6 Social effects on drivers and stores

Driver effects	Store effects
• Faster and safer truck Loading • Delivery time reduction • Consistent on-duty time • Fairer delivery task assignment	• Faster and safer truck unloading • Convenient and faster store replenishment • Reduction of local traffic congestion • Less disturbance on store customers

Discussion

The case firm has gone through a major transformation in its supply chain with high investment in the cross-docking facilities and equipments. However, the centralized delivery operations remained outdated using an intuitive route planning approach. A research team was appointed to redesign the route planning system using a smart route planning approach.

The contributions of this study are threefold. First, a VRP-based heuristics is developed and embedded in a spreadsheet modeling system to assist the planning of delivery routes of a large cross-docking distribution center of a supermarket chain. Second, the performances before and after the transformation from a multi-layer distribution model to a direct-to-store cross-docking supply chain are extended to assess not only financial performance but also environmental and social performances. It is found that the transformation creates not only large cost savings but also very good environmental and social effects for the supply chain. It has validated a recent proposition: "Achieving sustainable logistics does not mean sacrificing profits (Waters 2013)." Third, the spreadsheet model can serve as a template and be applied to other supermarket chains that are still using intuitive route planning approaches, typically found in emerging markets.

We deem the technology developed in this study with a low-tech nature rather than a high-tech one since it is developed by a common software (MS Excel) using mainly a modified sweep algorithm (relatively easy to implement) to find delivery routes. The planning time is not fast but quite reasonable; while the planning results are not optimal but much better than those derived from the intuitive/experience-based approach.

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