HEC MONTRÉAL

A simulation approach to

Analyze resource-sharing policies from a

Health equipment rental service provider's perspective

by

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ABSTRACT

This thesis studies a distribution network for health equipment rental service between the service provider and its clients. How to provide professional and guaranteed services to more patients with limited resources is a challenge that the service provider should face. Uncertainties accompany this challenge on many fronts. First, demand is uncertain: it is difficult to precisely predict when and how many patients will need rental equipment. Second, each patient's duration of rehabilitation differs from others. Third, the inventory of health equipment is limited.

These challenges allow us to apply resource-sharing strategies to see if resource-sharing among several regions in the same network can improve the service without adding additional inventory. We measure the degree of improvement in fulfillment rate by applying various resource-sharing strategies within a group of several selected neighbouring regions. Furthermore, we also assess the impact of transportation times on fulfillment rates incurred by shared equipment transshipment between regions. This study is carried out with the help of a simulation approach.

We found that appropriate resource-sharing strategies are helpful in improving the fulfillment rate of the health equipment rental service. Especially applying resource-sharing strategies in a decentralized network where health equipment is stored in each region can improve total fulfillment performance as well as better reduce patients' additional waiting time caused by equipment transshipment.

Chapter 1. Introduction

Delivering high-quality care in time at the right cost is always the ultimate goal for healthcare systems. The Institute of Medicine (Reid et al., 2005) identified time pertinence, patient focus and efficiency as the most important criteria to ensure high-quality healthcare systems. However, these criteria are subject to limited budgets and a shortage of resources (Matta et al., 2012). Along with the increasing ageing population and prolonged life expectancy, the expenditure on health care continues to increase. Meanwhile, medical providers, such as hospitals, undergo a growing demand. These trends have aggravated the financial and managerial challenges in the healthcare sector.

Researchers found that home-based health care is a good alternative to traditional hospitalization. It has been proven that in-home health care decreases hospitals' load, allowing the resources and materials in hospitals to be reserved for other cases, such as emergency healthcare. Furthermore, it also improves access in rural areas – the radius of service expands, and more patients are able to get professional healthcare services (Rodriguez et al., 2013).

A wide range of healthcare services can be provided at the patient's home, and the practices have shown both financial advantages and non-economical benefits (Baker and Swana, 2017). By adopting home-based rehabilitation, the total cost for healthcare providers has substantially decreased (Andersson et al., 2002). Moreover, the turnover rate of hospital beds has been improved due to the reduction in the total duration of the hospital stay (Anderson et al., 2000). On the other hand, patients can get similar health gains from home-based rehabilitation compared with the hospital-based reference group (Taylor et al., 2006).

Compared with hospital-based patients, patients who choose in-home rehabilitation may have their specific needs to reach an ideal rehabilitative result. For example, one study showed that in-home patients spent more on rehabilitation equipment (Taylor et al., 2007). That requires a reliable and efficient healthcare supply chain to ensure that patients can access or receive the equipment. Previous studies have already shown that home-based rehabilitation is helpful in the reduction of total medical expenditures both for healthcare providers and patients (Baker, Swana.

2017). However, the results might vary due to the specific distribution configuration strategy deployed (Pasin et al. 2002; Smith et al. 2016).

This thesis will analyze a distribution network between a health equipment rental service provider and its clients. As one type of service provided, the healthcare provider offers health equipment rental service to patients for rehabilitation treatment and to ensure they stay at home safely. Then, after the rehabilitation period, the equipment is returned to the provider. After inspection and maintenance, if necessary, the returned equipment will be back on the shelf and wait for other patients to use it. The requests will be referred to other service providers outside the network if an inventory shortage occurs and clients' demands cannot be satisfied. Thus, ensuring the distribution network can respond to client requests is essential, especially if the provider needs to respond to requests from multiple regions. Furthermore, healthcare service providers, such as non-profit organizations, must carefully consider their costs. Because this type of organization does not directly aim at making a profit, cost control will directly affect the quality and possibility of its services. Finally, all participants, including all sectors of the service provider and its clients, should ideally benefit equally from a well-designed distribution network. Therefore, it is necessary to identify the proper amount of equipment in the system and consider where to store them.

Generally, the provider could apply two main network configuration layouts to manage and distribute the equipment. The first is the centralized layout if the equipment is stored at central distribution centres. The service provider can pool all its inventory in the same place to achieve the goal of unified deployment and management of inventory by choosing a centralized layout. The second is decentralized if the equipment is stored at the endpoints (service points or SP in this case) that directly reach customers. In addition, the service provider can share equipment across regions by different equipment-sharing rules when a region is out of stock to reduce the number of times the order is transferred out of the network.

This thesis intends to analyze and evaluate the health equipment rental network's performance under different network configuration strategies under several scenarios. In general, with the help of simulation, we will illustrate a health equipment rental service provider's business pattern.

Equipment-sharing policies will be applied across the regions served by the provider. Furthermore, we will gradually centralize the health equipment inventory from each region to a central warehouse. The network's performance will be evaluated at three demand levels. The assessments will mainly focus on request fulfillment rates both in each region and for the overall network, the impact of transportation delays on request fulfillment and evaluating the extent to which the overall network benefits by enhancing the efficiency of the inspection and maintenance process.

This thesis paper is divided into six parts. The first chapter contains a general introduction. The second chapter will provide a literature review that includes the purpose of design of supply chain networks (SCND), SCND strategies, and the comparison between healthcare supply chains and commercial supply chains. In the problem description and conceptual models chapter, we will describe the operation process of health equipment rental service and identify the problems and challenges that we intend to solve in this thesis. Furthermore, we will describe the conceptual framework of the service network model. The steps in the simulation process will be explained in the Conceptual model implementation chapter. The main method is appraising a series of pooling scenarios by adjusting the conditions and rules based on a simulation approach. The fifth part contains the analysis and discussion based on the quantified results generated from simulations. In the last chapter, we will summarize our observations and the limitations of our study.

Chapter 2. Literature review

In this chapter, we summarize some previous research results and divide them into five parts:

First, a brief introduction of the three steps of supply chain network planning is given to show the different activities and tasks that should be focused on at the different phases. Secondly, we discuss network design at the strategic level. The purpose is to explain how organizations decide their supply chain network structure based on the nature of their service and business model. Furthermore, we also discuss the considerations that affect the degree of centralization when an organization designs its supply chain network. And then, the configurable network is discussed: a network that can be reconfigured at any time to respond to the changes can enhance a supply chain network's flexibility. The third part will introduce the risk pooling strategy and how the different pooling methods can help mitigate the uncertainty risks from supply, demand, and other factors in supply chain management. The fourth part of this chapter shows how some researchers compared healthcare supply chains and commercial supply chains. The purpose is to emphasize the specific characteristics of healthcare supply chains. We also present cases where researchers successfully introduced network configuration methods to redesign some healthcare providers' supply chain networks.

In the last part, we will discuss how the concepts and finds discussed in this chapter link to our study.

2.1 Network planning

According to the definition given by Simchi-Levi et al. (2014), network planning is a process to determine the structures of supply chains and manage supply chains in order to "find the right balance among inventory, transportation and manufacturing; match supply and demand under uncertainty by positioning inventory effectively; utilize resources effectively in a dynamic environment." Furthermore, they divided this process into three steps: network design, inventory positioning and resource allocation, as shown in table 2.1.

Step	Level	Description
Network Design	Strategic level	- Focusing on infrastructure; - Decisions on the number, locations and size of plants and warehouses; - The assignment of retail outlets to warehouses and other distribution rules; - Major sourcing decisions
Inventory Positioning	Strategic to Tactical level	- Focusing on safety stock; - Identifying stocking points to keep different types of productions; - Setting stocking levels at each facility
Resource Allocation	Tactical to Operational level	- Focusing on production and distribution; - Making production and distribution plans by taking into account the capacity of all resources as well as other business rules and constraints

Table 2.1: The network planning process and the corresponding levels according to Simchi-Levi et al. (2014).

This complex process covers all three logistical decision levels: strategic, tactical, and operational (Hax & Majluf, 1984). For optimal performance, it requires the decision-makers to consider the entire network by taking into account production, warehousing, transportation, inventory costs, and service-level requirements. That may require transforming raw data and problem characteristics into modelling assumptions to assist decision-making.

2.2 Network design

As the first step of network planning, network design determines the physical configuration and infrastructure of the supply chain. Langevin and Riopel (2005) emphasized that it should be considered strategically. In particular, the logistics network structure should be planned to match the nature of an organization’s services to its customers and its business pattern.

2.2.1 Forward logistics networks

One type of supply chain network system contains only one forward logistics flow. In a typical forward network, suppliers provide raw materials to manufacturers to produce work-in-process inventory and finished products at one or more factories. Those items will be shipped to warehouses and distribution centers for intermediate storage and then delivered to retailers and their customers (Simchi et al., 2014). Figure 2.1 shows a typical process of a forward logistics network.

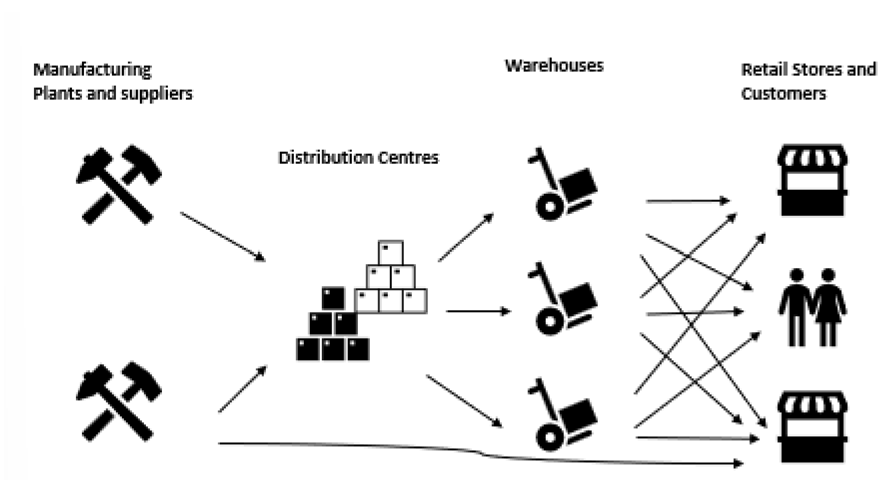

Figure 2.1: A typical forward logistics network

Adapted from Simchi-Levi, D., Bramel, J., & Chen, X. (2014).

Consequently, to reduce cost and improve service levels, managers must take into account the coordination among every step in their logistics flow and the collaboration with all stakeholders in their network, such as suppliers, third-party service providers and their customers.

2.2.2 Reverse logistics networks

Compared with a network system that only contains a forward flow, the reverse logistics, as shown in Figure 2.2, is concerned with the return flows of products or equipment back from use points to the logistics network for reuse, recovery or recycling for environmental, economic or customer service reasons (Bostel et al., 2005).

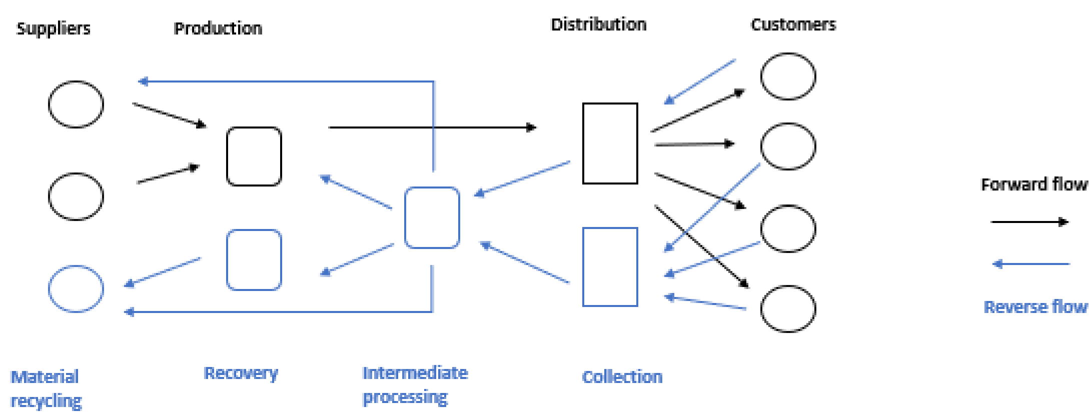

Figure 2.2: A framework of an integrated logistics system with forward and reverse flows

Adapted from Langevin, A., & Riopel, D. (2005).

A series of activities such as collection, inspection, repair, sorting, storage, and redistribution build up a backward flow in a reverse network system, in addition to the forward flow from a producer to its customers that is in the order of production, storage, distribution, and delivery to use points.

Based on the above point of view, reverse logistics networks attract attention in academic research and practical applications as an alternative to better match some particular emerging business patterns and service requirements. For example, in the field of fast fashion and consumer electronics, some merchants are working on using recycled components and fibres from old devices and clothes. This requires a well-designed reverse logistics flow to ensure that the recycling process is efficient and economical.

The concept of reverse logistics dates from a long time ago. Before “reverse logistics” became a terminology, this type of backward flow system was described as a “wrong direction” or “going the wrong way” (Carter & Ellram, 1998; Murphy & Wood, 2004). This description demonstrated the movement of flows against the traditional flows in the supply chain. In addition, it indicated the nature of services provided, such as recycling, repair and other waste management activities. Rogers and Tibben-Lembke (1999) established a reverse logistics process definition that is fairly all-encompassing and widely accepted by a majority of the field:

“The process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, packaging, finished goods, and related information from the point of consumption to the point of origin to recapture or create value or proper disposal.”

The definition has kept developing and being extended during the emergence of new economic and social needs. For example, Brito and Dekker (2004) employed the expression “use point” and “point of recovery” instead of “point of consumption” or “point of origin.” One reason is that those goods in the backward flow of a reverse system may not have been consumed yet. For instance, a company may deal with its stock adjustments due to overstock or spare parts which have never been used. The other reason is that goods may go to a different point of recovery than the original. For example, recycled plastic bottles may go to recycling centers outside the original chains and be further transformed into renewable raw materials.

Considering that reverse systems can be classified into various categories depending on the characteristics that are emphasized, it is necessary to plan the structure of a reverse system at the strategic level based on the types of return items and the main option of recovery (Fleischmann et al., 1997; Thierry et al., 1995).

Brito and Dekker (2004) compared existing reverse logistics definitions and then distinguished several types of recovery activities: product recovery, component recovery, material recovery and energy recovery. Table 2.2 provides a summary of their works.

Type of Activity	Description
Product Recovery	Products may be recycled directly into the original market, a secondary market or repaired and sent back to the user under conditions such as the warranty
Component recovery	Products are dismantled, and parts can be remanufactured into the same kind of product or different products
Material recovery	Materials are recuperated and recycled into raw materials like metal, plastic, paper or glass
Energy recovery	Incineration

Table 2.2: Types of recovery activities in the reverse flow of reverse logistics

Four types of general reverse logistics networks can be proposed: directly reusable network, remanufacturing network, repair service network and recycling network (Langevin & Riopel, 2005). A directly reusable network is suitable for processing return items that can be directly reused after cleaning or minor maintenance but without major operations. This type of network is a closed-loop system because the forward and the reverse flow are closely associated in the same closed circle. The remanufacturing network is designed for remanufacturing the returned products at the end of their life or those needing major maintenance. After remanufacturing, some parts or components from returned products will be used as new components. This type of network may also be a closed-loop system if the original producer implements remanufacturing.

The repair service network and the recycling network are usually considered open-loop systems. This is because specialized third parties often carry out the process of repairing defective products, recycling items and raw materials or collecting and eliminating waste. These options have few links with the forward chain attached to the original producers.

Uncertainty lurks inside the forward and backward flow in a reverse system. That leads to more complexities compared with a one-way flow system. The main concerns include the quantity and quality of returns, the selection of recovery methods, the supply of returned products, and the demand for recovered products (Bostel et al., 2005). The major difficulty is due to the uncertainty of the timing, quantity and quality of return flows. Fleischmann et al. (1997) emphasized that the interaction of forward and reverse flows in the same system adds complexity. Thus, the two flows cannot be treated independently in most contexts but must be considered simultaneously to achieve adequate planning.

The strategic application of reverse supply chain logistics plays an important role in saving landfill space, energy and resources, thereby contributing to economic, environmental and social sustainability. However, the costs generated in the reversed flow, such as the costs of recycling, transportation, warehousing, remanufacturing and labour, may diminish the potential benefits (Sarkis et al., 2009). Therefore, the authors suggested a careful cost-benefit analysis on the operational side to successfully design and use reverse logistics systems.

2.2.3 The degree of centralization

The degree of centralization (or decentralization) is another key decision in the network design phase. Choosing either a centralized or decentralized network structure impacts customer service objectives, the degree of vertical integration with suppliers and outsourcing partners and the extent to which information is shared and integrated (Riopel et al., 2005).

The advantages of a resource centralized network are mainly related to cost, scale, and control. Studies showed that centralized inventory is better controlled and kept to a minimum (Croxton & Zinn, 2005). Usually, adopting a centralized network structure requires lower safety stock (Zinn et al., 1989) and fewer warehousing locations, which generally leads to reduced facility investment costs and lower inventory costs (Teo et al., 2001).

On the other side, the drivers for the decentralization of warehousing are mainly related to customer service and transportation (Pedersen et al., 2012). Because inventory is stored close to customers, it may decrease delivery times and costs (Das & Tyagi, 1997) and increase customer service level by quickly responding to local customers' demands. Thus, companies with high inventory turnover are more likely to pursue a decentralized warehousing structure (Wanke & Zinn, 2004).

As well as theoretical and mathematical contributions, some researchers focused on qualitative considerations in practice. For example, based on a case study in Denmark, Pedersen (2009) pointed out that most research does not deal with the difference between small and medium-sized (SME) enterprises and large companies when speaking of centralized versus decentralized. SMEs also have the same needs but face more challenges in making their decisions both in the network design and daily management phases. More precisely, SMEs generally lack the capacity and financial resources to support a decentralized setting. On the other side, there are fewer advantages of economies of scale in a centralized setting and fewer management resources to carry out a centralization project.

2.2.4. Network reconfiguration

Sometimes the current set of facilities in a physical supply chain network and the way to manage the network may no longer be deemed appropriate due to changing demand patterns, the termination of a leasing contract for some existing warehouses or other factors. In this situation, management may want to reorganize or redesign the distribution network by creating a new flow pattern of goods throughout the distribution network to maintain reasonable costs and provide service at a consistent level (Simchi-Levi et al., 2014). Considering that this situation is not uncommon in practice, it will be more efficient and economical to reconfigure the current network than design a new network system from scratch if the existing system is configurable.

Network reconfiguration emphasizes upgrading and reconfiguring an existing system with flexibility and agility rather than replacing or redesigning it. Thus, the whole process and adjustment are attached to the network's underlying structure. Therefore, it is essential to consider the possibility and capacity of reconfiguration at the beginning of the network design phase to determine its physical structure.

In practice, reconfiguration is about adjusting current links and establishing new links between the functional units on a supply chain (Chandra & Grabis, 2016). In comparison, supply chain redesign may change and rebuild an existing network's layout. Therefore, a reconfigurable system is supposed to introduce new products or deploy new processes with considerably less expense and ramp-up time than a supply chain network redesign. Figure 2.3 illustrates the adjustment in a reconfigured network.

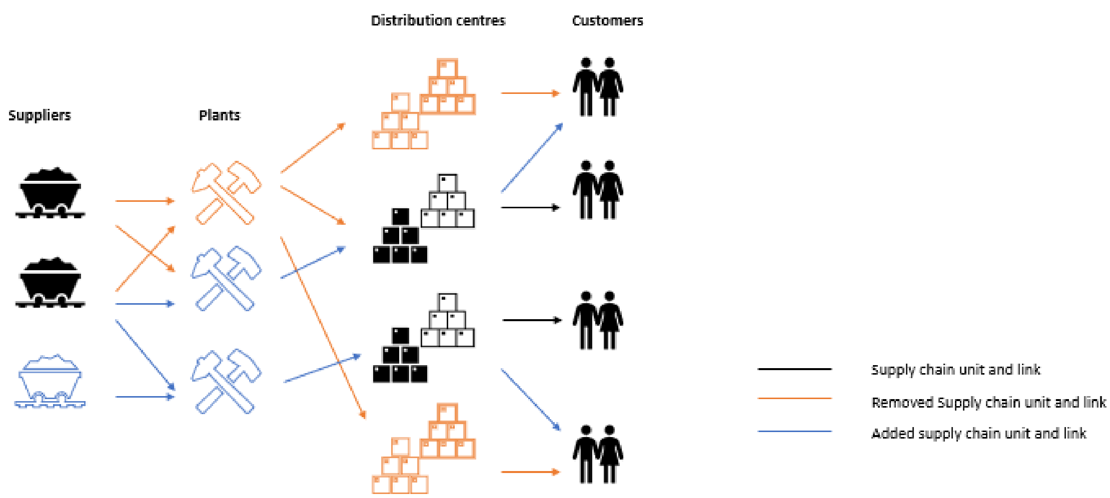

Figure 2.3: Illustration of reconfiguration patterns

Adapted from: Ch, C., & Grabis, J. (2016).

Research supports this standpoint with evidence. For example, Croxton and Zinn's work (2005) focused on systematically reducing safety stock and inventory costs in a national retailer's network in the Midwest US. They conducted a scenario analysis based on the collected data. In the simulation, they reduced the number of warehouses in use and reallocated some selected warehouses to retail stores to achieve centralized inventory with lower total safety stock. As a result, they observed that this reconfiguration could achieve inventory savings without compromising service level.

2.3 Risk pooling

Once a network structure is confirmed at the network planning phase, the next step is to consider managing the network system at tactical and operational levels. Simchi-Levi et al. (2014) indicated that most challenges throughout supply chain management could all be related to two factors.

The first one is the trade-off between costs and service level. Designing and operating a logistics system is challenging to minimize system-wide costs while systematically maintaining a service level. The difficulty increases significantly when an entire system is being considered. The other factor is a series of inherent uncertainties in every logistics network. They may manifest themselves as inaccurate demand forecasts, breakdown of production and transport machinery, and uncertain travel times. Thus, supply chain networks need to be designed to eliminate as many uncertainties as possible and effectively control the remaining uncertainties if they are impossible to be eliminated.

For managing uncertainty and the additional costs resulting from this, risk-pooling is a strategy to address demand and lead-time variability in the supply chain and mitigate risks of uncertainty caused by any change in the real business world (Simchi-Levi et al., 2008).

Oesser (2015) defines risk pooling in business logistics as “consolidating individual variabilities of demand and/or lead time in order to reduce the total variability they form and thus uncertainty and risk.” He classified risk pooling in logistics into ten types: inventory pooling, virtual pooling, transshipments, centralized ordering, order splitting, component commonality, postponement, capacity pooling and product pooling and product substitution:

“Inventory pooling” is the combination of inventories in order to reduce inventory holding and shortage costs without reducing service level. It can be achieved through inventory or warehouse centralization. One example is Croxton and Zinn’s work (2005), as mentioned in session 2.2.4. The other way is coordinating inventory levels while keeping the original network layout. For example, Darmawan et al. (2020) proposed reducing the total inventory held in the supply chain by coordinating inventory from all regional distribution centres without jeopardizing end customer service. This approach allowed inventory shortage to a certain degree at the upstream stage in a supply chain for cost-saving purposes. At the same time, it kept the possibility to guarantee the service levels provided for end customers at the downstream stage.

“Virtual pooling” extends the physical inventory from one warehouse to the others belonged by one company or beyond its network to other companies by means of information and communication technologies (ICT), dropshipping, and cross-filling (Caddy & Helou, 2000; Memon, 1997; Christopher, 1999; Randall et al., 2002, 2006; Netessine and Rudi, 2006).

“Transshipments” allow inventory to transfer across locations in one network, such as between warehouses or retail stores. This policy provides the possibility of satisfying customer demands by permitting alternative locations to fulfill the orders when a stockout happens at a local level and reducing lead times by exchanging inventory across locations combined with partial stock replenishments.

“Centralized ordering” is an order pooling strategy by gathering and placing joint orders for several locations. This strategy gives bargaining power by buying in bulk and the flexibility to adjust the allocation based on any change in demand at each location by postponing the time of allocating the goods.

“Order splitting”, in contrast, divides a replenishment order into multiple orders with multiple suppliers or multiple delivery times. It is a strategy to pool and smooth lead times by splitting a single order into multiple orders. For example, placing multiple small orders to various suppliers can take up less capacity from each supplier and allow them to flexibly arrange production planning, which can lead to faster delivery than placing a large order with a single supplier.

“Component commonality” designs common components that can be used for several products to enhance generality and replaceability.

“Postponement” means delaying a decision in logistics, procurement, production, or distribution until using more accurate information to support decisions making. This strategy is adopted in industries with high demand uncertainty. One example is producing the generic components or the common parts of a product first and then processing the generic components into the customized final goods according to more recent and accurate demand information later.

“Capacity pooling” is the consolidation of several facilities’ production, service, transportation, or inventory capacities.

“Product pooling” is the unification of several product designs into a universal design or reducing the number of products or stock-keeping units (SKU).

“Product substitution” is a strategy to persuade customers to buy an alternative due to being out of stock or discontinued production. Substitution allows the manufacturer, retailer or service provider to aggregate demand across substitutable components, products or services.

2.4 Healthcare supply chain

2.4.1 The challenges, need and opportunities

The healthcare sector shares some common considerations in management with other industries. For example, an ideal healthcare supply chain is supposed to “improve productivity, increase service levels, and reduce costs with fewer resources at their disposal” (Smith et al., 1990). In fact, cost pressures have led healthcare organizations to consider structural changes (Kaplan & Porter, 2011). But, more importantly, for a healthcare supply chain, the service level to patients should always be considered the primary objective over cost reduction and other objectives (Smith et al., 1990). This primary goal makes the patient care system and supply chain system interweave. Therefore, the SC process is the essential link in the delivery of healthcare services (Rakovska and Velinova, 2018). Based on the above points of view, all healthcare supply chains are distinctive from commercial supply chains due to their critical impact on saving lives (Kim and Kwon, 2015).

McKone-Sweet et al. (2005) reviewed the main challenges in healthcare supply chains, including short product life cycles, unpredictable patient flow, lack of standardization, outdated information technologies, and inadequate knowledge of supply chain management issues. Chandra and Kachhal (2004) summarized five areas, as shown in Table 2.3, that need to be focused on in healthcare supply chain management: Demand management, order management, supplier management, logistics management and inventory management.

Supply chain management area	**Goals and measures**
Demand management	Demand-driven ordering; more accurate demand prediction to minimize inventory overbooking
Order management	Consolidated purchasing to achieve cost saving
Supplier management	Supplier consolidation and optimal direct-from-manufacturer implementation
Logistics management	Consolidated service centre; integrated transport and distribution network; increase in capacity utilization
Inventory management	Reduction in SKUs; stockless or rapid replenishment

Table 2.3: Supply chain management areas for healthcare

Source: Chandra, C., & Grabis Jānis. (2016).

2.4.2 Application of network management for healthcare

Some general experiences in supply chain management can also be applied in healthcare to improve management performances in these five areas. For example, one potential measure for logistics management is integrating logistics management by consolidating the distribution network: reducing storage space, minimizing stocking levels, and maximizing inventory turnover rates can achieve integrated management savings for inventory management (Chandra & Grabis, 2016).

For example, Rudi et al. (2000) studied the returns of medical devices at Technical aid centres (TACs) for the Norwegian National Insurance Administration to control the purchase of new devices and standardize the process to refurbish or scrap return devices in a recoverable reverse network. They found that return devices from patients, such as wheelchairs and hearing aids, were scrapped too frequently, and some of the units were unnecessarily sent to landfills. Therefore, their study provided a more comprehensive decision-support model that accounts for the full cost to scrap a unit, the cost of refurbishing, the potential saving from reuse and the benefits of refurbishing to evaluate the recovery process of return devices.

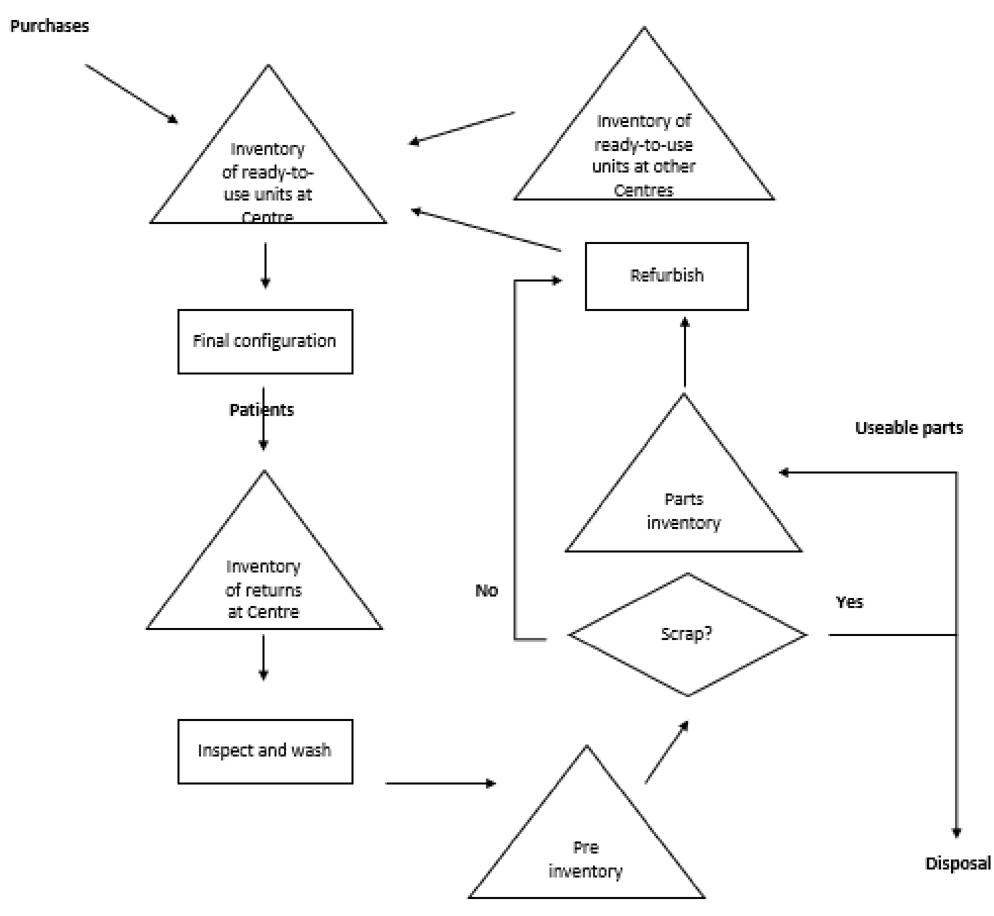

Figure 2.4: Distribution and product recovery at the TACs

Adapted from: Rudi, N., Pyke, D. F., & Sporsheim, P. O. (2000).

This new model, as shown in Figure 2.4, changed the old decision pattern that was mainly based on “the hours of labour required” and resulted in fewer units being scrapped and more being refurbished to reuse. In addition, this concise and visualizable model could be executed at each TAC, allowing each TAC to refurbish units or give them away according to its own situation.

Saif and Elhedhli (2019) focused on centralizing medical device sterilization services at sterilization centres in a closed-loop reverse network for a group of hospitals in Southwestern Ontario, Canada. To determine the optimal solution to minimize long-term total cost while ensuring a high service level, they analyzed three scenarios:

1. The current pattern: each hospital undertakes the sterilization functions and holds its own stock internally without any coordination;

2. Centralize sterilization service at external sterilization service centres, but each hospital manages its stock;

3. All tasks, including sterilization service, distribution and stock management, are centralized at external centres.

They found that both schemes 2 and 3 could achieve an ample cost-saving in holding costs of reused medical device stocks and the annual cost of equipment and personnel by centralizing sterilization functions in terms of pooling equipment and personnel resources. The potential saving is enough to offset the set-up cost of centralized sterilization centres and the transportation cost between the centres and hospitals. However, centralizing the stock-keeping in sterilization centres in the third scenario only resulted in a small saving in capacity cost compared to storing the devices in hospitals.

In a case study of healthcare logistics in Northern Finland, Kotavaara et al. (2017) demonstrated how a centralized warehousing system could effectively support patients’ needs within areas characterized by long distances and relatively low demand-based. Reassigning designated warehouses to hospitals and health centres combined with optimizing vehicle routing showed that a delivery network based on one or two warehouses could effectively reach most health centres and hospitals with a constraint to provide service to at least 90% of delivery demand.

Pasin et al. (2002) assessed the impact of inventory sharing among a group of local community service centres (CLSCs)-- a network of medical clinics in Montreal, Quebec, Canada. They introduced an inventory virtual pooling strategy to replace the previous stock-keeping pattern of each CLSC independently managing its inventory. The results showed that the overall network-wide cost reduction of 29 CLSCs could be achieved by inventory pooling in scenarios with current demand and demand increased by 10%, 20%, and 30%, respectively. Furthermore, cost reduction could be maximum when all CLSCs can freely share their resources without constraints. However, those CLSCs who tended to overstock their inventory got less benefit from this pooling strategy because they did not need to borrow very often. Thus, under the premise that each CLSC faced similar potential demands, a resource pooling strategy can benefit most parties when inventory levels are similar in all sites in the network. In addition, pooling and sharing resources inside the network provided a more economical alternative than renting from third-party suppliers when inventory shortages occurred in one or several CLSCs by saving from additional rental costs.

Smith et al. (2017) conducted a simulation approach to compare the performance under centralized and decentralized strategies through a case study related to an antibiotic supply to patients.

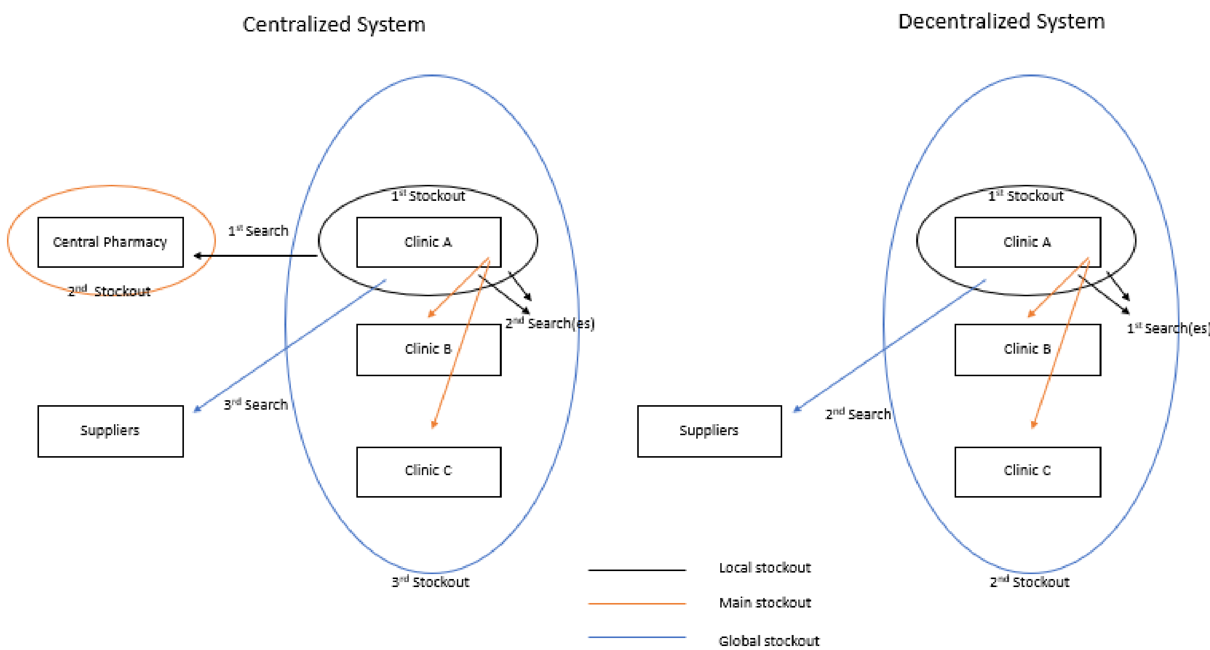

Figure 2.5: Demonstration of an antibiotic supply in the two types of systems

Adapted from: Smith, K. N., Vila-Parrish, A. R., Ivy, J. S., & Abel, S. R. (2017).

As shown in Figure 2.5, a clinic will first seek to fill stock from the central pharmacy in the centralized model. Then, if the central pharmacy cannot satisfy its requirement, the clinic will seek help from the other clinics before seeking help from outside suppliers.

In the decentralized model, there is no central pharmacy in the system. Therefore, the first step to solving stockout is seeking other clinics' help. Similar to the centralized system, if the other clinics cannot fulfill the requirement, the requirement will be filled outside the system. The results show that due to reducing one echelon, the decentralized system without central pharmacies was almost always higher performing in terms of the total cost, including unit cost, holding cost, and stockout cost.

The centralized system performed better at system-wide lower inventory levels in terms of demand satisfaction. In other words, the centralized system provides more abilities to adjust the medicine distribution and reduce the risk of inventory shortage in the entire system to ensure patients' needs.

The studies mentioned above show that logistics innovations can offer significant potential for performance improvements in healthcare (e.g. Jarrett, 1998). In many cases, lower cost structures and improved service-level in healthcare are achieved by reconfiguring material logistics and risk pooling strategies.

2.5 The link to our study

As mentioned in the introduction, we will focus on a health equipment rental network. It contains a forward flow from the rental service provider renting out equipment to its clients and a reverse flow from its clients' side when they return the equipment to the provider. The works of literature relevant to reverse logistics networks emphasized the characteristics of this type of network that provide the focus for our research. Furthermore, we will test the performance of this rental network in a series of scenarios by coordinating inventories from all regions without totally changing the origin network layout. Finally, the previous studies relevant to the comparison between centralized and decentralized networks in the healthcare sector mentioned in this chapter provided enlightening knowledge in choosing network deployment strategies. However, we also noticed that the performance of a network also depends on resource allocation, business patterns, and other factors according to each specific case. Therefore, in our case, we will test both network configurations by gradually centralizing resources in a few locations by combining resource-sharing strategies.

Chapter 3. Problem Description and Conceptual modelling

This chapter contains two parts. In the first part, we will describe the general service pattern of health equipment rental service and the major challenges that the service providers face. Then, we will introduce the conceptual models of decentralized and centralized network layouts that reflect the service pattern and capture the major challenges in the second part.

3.1 Problem Description

Health equipment rental service provides health equipment to individuals recovering from illness or injury.

Several organizations from different backgrounds run this kind of service in Canada. For example, some of them are NGOs dedicated to humanitarian aid. The second type of service providers consists of national or regional-wide chain pharmacies as well as profit-making in-home healthcare equipment producers.

These providers have distinct operating advantages in providing this rental service based on their backgrounds. However, they may face their unique problems due to different operating models.

For example, a reliable, mature, and vast distribution network is an advantage that chain pharmacies have. It provides more locations to store, distribute and inspect the equipment and the possibility to reach more clients. In addition, a vast network allows chain pharmacies to adjust and rebalance their inventory in the entire network according to the change in demand. But it should be noted that health equipment rental s may not be one of the main businesses of chain pharmacies.

Those service providers, who can integrate production, sales and rental, may have cost advantages considering that the health equipment is produced by themselves instead of purchased. Same as chain pharmacies, this rental service usually is not the main business of this kind of provider. Therefore, they may only provide the rental service in a few regions where they run their main business.

NGOs also play an important role in providing health equipment rental services. Unlike the two types of providers mentioned earlier, who offer this service as a sideline, most NGOs offer health equipment rental as their one type of leading service. For instance, as an NGO, the Canadian Red Cross provides its "Health Equipment Loan Program (HELP)" for short-term and long-term use in Alberta, British Columbia, Nova Scotia, Newfoundland and Labrador, New Brunswick, Prince Edward Island and Yukon. This program is run mainly by volunteers; their equipment inventory relies on donated used equipment. Therefore, they may be able to keep labour and unit costs low.

Furthermore, this low-cost operation model provides a more flexible pricing policy. For example, fees could be charged based on each applicant's income and the equipment's type, quantity, and condition (Nova Scotia Department of Health, 2014).

However, a misallocation between available resources and demands may arise as the equipment is mainly dependent on donations. For example, it is almost impossible to control where and when people will donate and what specific type and quantity of equipment will be donated to the organization. On the other hand, this type of NGO generally has only one or a limited number of offices in one region. Due to the space limitations of depots, not all donations can be accepted at any time. And forced by rising rents, some of them have to keep looking for smaller but cheaper locations as their depots (CBC News, 2017).

Furthermore, some NGOs mainly provide their services in a few regions. Even some national-wide organizations only provide this type of service where their regional offices are located. Usually, there is no established network or resource coordinating mechanism among their offices in different regions. Thus, the lack of a vast and unified network makes it challenging to reallocate inventories from one branch that faces a surplus to another with a shortage. For example, Figure 3.1 compares the number of stores of The Jean Coutu Group -- a Canadian drugstore chain-- and the Canadian Red Cross branch in Moncton, New Brunswick, Canada. Both organizations provide similar health equipment rental services in this city with a population of more than 85,000

(Statistics Canada, 2017). Patients can choose any store in Jean Coutu's network where it is most convenient for them to rent and return the health equipment. However, by comparison, they have to go to the only office in this region if they choose the Canadian Red Cross to provide the service. In addition, the established network with multiple locations provides a bigger capacity to store more health equipment as inventory to satisfy more demands than a single site.

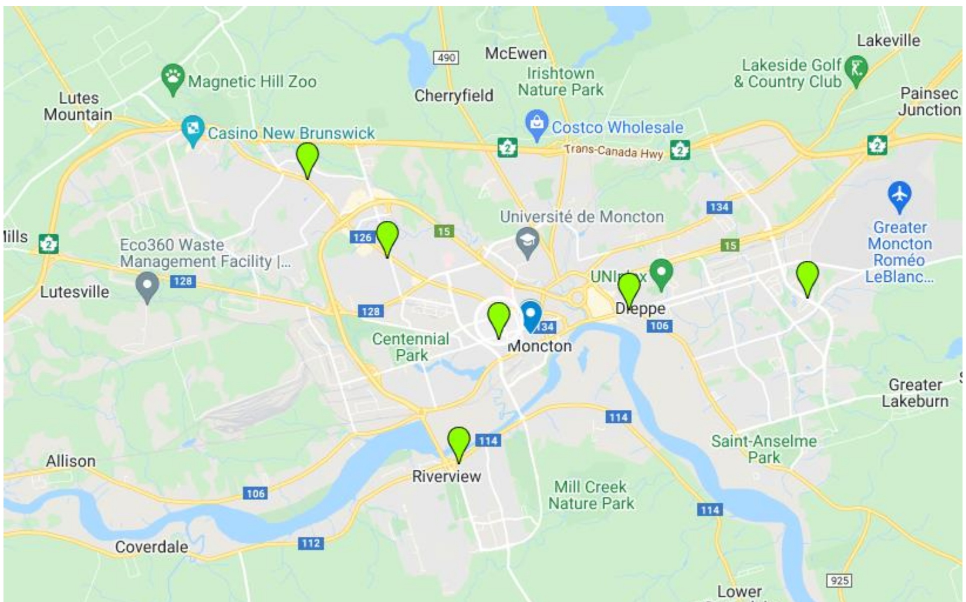

Figure 3.1: The comparison of the number of locations of PJC Jean Coutu (the green cursors) and the Canadian Red Cross office (the blue cursor) in Moncton, NB, Canada

In addition, the service providers also face some common challenges in providing a reliable service to clients and controlling operating costs regardless of the differences in their operation patterns.

The first is the uncertain demands from the patients who need health equipment. Several factors, such as post-discharge rehabilitation, injury recovery from accidents and recovering from illness, cause the need for health equipment. Due to the randomness of these factors, it is difficult to predict an accurate day-to-day demand even if the historic record can provide general information.

The second is the uncertainty caused by different usage and return times. Usually, the duration of short-term loans is no longer than six months. However, depending on each patient's recovery, the period may vary for every loan.

Briefly, the challenge is satisfying as many demands as possible with limited resources. For example, to deal with the healthcare network boil down, especially the intense pressure in Canada's ERs, hospitals and provincial governments plan to implement new measures to free up hospital beds, including discharging patients in inpatient beds to get home sooner. That is regarded as a bottleneck that has contributed to emergency department waits because there are no available beds for new patients to be admitted (CBC news, Global news, 2022). However, physicians and healthcare professionals are concerned about whether these early-discharged patients will have access to the equipment they need to recover at home. They also believe that the guarantee of home rehabilitation health equipment will be the key to whether the new measures can relieve the pressure on hospital resources.

This study takes the case represented by service providers like NGOs as the primary research object. Based on their non-profit nature, they provide services with less consideration for return on profit. Therefore, they can focus more on patients' needs to offer and extend their services. However, constrained by the limited funds and resources, they also face more challenges in running their programs and servicing more people. Table 3.1 lists the main challenges and potential solutions to be discussed in this thesis.

Problem and challenge	Potential solution
Uncertain demand	Pool demands from multiple sites to reduce the fluctuation due to uncertain demands
Equipment management	Increase equipment turnover rate to mitigate the risk of supply shortage, reduce idle time and the holding costs by resource sharing
Equipment circulation time	Reduce the risk of inventory shortage by reallocating equipment inventory and resource-sharing policy

Table 3.1: The list of problems and potential solutions for organizations with resources limitation

Based on the above, for the service providers who have the advantage of obtaining equipment at a low cost but the disadvantage of a reliable distribution network and cooperation mechanism, the major issue may be how to enhance resource allocation capabilities to respond to the change in demand and unstable supply. We will test the difference in performance between two network configurations: centralized and decentralized. Also, we will consider the impact of the network's size on its performance and the effect of different resource-sharing strategies.

3.2 Conceptual modelling

3.2.1 The general service process and main activities from the service provider's perspective

As mentioned, the business modes may vary among different service providers due to their backgrounds. Generally, healthcare professionals refer clients to service providers to rent the health equipment that meets each patient's need for recovery from illness or injury (Canadian Red Cross, 2022).

In our case, the rental process can be regarded as a loop and be broken down into five steps as shown in Figure 3.2:

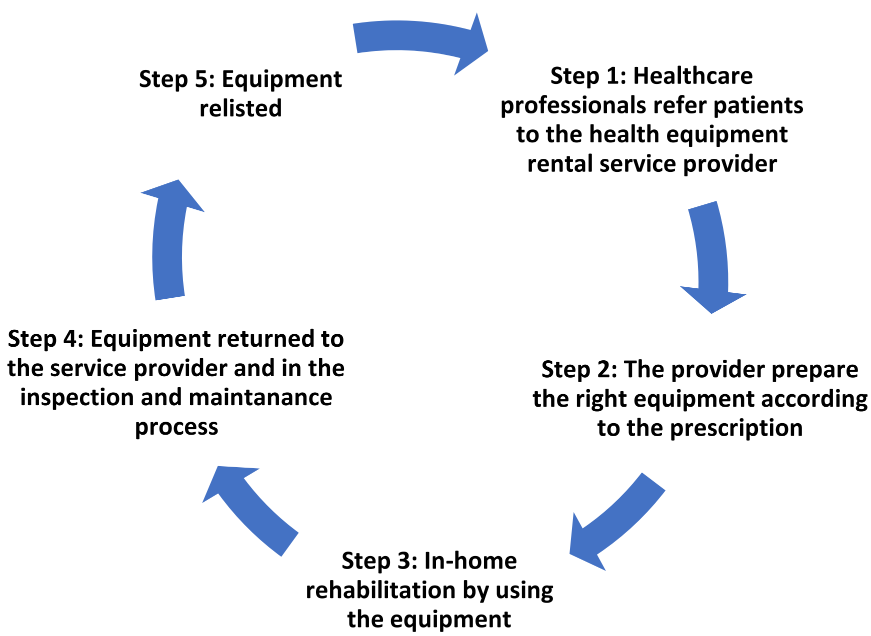

Figure 3.2: The process cycle of health equipment rental

The loop contains a forward flow (from step 1 to step 3) and a reverse flow (from step 3 to step 5): the forward flow indicates the processes in which the required equipment is sent from the service provider to patients. The reverse flow shows the steps of equipment returned from patients back to the provider after their rehabilitation treatments.

Several types of resources will be involved in each step, such as the health equipment for rent, inspectors responsible for the inspection and maintenance process, and the cleaning and disinfection equipment. The number of resources is the key variable affecting the performance indicator analyzed under different distribution strategies. Next, we will introduce in detail how each resource participates in the operation of the rental service step by step:

• Step 1: From the service provider’s perspective: once a patient’s request is received, the service provider will process this request and check the stock availability. The service provider needs to prepare the right equipment if the inventory is sufficient. Otherwise, they have to refer the patient’s request to another provider outside the network if an inventory shortage occurs, and the service provider will not continue to follow up on this request.

• Step 2: Once the availability is confirmed, one piece of equipment will be booked and seized for the patient. The equipment will be marked as “busy”.

• Step 3: The patient will pick up the equipment for the in-home rehabilitation need at the service point close to the patient. The duration of rehabilitation may vary from one week to six months. Any case with a recovery time of more than six months will be considered a long-term need and not covered by this service.

• Step 4: After the rehabilitation period, the equipment will be sent back to the service provider for inspection and disinfection. According to applied health equipment cleaning protocols (IPAC, 2015), a staff member will receive the returned equipment and the inspection process. As another type of resource, a household washing machine will be used to clean some removable and washable parts from the returned equipment, such as wheelchair cushions, pads and liners, and backrest covers. At the same time, the staff should carefully wipe and brush the other parts of the equipment with medical-grade disinfectant. This method is also applied to cleaning equipment that is not machine washable, such as crutches, canes, and bath benches. And considering the volume of an average household washing machine, one machine may only be able to clean one piece of equipment’s washable parts at one time. Finally, the staff will reassemble all the parts back together after drying.

The cleaning can also be done by using a Wheelchair Washer, as shown in Figure 3.3, to replace household washing machines. This type of washer machine is designed specifically for cleaning and sterilizing health equipment to save time and workforce and achieve a high-level disinfectant cleaning (IPAC,2015).

Figure 3.3: Illustration of wheelchair washer

One wheelchair washer can process the disinfectant cleaning for two to four wheelchairs or other equipment of the same volume in three to seven minutes. However, it might not be affordable on a limited budget, considering the price of this type of washer could be more than $20,000. Therefore, we will compare the performance of these two different approaches in the cleaning process and the impact on the overall on the rental service.

• Step 5: After the inspection and maintenance process, the returned health equipment will be relisted for future patients with in-home rehabilitation needs in the fifth and final step.

We summarize the main activities and the resources involved in each step in Table 3.2.

Process	Related Activity Description
Step 1: Receive and process the patient's request	- The service provider will check inventory availability after receiving requests
Step 2: Prepare health equipment for patient	- The equipment will be seized for picking up
Step 3: Patient's rehabilitation period	- Patients pick up the equipment for rehabilitation treatments
Step 4: Health equipment returned for inspection and maintenance	- Inspector receives returned equipment and handles the inspection process - Household washing machine or specialized wheelchair washer will be used for the cleaning and disinfection process
Step 5: Health equipment relisted	- All resources will be released

Table 3.2: The list of related resources in the process cycle

3.2.2 The Conceptual models of the health equipment rental service's distribution network

After identifying these key resources, the next step is developing the conceptual models to deploy distribution strategies.

(1) Decentralized network

First, we recap the service flow in a decentralized network. This deployment will serve as a benchmark. Each service point manages its own inventory and independently provides health equipment rental services to a set of predetermined local residents. Figure 3.4 describes the main steps of health equipment rental service at each service point, and this corresponds mainly to what was described previously:

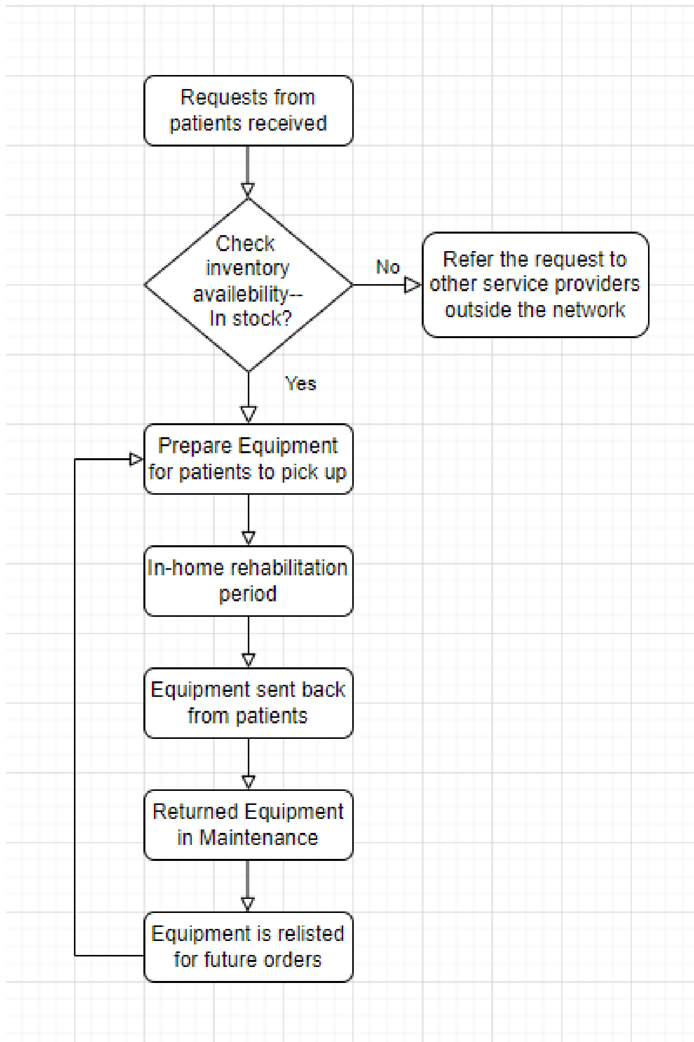

Figure 3.4: The service process from a service point perspective in a decentralized network

(2) Decentralized network with equipment-sharing policies applied

As the second model, we will introduce a "virtual pool" concept into our model. For this purpose, we regard the service points in several vicinal municipal areas as in the same network system. The virtual pool will gather equipment usage information from all SPs in this network and note that the network's physical structure is not changed. Therefore, under the premise of prioritizing local needs, one SP will lend its available equipment to fulfill the requests from other SPs if the borrower SPs suffer an inventory insufficiency. Figure 3.5 shows the workflow under this virtual pooling strategy.

This new change combines virtual capacity pooling and transshipment strategies. In our literature review section, we discussed the role of the risk-pooling strategy in managing uncertainty and the additional costs that come with it. In theory, it may enhance the capacity and flexibility of resource allocation. Thus, we intend to explore the impacts of resource-sharing and pooling strategies among SPs in this decentralized network. Different sharing rules can be applied in this model, considering the equipment is still stored locally. We will discuss this in detail in the next chapter.

This modification will generate a certain amount of transshipment costs that depend on how much equipment will be shared and moved among SPs. However, on the other hand, the change may also reduce the lost orders due to local inventory shortages.

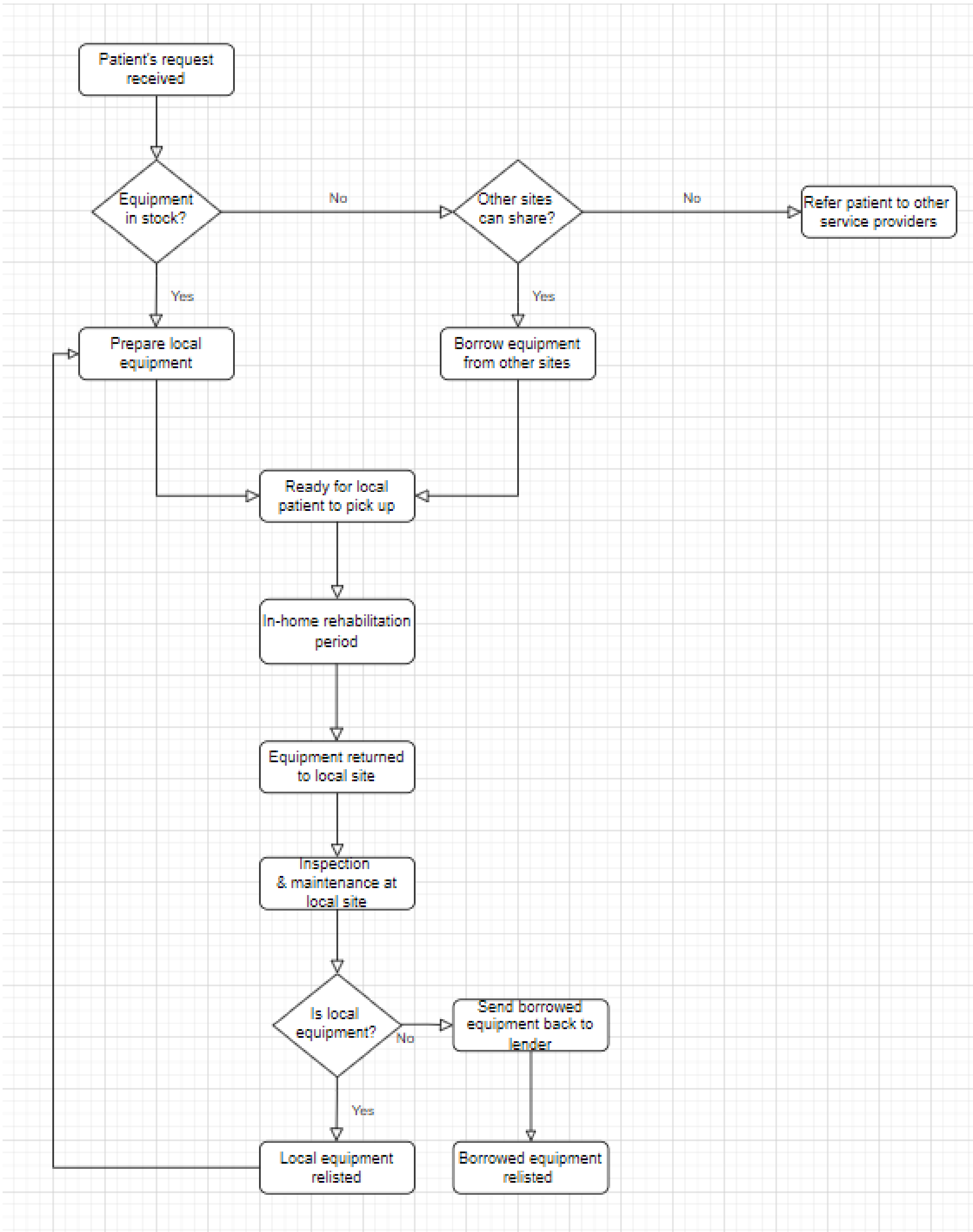

Figure 3.5: The process flow under the virtual pooling strategy in a decentralized network

(3) Inventories centralized in two zones

The previous study mentioned in the literature review showed that the resource pooling strategy benefits most parties when potential demands and inventory levels are similar in all sites (Pasin et al., 2002). In our case, there is a major metropolis and four small to medium-sized cities in the same network. The population in the metropolis is far higher than in any other city. Based on the differences in population, it is reasonable to assume that the potential demands in the metropolis could be significantly stronger than in other cities.

Considering that, we will attempt to enable every SP to benefit from pooling strategies equally by continuing to increase the degree of centralizing in our nest models. More precisely, we regard the four small to medium-sized cities as one geographic zone and the metropolis as the other. The purpose is to improve the similarities of potential demands and inventory levels between the metropolis and the rest regions. In the group of four cities, we will choose one SP from the four to be their regional distribution centre to store and manage their equipment. The other three SPs will serve as a pickup point only. With this adjustment, they can use their office locations as pickup points and no longer need depots in the other three cities. The new regional distribution centre will share equipment with the SP in the metropolis if an inventory shortage occurs on any one of both sides.

The sharing between lender and borrower may generate a question: who is supposed to be responsible for maintaining the shared equipment? In consideration of fairness, the borrower should take this responsibility. However, because in the centralized network, maintenance could be done only in regional DCs, it may cause additional transactions for sending the returned shared equipment from the pickup point to the borrower's DC and then back to the shared equipment's home.

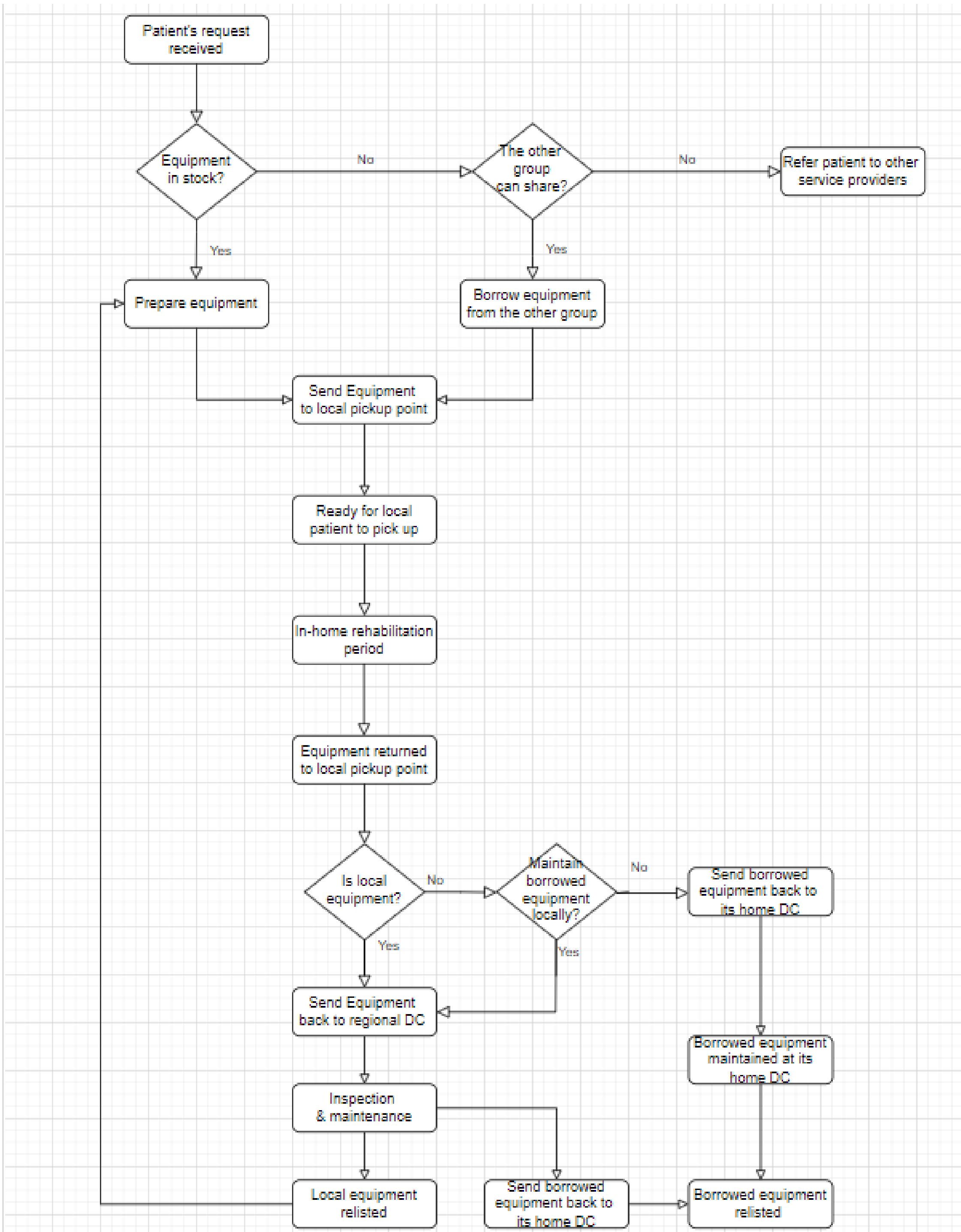

Figure 3.6: Inventories centralized in two regions under pooling strategies

The alternative is that once the client returns the shared equipment, it will be directly sent back to its home regional DC from the borrower's pickup point. The transaction is only between the lender and borrower, and the maintenance will be done at the shared equipment's home DC. We will compare the different impacts of these two approaches on human resources, time and transportation costs. Figure 3.6 shows the workflow in the two zones system.

(4) Centralized network – Inventory centralized at one site

Ultimately, we will regard the entire network as totally centralized: physically pool all inventories in one distribution centre. Previous studies suggested that a lower stock level can provide the same service level. This is because the fluctuations caused by uncertain demands are smoothed when centralizing inventories (Smith et al.,2017; Saif et Elhedhli, 2018). The reason is the maximum combined demand from two or more sites is usually lower than the sum of the maximum demand of each site unless their demands are perfectly correlated (Saif et Elhedhli, 2018). Thus, centralized inventory can meet demand more often than decentralized inventory if the total stock amount is fixed at the same level. However, transportation costs for equipment moving between central DC and each pickup point may increase. Furthermore, pooling demands and centralizing inventories in one site could make using the specialized wheelchair washer more cost-effective and accelerate the cleaning and disinfection process. The workflow in the total centralized network is shown in Figure 3.7.

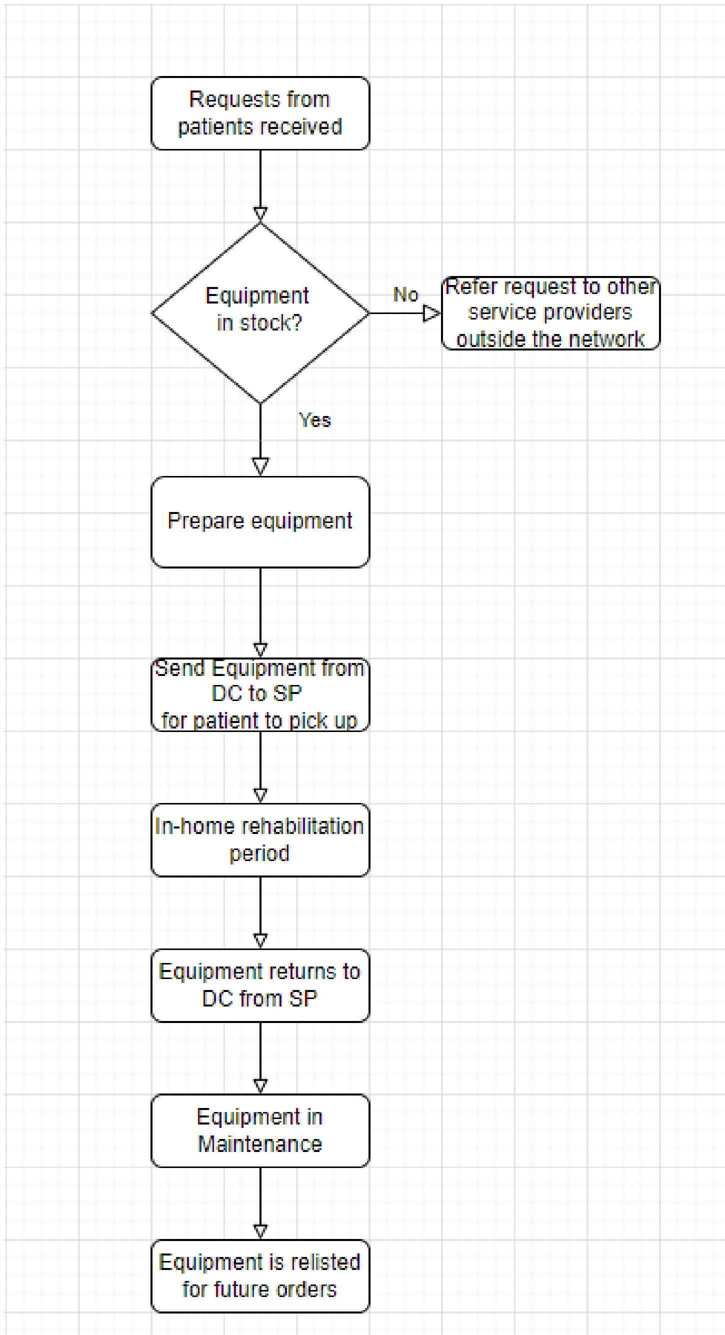

Figure 3.7: The process flow in a centralized network

Chapter 4. Conceptual model implementation

The next step is implementing the conceptual models into the simulation software. Simulation as a tool provides the means for a detailed evaluation of the decisions before their physical implementation. We can verify and evaluate the network's performance under different strategies by converting the conceptual models discussed in the previous chapter into simulation models.

4.1 Different kinds of simulation models

Simulation models can be classified in different ways. Kelton (2002) summarized three classification dimensions:

1. Static or Dynamic: Time plays a natural role in dynamic models but does not in static models. Most operational models, including our models, are dynamic from this point of view.

2. Continuous or Discrete: The system's state can change continuously over time in a continuous model; in a discrete model, changes only occur at separate points in time. Because the events that may change the state of a system only instantaneously occur at these particular points in time (Law, 2007), combined with the first dimension, time plays a natural role in discrete-event simulation models. Considering the system's state can change over time in both continuous and discrete models, both types of models have a dynamic nature.

3. Deterministic or Stochastic: Models without random input are deterministic. On the contrary, stochastic models operate with random inputs. Usually, a model contains both deterministic and random inputs in different components or steps. Taking our models as an example, both request arrival time and the duration of the patient's rehabilitation period are random to a certain extent, but the transportation time of transferring equipment between regions is deterministic.

Therefore, measured by these three dimensions, our models match the classification of discrete-event simulation models with dynamic and stochastic characteristics.

4.2 Brief introduction of the Arena Simulation software

'Arena' is a general-purpose simulation software; thus, it can be used for any application, such as manufacturing, supply chains, defence, health care, and contact centers (Law, 2007). Users can build experimental models by choosing and placing modules with different functions to represent processes or logic.

Simulation modelling in Arena follows the 'process approach' – time intervals separate a series of interrelated events with a time-ordered sequence. This sequence illustrates the entire flow of an 'entity' that is processed through a 'system' (Law, 2007).

Based on this time-ordered process approach, we can convert conceptual workflow models into Arena simulation models while respecting the processing logic.

4.3 Convert conceptual models to simulation models

In the previous chapter, we mentioned four types of layouts we intend to implement in the health equipment rental network. Based on this, five simulation models are derived:

4.3.1 Decentralized network

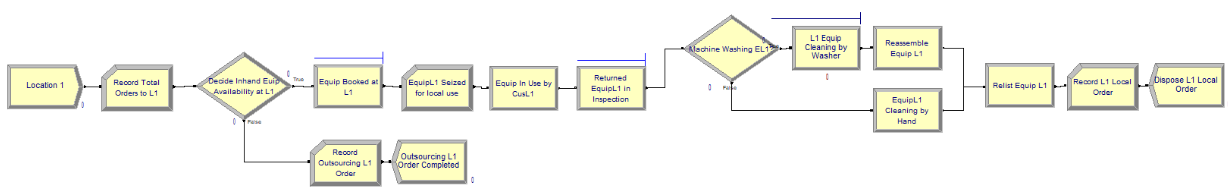

Figure 4.1: Decentralized network Arena model

Figure 4.1 shows the decentralized network model's entire flow for one specific region. The whole flow can be broken down into the following steps:

1. The service points at each region receive requests for orders from clients, as shown in Figure 4.2.

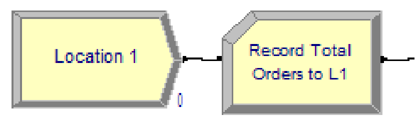

Figure 4.2: Order requests enter the system

2. Each service point will check Inventory availability after receiving equipment rental requests from clients. The 'Decide module' shown in Figure 3 will execute this function.

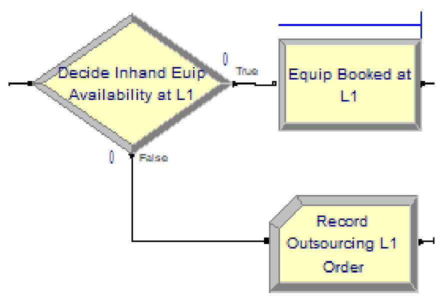

Figure 4.3: Check inventory availability

3. Following the second step, as shown in Figure 4.3, equipment will be seized for delivery or waiting for clients to be picked up if inventory is sufficient. Otherwise, the requests will be transferred to other service providers outside the network who will provide similar equipment and services, and this order will be terminated.

Considering the urgency of the need, patients always need the equipment right away for rehabilitation. Therefore, their requests will be immediately transferred to other providers as 'outsourcing orders' once either local or shared equipment in the network cannot satisfy the demands.

4. Clients use the equipment for their rehabilitation treatments. A delay module records the duration of the client's rehabilitation period, as shown in Figure 4.4.

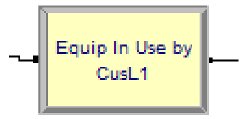

Figure 4.4: Delay module to record rehabilitation duration

5. After the equipment returns from the clients, it must be carefully inspected and sterilized before going back onto the shelf. At this step, the inspector, as a type of resource in the system, is responsible for this whole process.

6. Process inspection and cleaning is done in two ways. Considering some parts of the equipment or some types of equipment are not machine-washable, the inspector needs to clean and sterilize these parts or equipment by hand. For the machine-washable equipment, a washer as another type of resource in this process will be seized. After washing and cleaning, the inspector needs to reassemble the equipment in one piece.

7. When the equipment is ready for the next client, we assume the whole process of one order is completed. Finally, all resources, including the health equipment, inspector and washer, are released. Figure 4.5 shows the whole inspection process.

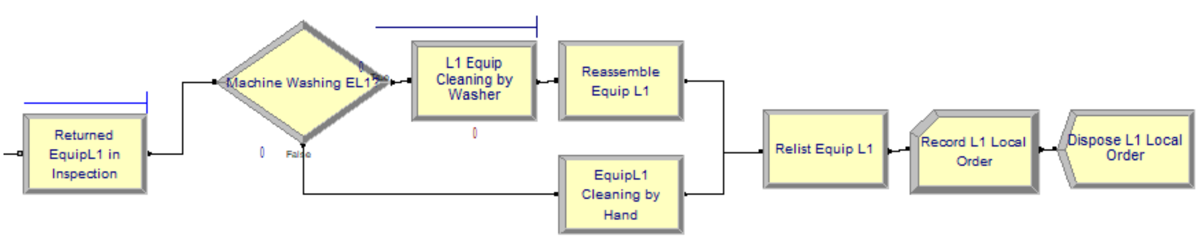

Figure 4.5: The inspection process

In this decentralized strategy, all five service points in the five regions follow the same process flow. Figure 4.6 shows an example including the five regions, as in our case, that will be presented later. They independently manage their inventory and provide service to clients in their own region.

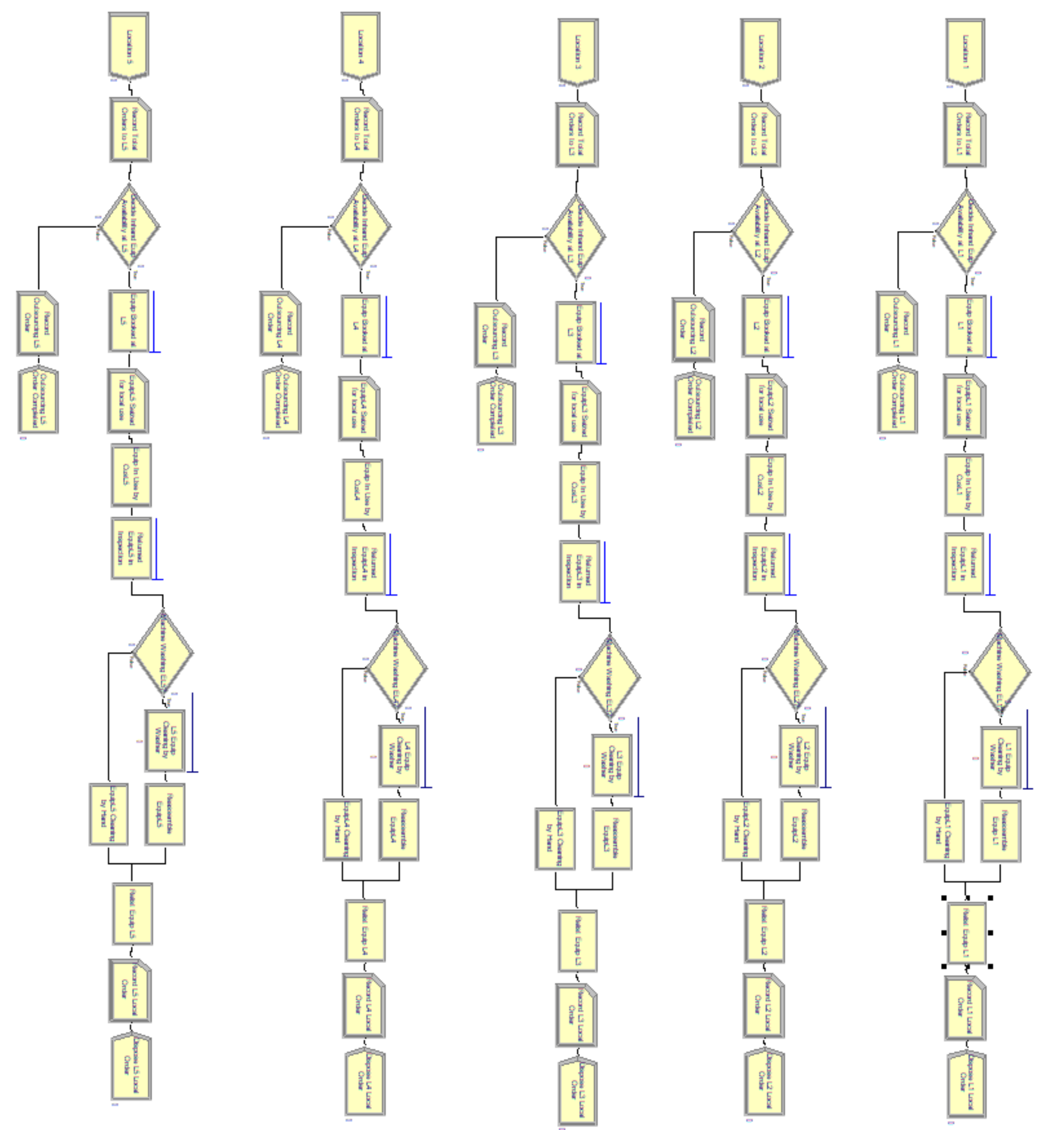

Figure 4.6: Illustration of the entire decentralized network

4.3.2 Decentralized inventory with equipment sharing across all service points

Compared with the first model, the first adjustment is at the available inventory check step. The adjustment is made to capture the effect of sharing policies if the local inventory is insufficient: the service point will ask to borrow equipment from other regions before transferring the request to other service providers outside this network if its inventory is insufficient. Figure 4.7 shows this adjustment in one specific region through additional decision steps executed by the Decide modules. This adjustment also creates connections and leads to interactions across regions that do not exist in the first model.

At this adjustment, we set up three different decision rules to regulate the equipment-sharing activity if multiple regions have the available equipment to lend at the same moment. We will test each of the three rules respectively.

The first rule is that the borrower always borrows equipment from the service point where the amount of available inventory (Total equipment – Equipment in use) is the largest. Under this rule, if there is more than one area with the most available equipment, the available equipment will be reserved for local use and not be shared. This is to make the rules as simple as possible, with fairness in mind.

Under the second rule, the shared equipment is from the service point where the ratio of busy equipment (Equipment in use / Total equipment of the lender) is the smallest. The instructions for the first and the second rules will be set up in each Decide module.

And under the third rule, the borrower always tries to start borrowing equipment from another service point closest to the borrower. In addition, we need to set a certain sequence at this step in our model to achieve the third rule. We will discuss the specific setup process in the 'general setting up and data input' section.

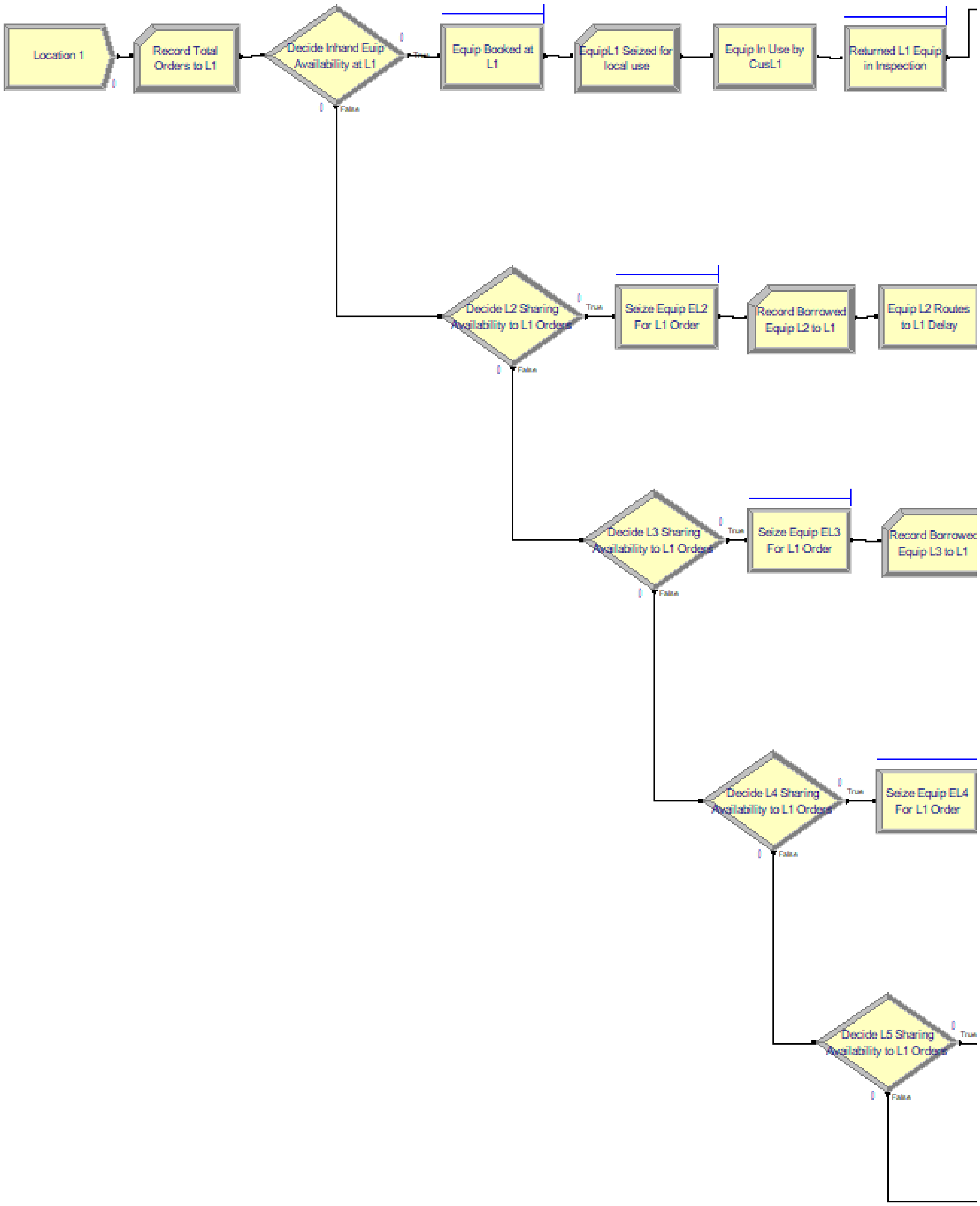

Figure 4.7: The process at region 1 to inquire about equipment sharing availability from other regions

The second adjustment is the transportation time that occurred to transship shared equipment between two regions. As shown in Figure 4.8, the first ‘Delay module’ is added to the step when the equipment is transferred from the lender’s region to the borrower’s region.

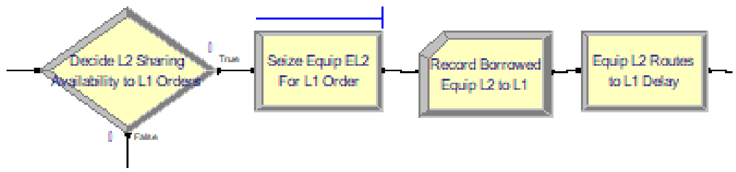

Figure 4.8: Delay module records the shared equipment’s transportation time to the lender region

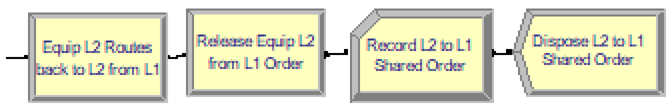

Figure 4.9: Delay module records the transportation time when shared equipment returns

Figure 4.9 shows the second ‘Delay module’ added to the step when the shared equipment returns from the lender’s region.

Figure 4.10 shows the partial model that illustrates the workflow of the service point in region 1. In addition, the other regions also follow the same pattern.

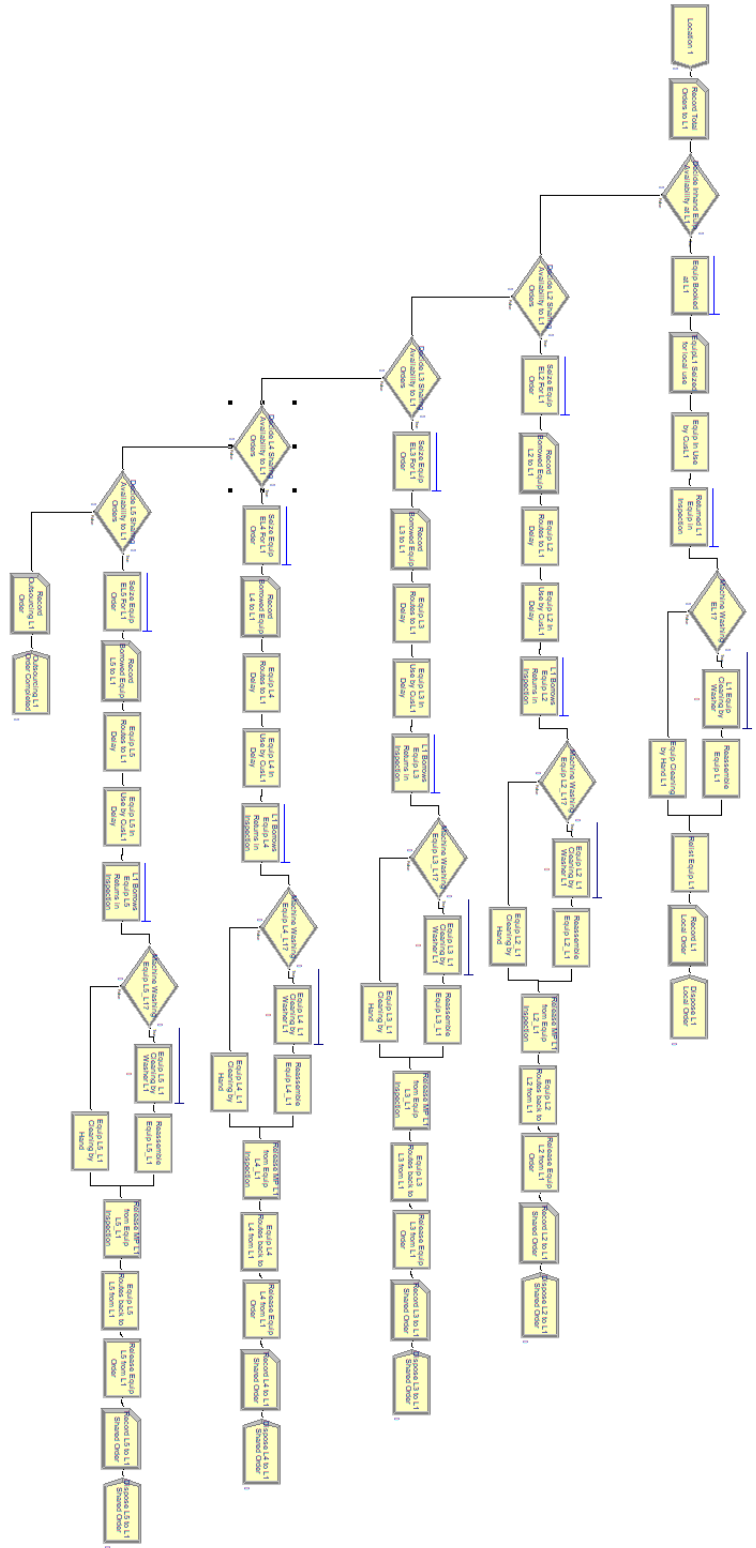

Figure 4.10: The workflow in one specific region under strategy 2

4.3.3 Two zones with equipment sharing – Equipment is inspected at the lender's facility

Under this strategy, each region is assigned to one of the two zones, and there is one regional warehouse in each zone. Equipment will be sent from the regional warehouse to the same zone's service points that it serves. Therefore, every equipment transshipment, including local and between the two zones, will incur transportation time. The only exception is when the requests are from exactly where the two regional warehouses are located.

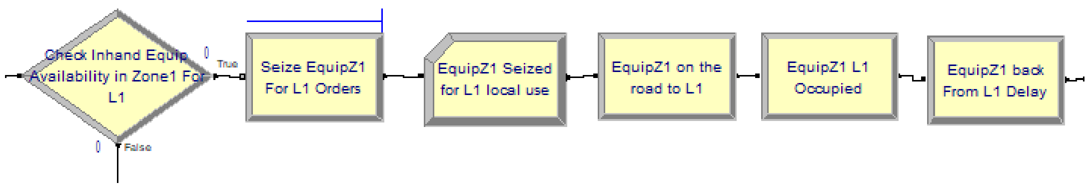

Figure 4.11: The equipment transportation time in the same zone

As shown in Figure 4.11, transportation times will be incurred when Zone 1's equipment is sent to region 1's service point and when it is sent back to the regional warehouse.

The service point will ask to borrow equipment from the regional warehouse in the other zone if its regional warehouse cannot satisfy the local requests. The equipment will be directly sent to the lender's service point from the other zone. This process and the transportation time that the 'Delay module' captured are shown in Figure 4.12.

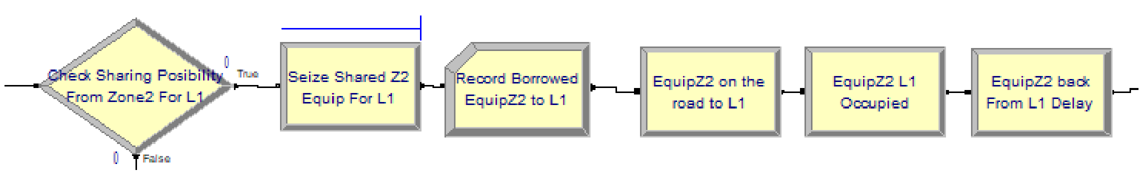

Figure 4.12: Region 1 borrows equipment from other zone's regional warehouse

The inspection and cleaning process remains unchanged but will be processed at the regional warehouses instead of at each service point. The lender is responsible for inspecting and cleaning all its equipment, including the equipment for local clients' needs and lending to the other region at its regional warehouse.

Figure 4.13 shows the partial model that illustrates the flow of the service point in region 1, and the other regions follow the same pattern.

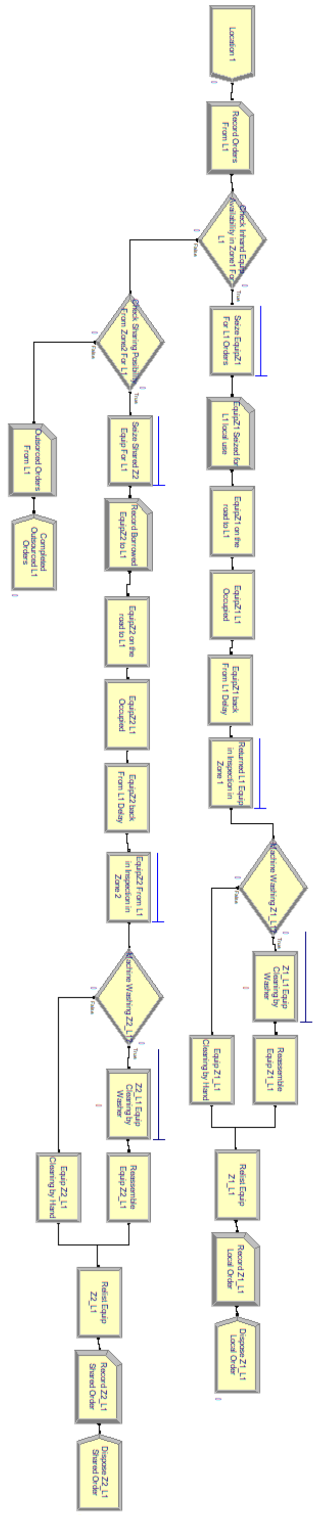

Figure 4.13: The workflow in one region under strategy 3

4.3.4 Two zones with equipment sharing – Equipment is inspected at the borrower's facility

The structure and most rules are similar to the third model, except that the shared equipment is inspected at the borrower's facility.

This change will generate an additional transshipment when the client returns the equipment: the shared equipment will be sent to the borrower's zone before returning to its home zone's warehouse. Therefore, it will incur one more transshipment compared with the third strategy.

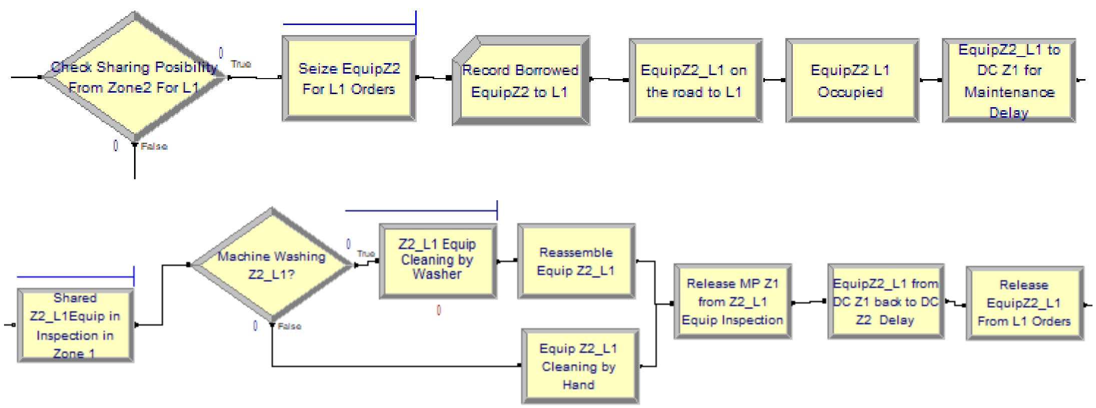

Figure 4.14: One additional transportation of shared equipment between two zone's regional warehouses

Figure 4.14 illustrates the flow of shared equipment between the two zones. The shared equipment needs to travel to the regional warehouse of the borrower's zone for inspection, and an additional 'delay module' records this transportation time.

4.3.5 Centralized network model

This model reflects the most centralized structure – only one warehouse inside the system serves all the requests from all five regions' service points.

The equipment will be seized to be prepared for transfer from the central warehouse to the service points if inventory is sufficient. Otherwise, the requests will be transferred to providers outside the network. All the equipment will be returned from service points to the central warehouse for inspection and cleaning after the clients finish their rehabilitation treatments.

All equipment transfers between service points and the central warehouse will lead to transportation times, except for requests from where the central warehouse is located.

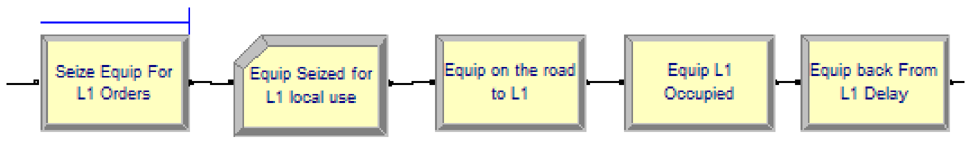

Figure 4.15: Transportation time between the central warehouse and the service point in one region

Figure 4.15 shows the transportation time of equipment moving between the central warehouse and service points. Figure 4.16 illustrates the entire centralized model structure. In the model, one specific region takes the responsibility as the central warehouse; therefore, the equipment for this region s clients will not incur any transportation time. We will discuss the steps of warehouse location selection later.

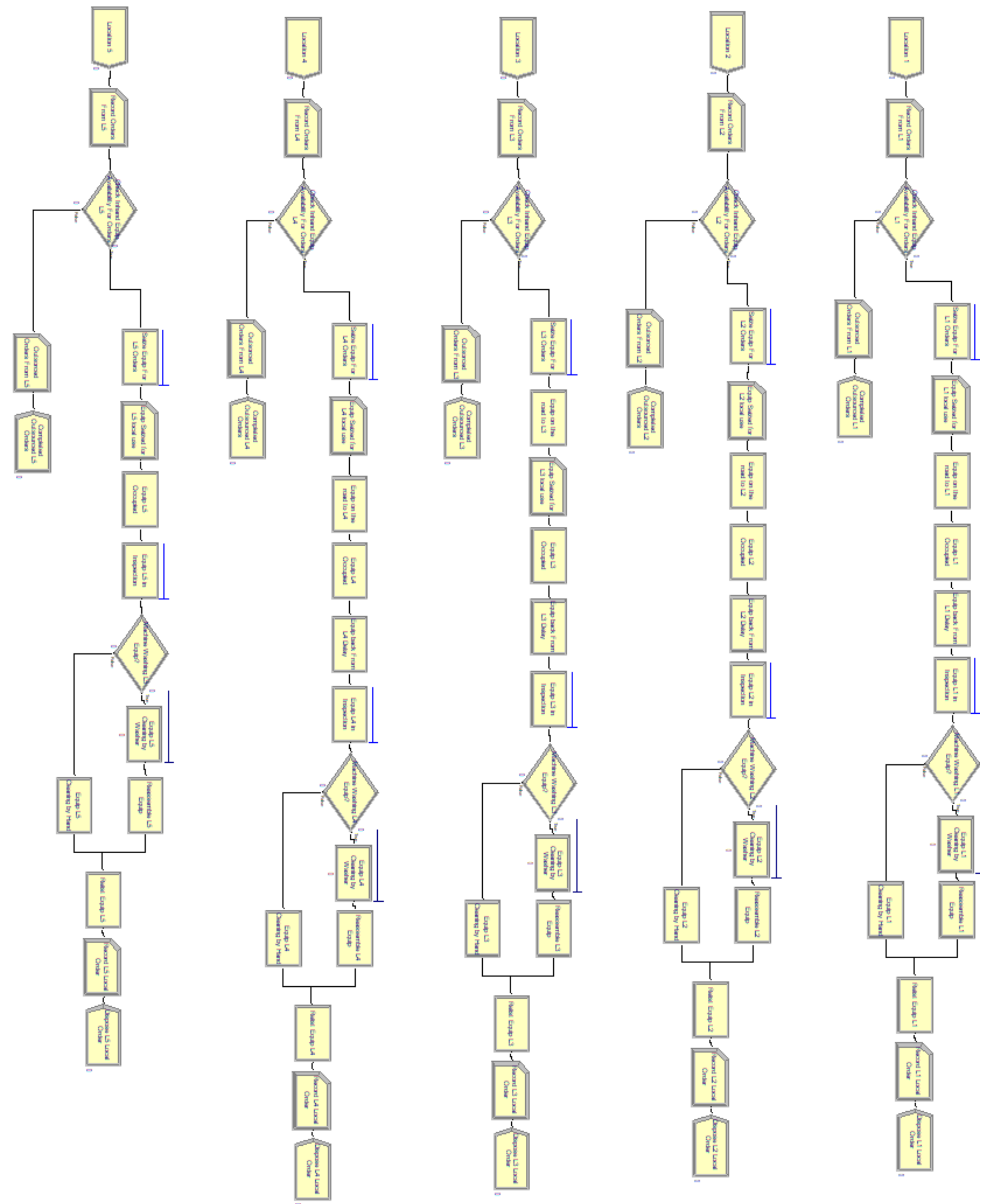

Figure 4.16: The centralized network model

4.3.6 Adjustment for using a wheelchair washer in the inspection and cleaning process

In the total centralized network under strategy 5, we introduce a wheelchair washer – a professional washing machine to clean and disinfect our health equipment – to accelerate the cleaning process. Therefore, we need to modify the original model to accommodate this change.

In the adjusted process shown in Figure 4.17, because the wheelchair washer can handle all types of equipment, all equipment will be cleaned by the wheelchair washer. Therefore, the inspector does not need to hand wash some equipment. The only job that the inspectors need to do is sorting and putting the health equipment in the wheelchair washer orderly and then taking them out after the automatic cleaning process is completed.

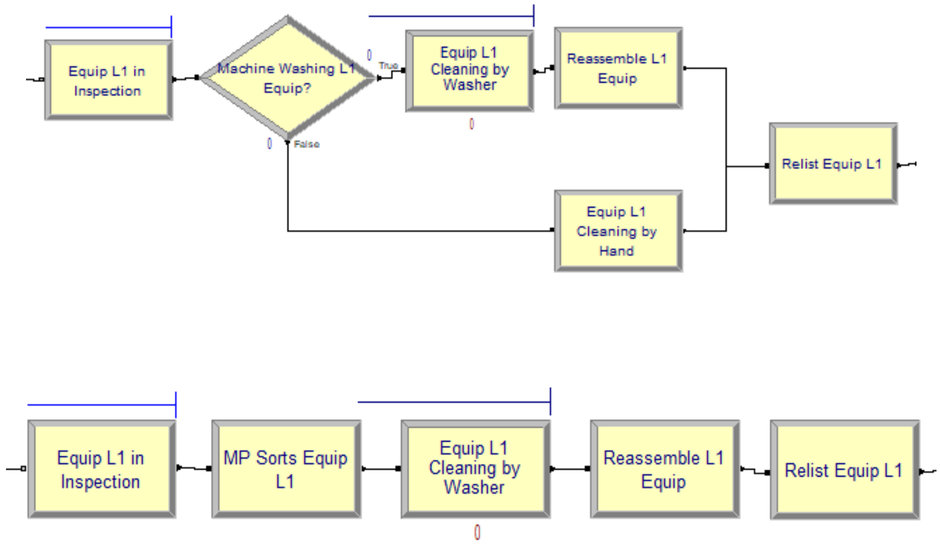

Figure 4.17: The comparison of the original (above) and adjusted (below) inspection and cleaning process

4.4 General setup and data input

We also need to identify a series of general parameters to use in the simulation models in all scenarios.

4.4.1 Identify the five regions' potential demands and available inventory of the health equipment

As mentioned in the previous chapter, we intentionally analyze a set of regions consisting of a large metropolis and several adjacent small to medium-sized cities. This initiative aims to ensure that our research covers different demand levels. And also, the total populations of all the small to medium-sized cities are approximately the same as the population of that metropolis. This condition ensures similar potential demand and inventory levels compared with that in the metropolis area when pooling the demands and inventories from all the small and medium-sized cities together. Furthermore, the geographical proximity of these regions to each other will ensure that transferring equipment does not result in long-distance transportation.

Based on these prerequisites, we chose five regions in Quebec, Canada, as shown in Figure 4.18.

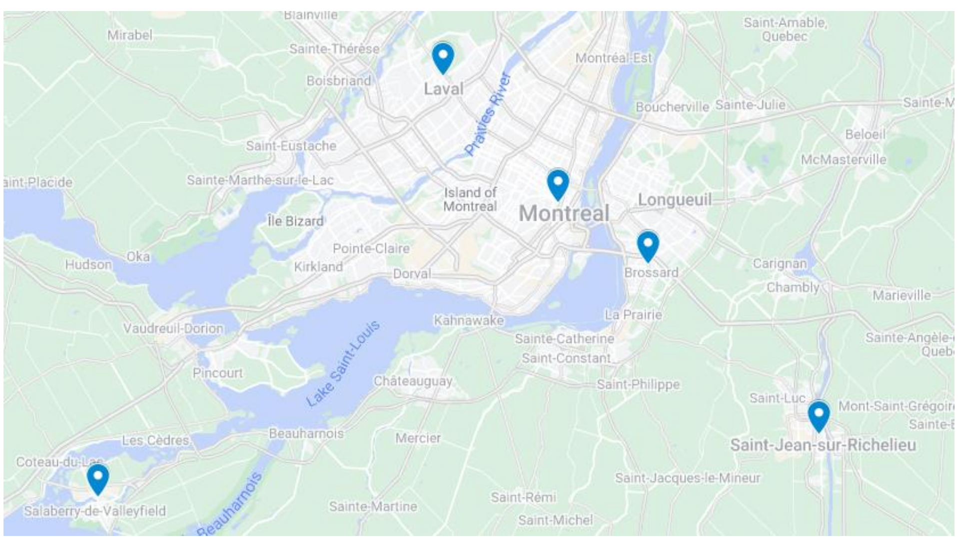

Figure 4.18: The map to show the five regions

First, Montreal's population is much bigger than the other regions, but the sum of the other four regions is similar to that of Montreal. Table 4.1 provides information on the population in the five regions.

Regions **(L)**	**Population** (Source: Statistics Canada)
Salaberry-de-Valleyfield (L1)	435,436
Laval (L2)	437,413
Longueuil and Brossard (L3)	415,347
Saint-Jean-sur-Richelieu (L4)	656,287
Montreal (L5)	1,704,694

Table 4.1: the population in the five regions

Second, the five regions are geographically close to each other. The furthest straight-line distance between any two regions is no more than 65.2 km. Since this thesis does not address routing planning and optimization, the precise location of each service point in the five regions is not in consideration. Therefore, the geographic coordinates of the five regions and their distances from each other are based on the information provided by Google Maps. Figure 4.19 is the map that shows the five regions by the blue cursors and the furthest Euclidean distance between two of the five regions.

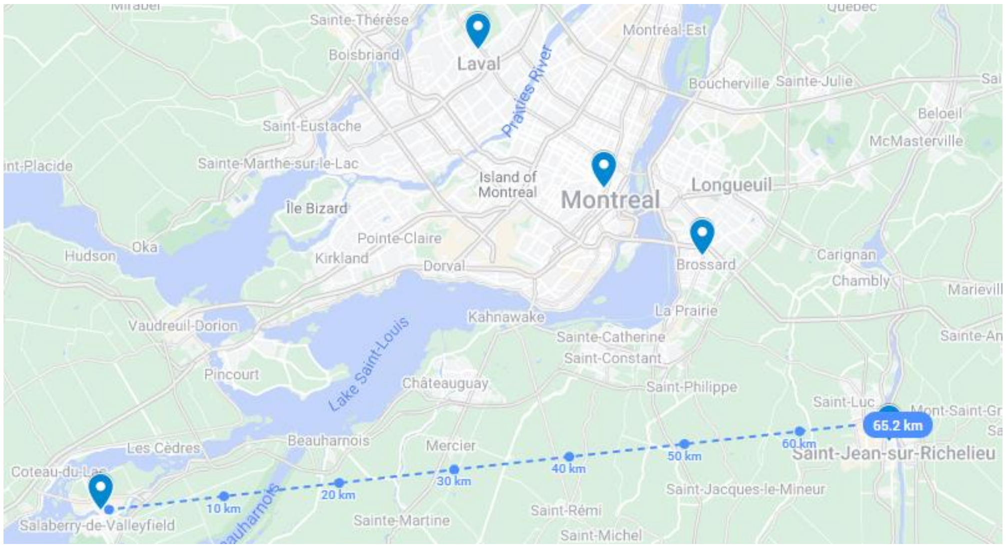

Figure 4.19: The furthest Euclidean distance between any two regions

The Euclidean distances in kilometres between each two service points are shown in Table 4.2:

Region	L1	L2	L3	L4	L5
L1	-	46.1	53.85	65.2	31.2
L2		-	25	46.1	14.15
L3			-	21.2	11.2
L4				-	32
L5					-

Table 4.2: Distances between each two service points

According to the "Health Reports – Unmet home care need in Canada (Gilmour, 2018)" issued by Statistics Canada, in 2015/2016, "an estimated 3.3% of Canadians aged 18 or older had received home care services" as well as another 1.6% of the adult population's requests were unmet. Among them, 22.5% of the home care receivers requested medical equipment or supplies (Gilmour, 2018), based on the data in "Formal home care use in Canada" from the same series of health reports by Statistics Canada. Thus, we assume that about 1% of the total population in our sample needs to rent health equipment in a given year, as shown in Table 4.3.

Regions	**Population**	**Potential annual demand** (3.3%+1.6%) *22.5%
L1	435,436	4,354
L2	437,413	4,374
L3	415,347	4,153
L4	656,287	6,563
L5	1,704,694	17,047

Table 4.3: The potential annual demand in the five regions

Based on the assumptions above, the next step is identifying the initial inventory amount in each region. In this step, we used Arena simulation to generate an initial result for assigning and allocating health equipment inventory. The result showed that in a decentralized network where the resource-sharing policy is not applied, each location's inventory level needs around 50% of the potential annual demands to cover all the demands without transferring patients' requests to other service providers. Table 4.4 shows the amount of health equipment inventory in each region to cover 100% of potential demand during the simulation cycle.

Regions	Inventory
L1	2,177
L2	2,187
L3	2,077
L4	3,281
L5	8,524

Table 4.4: Inventory level to cover all potential demands

However, this theoretical configuration is not practical. First, reaching such a high inventory level might not be achievable for a service provider whose inventory mostly relies on donations. For example, in 2011, the Red Cross in Ontario received 459 donated items, 350 of which were wheelchairs, in the entire province (Teotonio, 2012). Second, the holding cost of keeping such a quantity of inventory might be unaffordable. According to public reporting, the increasing holding costs that include the rent for the storage facilities forced health equipment service providers to relocate their facilities to smaller, cheaper and usually more remote spaces (Cook, 2017). Considering the above constraints, we need to adjust the preliminary demand that we aim to fulfill to ensure it is achievable.

Two sources can support this adjustment. First, according to the annual reports of ALS Canada -- a society dedicated to changing what it means to live with amyotrophic lateral sclerosis -- in 2021, 2309 pieces of health equipment were provided to their patients by their health equipment rental service in six clinics in Ontario, Canada. That means each clinic serves an average of 300-400 requests. The other information is from Canadian Red Cross – the organization has more than 300 branches across the country: 270,000 pieces of health equipment, including wheelchairs, crutches and walkers, were rented in 2014. However, not every branch of them provides this kind of service. Therefore, we assume each branch may provide the equipment for 1,800 requests if at least half of their branches offer health equipment rental services. Based on that information, we assume a reasonable range of annual demands that one branch or service point can fully serve should be between 300 and 1,800 requests per year. Therefore, approximately 10% of the original potential demand is in this range. Accordingly, we reduce the inventory level to 10% of the original quantity and assume the new inventory level could fully cover the adjusted demands. The adjusted amounts are shown in Table 4.5. We will verify this assumption by Arena later.

Regions	Adjusted Potential Demand	Adjusted Inventory
L1	435	218
L2	437	219
L3	415	208
L4	656	328
L5	1,705	852

Table 4.5: Adjusted preliminary demands and inventory

4.4.2 Selecting warehouse locations

Under strategy 3, two regional warehouses should be located respectively in two zones. On the basis of population, regions 1 to 4 (L1-4) are aggregated as zone 1, and region 5 (L5) alone as the other separate zone. Thus, we need to select a location to allocate zone 1's regional warehouse that will serve the demands from regions 1 to 4. For this purpose, we calculated the total cost in terms of the product of distances and demands if each of the four regions was selected in turn, and chose the one with the smallest total cost as the location of the regional warehouse.

If the service point in region 1 was selected:

Location	Distance	Demand	Total cost (Demand*Distance)
L1	0	435	
L2	46.1	437	85,264.7
L3	53.85	415	
L4	65.2	656	

If the service point in region 2 was selected:

Location	Distance	Demand	Total cost
L1	46.1	435	
L2	0	437	60,670
L3	25	415	
L4	46.1	656	

If the service point in region 3 was selected:

Location	Distance	Demand	Total cost
L1	53.85	435	
L2	25	437	48,235
L3	0	415	
L4	21.2	656	

If the service point in region 4 was selected:

Location	Distance	Demand	Total cost
L1	65.2	435	
L2	46.1	437	57,306
L3	21.2	415	
L4	0	656	

According to the above calculation, choosing the service point in region 3 as the regional warehouse generated the lowest total cost.

Next, we repeat the same procedures for locating the single central warehouse for all regions under strategy 5.

If the service point in region 1 was selected:

Location	Distance	Demand	Total cost
L1	0	435	
L2	46.1	437	138,461
L3	53.85	415	
L4	65.2	656	
L5	31.2	1,705	

If the service point in region 2 was selected:

Location	Distance	Demand	Total cost
L1	46.1	435	
L2	0	437	84,796
L3	25	415	
L4	46.1	656	
L5	14.15	1,705	

If the service point in region 3 was selected:

Location	Distance	Demand	Total cost
L1	53.8	435	
L2	25	437	67,331
L3	0	415	
L4	21.2	656	
L5	11.2	1,705	

If the service point in region 4 was selected:

Location	Distance	Demand	Total cost
L1	65.2	435	
L2	46.1	437	111,866
L3	21.2	415	
L4	0	656	
L5	32	1,705	

If the service point in region 5 was selected:

Location	Distance	Demand	Total cost
L1	31.2	435	
L2	14.15	437	45,396
L3	11.2	415	
L4	32	656	
L5	0	1,705	

According to the above calculation, choosing the service point in region 5 as the regional warehouse generated the lowest total cost.

4.4.3 Setting parameters in simulation models

Several general parameters that we used in our simulation models need to be indicated. We use the following notations to refer to them:

Three types of resources:

E: Health Equipment

MP: Maintenance personnel/Inspector

Washer: Washer machine

Location indicator:

Ln: Region n (n=1,2,3,4,5)

Zn: Zone n (n=1,2)

Health Equipment and which region it is from:

ELn : Equipment from Region n (n=1,2,3,4,5)

Variables:

MR(Resource type + Location indicator): Resource Capacity

NR(Resource type + Location indicator): Number of busy resource units

By showing this verification process, we also explain how we set up our simulation models and input data in Arena:

1. Request's arrival time

The health equipment rental requests come into the system randomly at discrete points in time. Exponential distribution (Expo) is often used to model interarrival times in random arrival in Arena. The potential annual demand in each region is the key to determining the mean between two arrivals. To calculate this, we assume the system runs 250 days per year and 8 hours per day.

The average interarrival time is calculated as 8 hours/(Annual demand/250 days). Table 4.6 shows the results in each region, and Figure 4.20 shows an example of how the corresponding module is set up.

Region	10% Annual Demand	Mean of interarrival time (Hours)
L1	435	4.6
L2	437	4.6
L3	415	4.8
L4	656	3.1
L5	1,705	1.2

Table 4.6: Mean time between two requests in each region

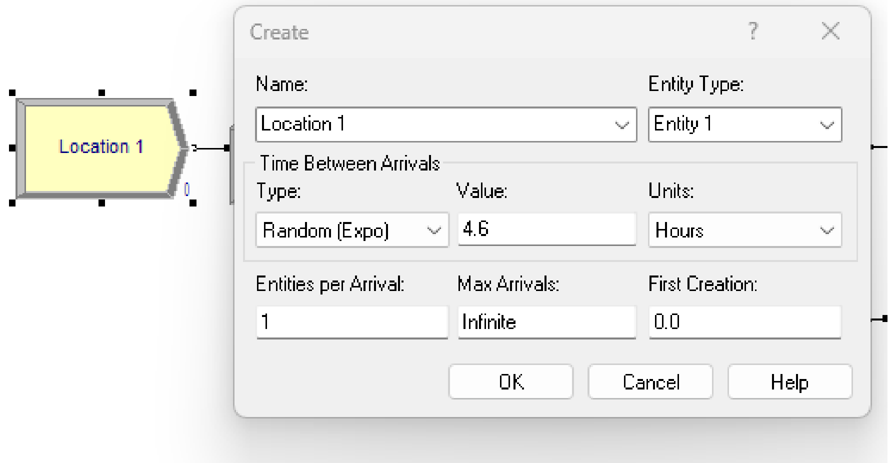

Figure 4.20: Setting up the request's arrival time in region 1

2. The rules for sharing equipment

Under strategies 2.3 (borrowing equipment from the closest neighbour), 3 and 4, the lender region will always share its equipment with the borrower regions as long as they have available equipment in hand. Figure 4.21 shows the input in the 'Decide module' to set up this rule when region 1 requires borrowing equipment from zone 2 under strategy 3. Zone 2 will share its equipment with region 1 if the number of units of busy equipment (NR) is smaller than the total number of equipment (MR) that zone 2 has.

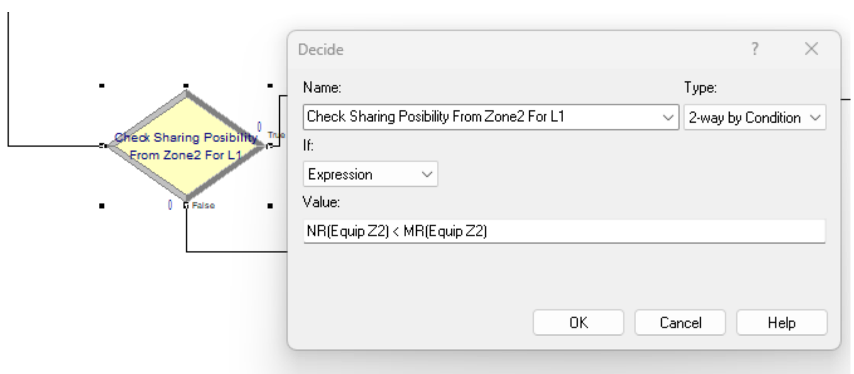

Figure 4.21: The rule to share equipment inter zones under strategy 3

It should be noted that, under strategy 2.3, each region needs to follow a distance-based sequence to inquire about and borrow equipment from other regions. Therefore, we summarized the sequences in Table 4.7.

Borrower	**Sequence of inquiry**			
L1	L5	L2	L3	L4
L2	L5	L3	L4	L1
L3	L5	L4	L2	L1
L4	L3	L5	L2	L1
L5	L3	L2	L1	L4

Table 4.7: The sequence of inquiries for borrowing equipment under strategy 2.3

In addition, the rules for sharing equipment are different under strategies 2.1 and 2.2.

The shared equipment is always from the region where the absolute number of available equipment is the largest under strategy 2.1. For example, if region 2 decides to lend equipment to region 1, it should match a condition as:

(MR(EL2)-NR(EL2))>(MR(EL3)-NR(EL3)) .AND. (MR(EL2)-NR(EL2))>(MR(EL4)-NR(EL4)) .AND. (MR(EL2)-NR(EL2))>(MR(EL5)-NR(EL5))

Figure 4.22 shows the same input in the 'Decide module'.

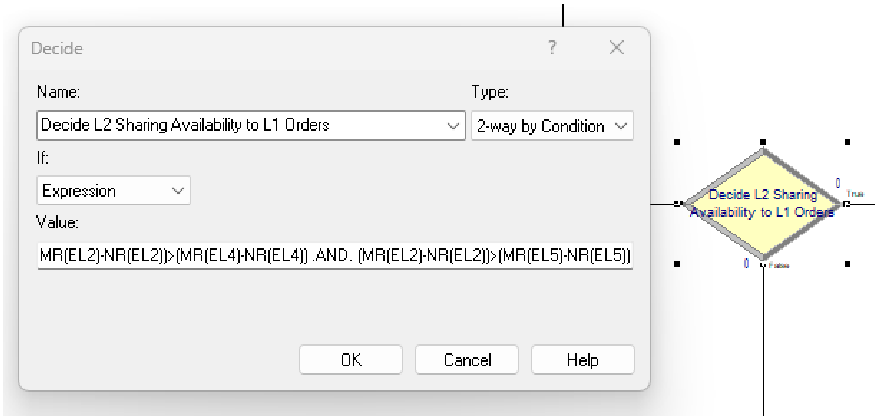

Figure 4.22: The rule to share equipment from regions 2 to 1 under strategy 2.1

Under strategy 2.2, the possibility of sharing equipment is based on the smallest ratio of busy equipment over total equipment. Therefore, if region 2 decides to lend equipment to region 1, it should match the rule as:

NR(EL2)/MR(EL2)<NR(EL3)/MR(EL3) .AND. NR(EL2)/MR(EL2)<NR(EL4)/MR(EL4) .AND. NR(EL2)/MR(EL2)<NR(EL5)/MR(EL5).

The setup is shown in Figure 4.23:

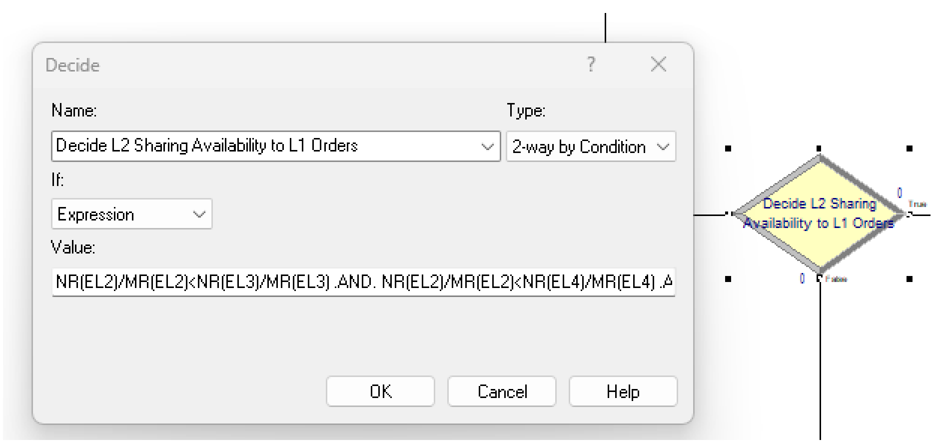

Figure 4.23: The rule to share equipment from regions 2 to 1 under strategy 2.2

3. Rehabilitation duration

Health equipment is provided to individuals to recover from illness or injury. According to the instruction of The Canadian Red Cross Health Equipment Loan Program (HELP), the duration for short-term needs is usually between 7 to 180 days. Therefore, we use a triangular distribution (a minimum of 7 days, a mode of 90 days and a maximum of 180 days) to capture the state in this process, as shown in Figure 4.24.

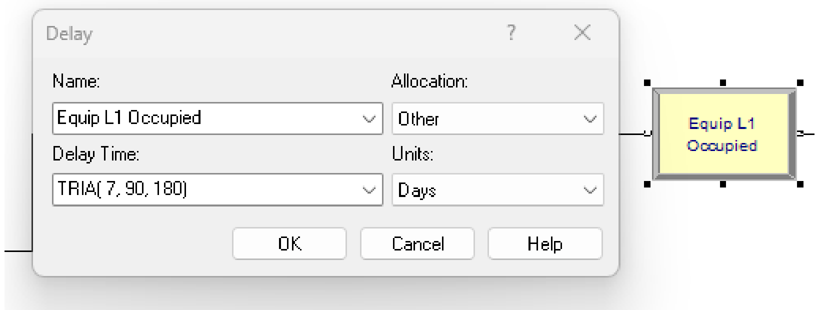

Figure 4.24: Triangular distribution to simulate patient's rehabilitation duration

This setup in the patient's rehabilitation duration process will remain unchanged in all of our models under the five strategies.

4. Inspection and cleaning process

Another two types of resources will participate in the equipment inspection and cleaning process as well as the health equipment in our models: the inspector (MP) and washing machine (washer).

The principle to determine the number of inspectors and washers is to ensure enough capacity of the resource combination to process the inspection, sterilization and cleaning procedure within one day once the health equipment returns from the patients' places to each service point or regional warehouse. This principle aims to prevent returned equipment from getting stuck at this phase before it can be put into service in the next round. We summarized the units of each type of resource in the five regions in Table 4.8. This resource allocation can ensure that the inspection and cleaning of each piece of equipment can be completed within one day under the baseline strategy (strategy 1) at 10% of the demand level. We will keep this allocation without any change for the following test.

Region	L1	L2	L3	L4	L5
Inspector	1	1	1	1	4
Washer	1	1	1	1	3

Table 4.8: Resource allocation under strategy 1 at 10% of the demand level

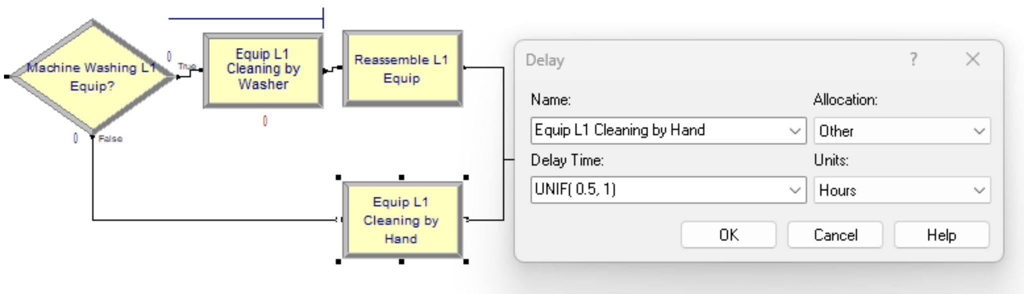

Figure 4.25: Uniform distribution to simulate inspection and cleaning process

Figure 4.25 shows the uniform distribution that we choose to capture this step's duration. Because the duration of inspection and cleaning is determined by various factors, including the type of equipment and the state of the equipment, as well as the equipment and components that can be machine washed or not, we can only roughly estimate the time consumption of this process as being in between 30 minutes and 1.5 hours. This assumption is based on the regular duration of the washing program of a household washing machine.

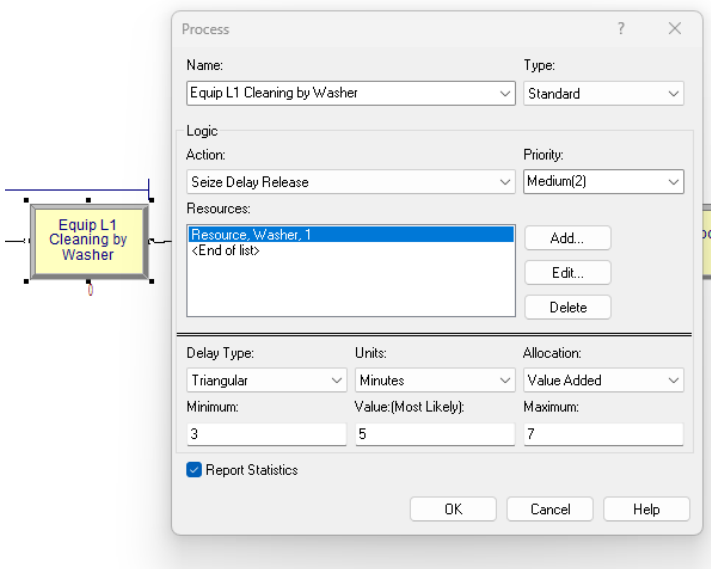

Figure 4.26: Uniform distribution to simulate inspection and cleaning process by using wheelchair washer

The alternative is using a wheelchair washer to accelerate the inspection and cleaning process. As shown in Figure 4.26, usually the average processing time of this type of wheelchair washer is 5 minutes, and the duration may be between 3 to 7 minutes, depending on the types of health equipment and the extent to which the equipment is contaminated.

5. Transportation/transshipment time

As we mentioned, the transportation time will be incurred when equipment is transferred from the regional or central warehouse to each region or shared between regions. However, considering the five regions are geographically close to each other, we assume the transportation time remains constant, and all equipment transshipments could be done in one day wherever the equipment travels in between.

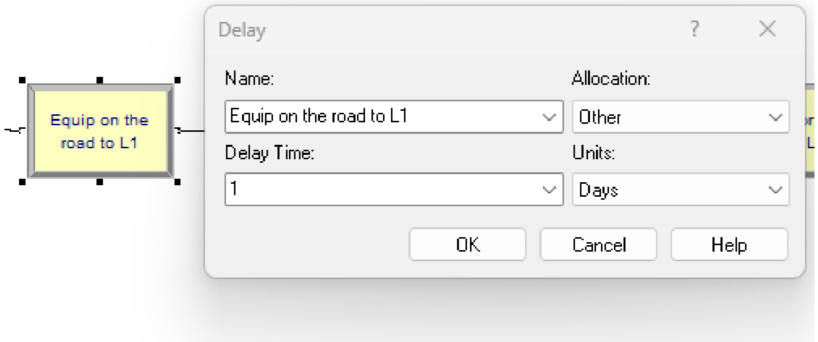

Figure 4.27: Consistent transportation time

Figure 4.27 shows the transportation time when equipment is transferred from the central warehouse to region 1's service point under strategy 5.

After all the setups, the results shown in Table 4.9 verified our assumption of adjusted inventory levels and the allocation of other resources in session 4.4.1.

Region	L1	L2	L3	L4	L5
Local fulfillment rate %	100	100	100	100	100
Total Fulfillment rate %	100	100	100	100	100

Table 4.9: Results generated under strategy 1 at 10% of the demand level

Since the baseline model (Decentralized without equipment-sharing) generated a 100% fulfillment rate at 10% of the demand level at local and network levels, we will test the five strategies at 12%, 14% and 15% of the potential annual demand levels in the five regions. In the meantime, the inventory levels remain unchanged. The summary of demand and inventory levels for further testing is shown in Table 4.10.

Region	12% of annual demands	14% of annual demands	15% of annual demands	Inventory
L1	522	610	653	218
L2	522	612	656	219
L3	498	581	623	208
L4	788	919	984	328
L5	2,046	2,387	2,557	852

Table 4.10: Demand and inventory levels for testing

4.4.5 Other Assumptions

There are some assumptions to facilitate the running of the simulation models.

- All the health equipment is regarded as one product family -- no specific distinction is made on what kind of equipment the patient is booking, such as a wheelchair, a pair of crutches or a bath seat, due to the variety of equipment and the relatively low demand specific to a particular type of equipment.

- There is no replenishment of new health equipment or deprecation of the old equipment in the inventory during the period of the model running.

- For all local orders, the process of booking and preparing the needed equipment follows the “first come, first served” rule.

- The local orders always prioritize being processed first before the requests from other locations if both types of orders come simultaneously.

- In the inspection and disinfection process, all the equipment, whether local or shared, follows the “first come, first served” rule.

Chapter 5. Analysis and discussion of the results

In this chapter, we will present and interpret the results generated by our simulation models.

5.1. Key performance indicators

We choose the following four indicators as the key performance indicators to evaluate the performance of responding to customers' needs under the five strategies:

1. Local fulfillment rate:

The rate indicates the percentage of rental requests (the demand) that are fulfilled by the equipment stored at local service points under the decentralized strategies or at regional warehouses under centralized strategies.

2. Total fulfillment rate:

It indicates the percentage of demand fulfilled by both local and shared equipment inside the network.

3. Total travelling mileage:

It is the sum of the travelling mileage caused by all equipment transshipments between every two service points or between the regional warehouses and the service points. Therefore, all equipment-sharing activities will lead to equipment transshipments as well as transporting equipment from regional warehouses to the service points under centralized strategies. Only one piece of equipment will be transported one time due to the randomness of clients requesting arrival times.

4. The waiting time before clients receive their requested equipment:

This indicator shows the percentage of clients who have to wait an additional time due to equipment transshipments under each strategy.

5.2 Simulation setting and results

The duration of each simulation was set as equivalent to 250 working days per year (8 hours per day). The first 21 days served as the warm-up period to ensure the health equipment resources will have been distributed relatively evenly in the system, including at the service provider's warehouses, clients' homes and on the road. Furthermore, each simulation process will replicate 360 times to reduce outliers and get smooth data. Finally, we take the average output of the 360 replications as annual data.

5.2.1 At 12% of the demand level

The fulfillment performances with the half-widths for 95% confidence intervals under the five strategies at 12% of the demand level are shown in Table 5.1. In our case, the half-width indicates the error margin of the average value of the total fulfillment by local or shared equipment or the unfulfilled requests due to inventory shortage. We can also use the intervals bounded by the half-widths to compare the statistical difference in fulfillment performances among all strategies if no overlap is shown in their intervals between each two strategies. According to the shown half-widths, the performance of local fulfillment under each strategy did not show a statistical difference from each other. Furthermore, the unfulfilled requests under Strategy 1 were covered by shared or pooled equipment under the other strategies. Therefore, the performances in terms of supplementary fulfillment by shared equipment are statistically similar to each other under Strategies 2 to 4. Next, we will analyze the fulfillment performance under each strategy respectively. For this further analysis, we will focus on the average, but we must keep in mind the observations about the statistical difference.

Strategy	Fulfilled Local Requests (95% confidence interval Half-Width)	Fulfilled by Shared Equipment (95% confidence interval Half-Width)	Unfulfilled Requests (95% confidence interval Half-Width)
1	3,980 (6.3)	-	7 (0.9)
2.1	3,980 (6.0)	8 (1.5)	-
2.2	3,979 (6.1)	8 (1.1)	-
2.3	3,980 (6.1)	8 (1.1)	-
3	3,986 (6.6)	-	-
4	3,987 (6.6)	-	-
5	3,985 (6.3)	-	-

Table 5.1: Fulfillment performance under the five strategies at 12% of the demand level

1. Under Strategy 1: The baseline model – Decentralized without resource-sharing

Region	L1	L2	L3	L4	L5	Avg.
Local / Total Fulfillment %	99.6	99.6	99.6	99.9	100	99.7

Table 5.2: Results under Strategy 1 at 12% of the demand level

We observed that a few requests could not be fulfilled under this baseline strategy at 12% of the demand level shown in Table 5.2. However, considering only a few requests could not be fulfilled and the fulfillment rate at each region was close to 100%, timing mismatches between when the equipment is available and when the requests arrive in the system may cause very few unfulfilled requests.

2. Under Strategy 2: Decentralized with resource-sharing policies applied

Strategy 2.1 – Maximum number of available equipment

By the rule of borrowing from the region with the largest number of available equipment, the results are shown in Table 5.3.

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	99.6	99.6	99.6	99.7	100	99.6
Total fulfillment %	100	100	100	100	100	100

Table 5.3: Results under Strategy 2.1 at 12% of the demand level

Compared with Strategy 1, the total fulfillment rate reached 100% at each location while the local fulfillment rates almost remained unchanged, as shown in Table 5.3. This is because the sharing policy shifted the redundant capacity of the equipment elsewhere to the regions with insufficient inventory to meet more demands from clients.

Strategy 2.2 - The smallest ratio of busy equipment

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	99.6	99.6	99.6	99.7	100	99.6
Total fulfillment %	100	100	100	100	100	100

Table 5.4: Results under Strategy 2.2 at 12% of the demand level

As shown in Table 5.4, Strategy 2.2 generated similar local and overall fulfillment rates to Strategy 2.1. However, the shared equipment's travel mileages between the lenders and borrowers may differ due to the different rules applied. We will compare the differences in distance generated under each strategy later.

Strategy 2.3 - The closest neighbour

For the rule of borrowing from the location closest to the lender, the results are shown in Table 5.5.

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	99.6	99.8	99.3	99.7	100	99.7
Total fulfillment %	100	100	100	100	100	100

Table 5.5: Results under Strategy 2.3 at 12% of the demand level

Unlike the other two derived rules of Strategy 2, the third rule is based on the shortest distance instead of the biggest capacity of available inventory. Therefore, the lender and the mileage travelled by shared equipment may differ from the other two derived rules when a specific region needs to borrow equipment, even though the fulfillment rates are similar.

3. Under Strategy 3: Equipment is centralized in two zones, and the lender is responsible for the inspection and cleaning of the shared equipment

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	100	100	100	100	100	100
Total fulfillment %	100	100	100	100	100	100

Table 5.6: Results generated by percentage under Strategy 3 at 12% of the demand level

As shown in Table 5.6, when locations 1 to 4 were integrated into one zone, all requests could be satisfied inside the zone. This result had never been reached under Strategies 1 and 2. Furthermore, compared with Strategy 2, there was no need to borrow equipment from location 5 when the equipment from locations 1 to 4 was centralized. This result confirmed the beneficial effect of the resource pooling strategy. Integrated demands and pooled equipment resources reduced the mismatches in time between available equipment and incoming requests.

4. Under Strategy 4: Equipment is centralized in two zones, and the borrower is responsible for the inspection and cleaning of the shared equipment

Based on the same logic, Strategy 4 shows similar results to Strategy 3, which can be found in Table 5.7. The only difference between Strategies 3 and 4 is executing the inspection and cleaning for shared equipment either at the lender's or borrower's facility. Because all requests were satisfied in each zone at this demand level and no equipment-sharing activity occurred, Strategy 4 did not generate any additional transportation time to transship returned equipment from the borrower's warehouse to the lender's compared with Strategy 3.

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	100	100	100	100	100	100
Total fulfillment %	100	100	100	100	100	100

Table 5.7: Results under Strategy 4 at 12% of the demand level

5. Under Strategy 5: Centralized

Region	L1	L2	L3	L4	L5	Avg.
Local / Total fulfillment %	100	100	100	100	100	100

Table 5.8: Results Strategy 5 at 12% of the demand level

As shown in Table 5.8, we can observe that all resources are centralized in region 5, and all requests from each region can be satisfied.

The summary in Chart 5.1 shows the comparison of the average fulfillment rates from all regions under different strategies. Generally, all the resource-sharing and pooling strategies can help the service provider improve its performance to fulfill demands without jeopardizing the local fulfillment performance at each service point at 12% of the demand level.

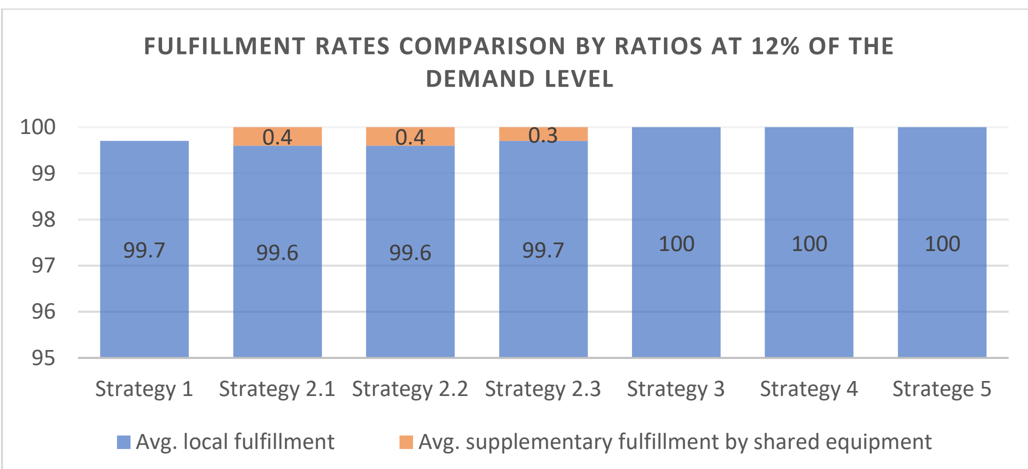

Chart 5.1: Comparison by ratios at 12% of the demand level

Although all resource-sharing strategies showed an improvement compared with our baseline model, and some showed similar fulfillment rate results, we also need to consider the distance travelled by the equipment in the system as the other key performance indicator. This is because the travelling mileage caused by equipment transshipment is directly related to transportation costs. In fact, only Strategy 1 – the inventories are stored separately in each region and only serve the local clients – will not generate any equipment transshipment activity.

Strategy	Number of Transshipment Equipment	Total Travelling Mileage
2.1	8	177
2.2	8	239
2.3	8	156
3	1,692	53,395
4	1,693	53,449
5	2,156	50,457

Table 5.9: Comparision of the travelling mileage at 12% of the demand level

The three derivatives of Strategy 2 appear more cost-effective in terms of travelling mileage, as shown in Table 5.9. Under these strategies, equipment is still stored at the local service points, and the capacity of the local inventory at the five service points can cover most of the requests at this demand level. Therefore, most requests can be satisfied locally without generating equipment transshipment. Only a few exceptions occurred that need to be covered by shared equipment with transshipment between two regions.

Unlike Strategy 2, under Strategies 3, 4 and 5, the equipment has to be transported from the regional warehouse to the local service points even for local requests when pooling inventory in one site. Therefore, we observed significant total travelling mileages under these strategies.

Compared with Strategies 3 and 4, the total travelling mileage under Strategy 5 is lower even though the number of transshipped equipment was bigger. This is because region 5 is geographically located in the center of the five regions, and its distances from the other four regions are similar. Therefore, when equipment is stored in zone 5, each piece of equipment does not travel very far to transport to other zones.

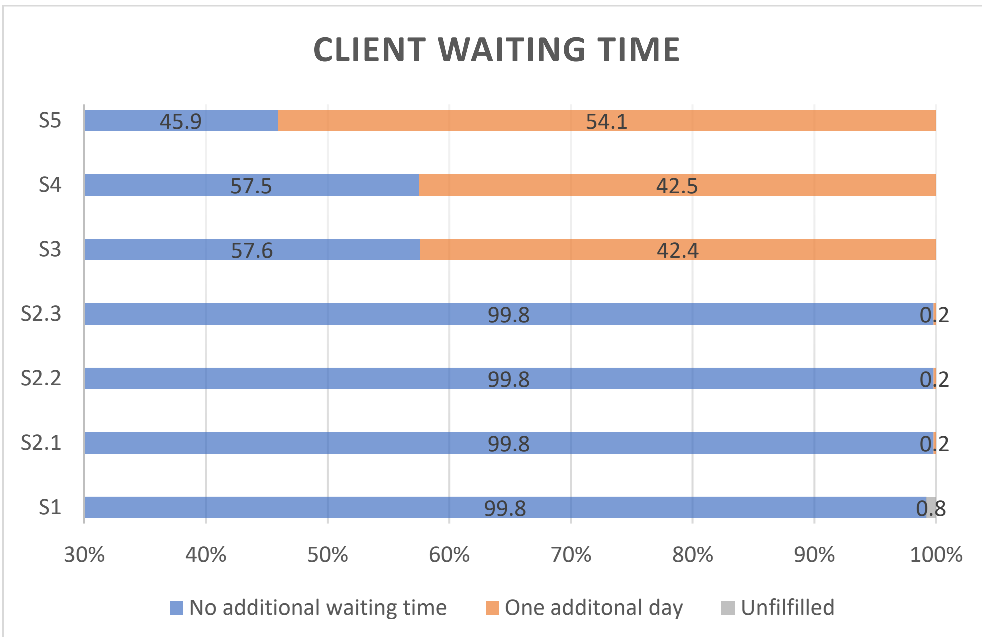

Chart 5.2: Percentage of additional waiting time under the five strategies at 12% of the demand level

The decision about where to store the equipment inventory also affects the waiting times for clients, which is how long it takes to receive the equipment they need after their requests are accepted. As shown in Chart 5.2, most patients could receive the equipment as soon as possible after their requests were accepted when the equipment was stored at each service point separately. However, as inventory becomes more centralized, more patients are waiting one more day to get the equipment they need due to equipment transshipments. More than half of the patients had to wait one additional day until they received the equipment when inventory was totally centralized under Strategy 5. This is because only the requests from region 5 were not affected by the transportation delays when all pieces of equipment were stored in region 5.

5.2.2 At 14% of the demand level

In this section, we will do the same analysis but assume 14% of the demand level. The fulfillment performance under the five strategies at 14% of the demand level is shown in Table 5.10. By comparing the half-width, all resource-sharing strategies showed a statistical difference in terms of unfilled orders compared with Strategy 1 – the baseline model.

Strategy	Fulfilled Local Orders (Half-Width)	Fulfilled Shared Orders (Half-Width)	Unfulfilled Orders (Half-Width)
1	4,461 (3.9)	-	213 (5.1)
2.1	4,256 (5.8)	255 (5.4)	167 (5.2)
2.2	3,971 (12.2)	548 (12.4)	159 (5.9)
2.3	3,842 (12.5)	677 (13.0)	155 (5.6)
3	4,244 (6.4)	256 (6.3)	177 (6.2)
4	4,241 (6.5)	257 (6.2)	177 (6.1)
5	4,495 (3.5)	-	189 (5.8)

Table 5.10: Fulfillment performance under the five strategies at 14% of the demand level

More precisely, the performances among the three derivatives of Strategy 2 did not show statistically different. The same observations can be found between strategies 3 and 4. As we explained in the previous section, the three derivatives of Strategy 2 are based on the same network layout, and the only difference between strategies 3 and 4 is where shared equipment is maintained. The similarity in resource-sharing strategies may ultimately lead to their statistical similarity in terms of unfulfilled orders. However, while the end result measured by unfulfilled orders is similar for some strategies, the way of implementation under each strategy may vary. Therefore, we will continue to analyze the performance of each strategy respectively. The average results at this demand level are still the priority that we will focus on; however, we also need to keep the observations about the statistical difference in mind.

1. Under Strategy 1: The baseline model – Decentralized without resource-sharing

Region	L1	L2	L3	L4	L5	Avg.
Local / Total Fulfillment %	92.8	95.1	94.0	95.7	96.4	94.8

Table 5.11: Results under Strategy 1 at 14% of the demand level

Generally, unfulfilled requests occurred in every region. We can see that the difference in fulfillment between the highest (region 5) and lowest performance region (region 1) is 3.6%, as shown in Table 5.11. The differences in fulfillment may be caused by the randomness of each request's arrival time, even though the equipment inventory in all regions is allocated based on 10% of local demand.

2. Under Strategy 2: Decentralized with resource-sharing policies applied

2.1 – Maximum number of available equipment

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	87.2	89.7	89.2	90.4	92.9	89.9
Total fulfillment %	96.3	96.9	95.3	96.8	96.5	96.4

Table 5.12: Results under strategy 2.1 at 14% of the demand level

As shown in Table 5.12, the total fulfillment rate increased in every region at the cost of a lower local fulfillment rate compared with our baseline model. This change is unlike what we observed at the 12% demand level. At the 12% demand level, the local supply rate is basically unaffected at the same time when the total supply rate is increased. This change is likely caused by more frequent lending and borrowing activities across regions due to the increase in demand and the uncertainty of the order arrival time.

2.2 - The smallest ratio of busy equipment

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	75.6	79.4	77.4	83.8	90.9	81.5
Total fulfillment %	96.7	96.6	96.7	96.6	96.6	96.6

Table 5.13: Results under strategy 2.2 at 14% of the demand level

As shown in Table 5.13, the total fulfillment rates turned out to be more even among regions when the rule of sharing equipment was based on the ratio of available equipment to total equipment instead of the absolute quantity of available equipment. Compared with the results under strategy 2.1, more lending and borrowing transactions happened across regions. The declined local fulfillment but increased total fulfillment rates indicated this change. Furthermore, local fulfillment is more variable across regions under this rule than the first rule. The gap between the highest (region 5) and lowest performance region (region 1) widens to 15.3%.

2.3 - The closest neighbour

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	78.3	78.5	71.9	85.7	85.4	80.0
Total fulfillment %	96.7	96.8	96.8	96.8	96.7	96.8

Table 5.14: Results generated by percentage under Strategy 2.3 at 14% of the demand level

Under the third rule, the results shown in Table 5.14 appeared to have a similar trend as the second, except for the significant drop in local fulfillment rates in regions 3 and 5. In addition, the total fulfillment rate in region 5 is slightly below the average. The reason is that region 5 is the closest neighbour of regions 1, 2, and 3, and region 3 is the closest neighbour to regions 4 and 5. Therefore, region 5 was the first responder for equipment-sharing requests from most regions and region 3 responded to the most equipment-sharing requests from regions 4 and 5. Table 5.15 summarizes the equipment-sharing across regions and the interaction between regions 3 and 5. The table shows that more than half of the shared equipment from region 3 went to region 5. In addition, region 5 lent the most equipment to other regions, and most units of the equipment from region 5 were lent to regions 1, 2 and 3.

Lender	Lend to				
	L1	L2	L3	L4	L5
L1	-	9	4	7	49
L2	12	-	6	9	76
L3	4	9	-	36	81
L4	11	14	31	-	39
L5	78	69	93	40	-

Table 5.15: Equipment sharing under strategy 2.3 at 14% of the demand level

3. Under Strategy 3: Equipment is centralized in two zones, and the lender is responsible for the inspection and cleaning of the shared equipment

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	90.9	90.6	90.7	90.8	90.7	90.7
Total fulfillment %	96.3	96.0	96.1	96.2	96.3	96.2

Table 5.16: Results under Strategy 3 at 14% of the demand level

As shown in Table 5.16, the local fulfillment rate picked up when centralizing equipment compared with Strategy 2, but it was still lower than our baseline model. This result shows the trade-off between local fulfillment and total fulfillment by centralizing equipment when demand increases. By equipment pooling and sharing, the total fulfillment in all regions reached a similar level of around 96.2%. Especially in zone 1, the total fulfillment performance improved in each region even though the local fulfillment rate was jeopardized compared with the baseline model under Strategy 1.

4. Under Strategy 4: Equipment is centralized in two zones, and the borrower is responsible for the inspection and cleaning of the shared equipment

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	90.7	90.8	90.7	90.9	90.6	90.7
Total fulfillment %	96.1	96.2	96.1	96.3	96.2	96.2

Table 5.17: Results generated by percentage under Strategy 4 at 14% of the demand level

The difference in fulfillment performance between Strategies 3 and 4 is not significant, as shown in Table 5.17. Because of the borrowing activity between the two zones, we can find a slight difference in the utilization rate of inspectors and washers under the two strategies, as shown in Charts 5.3 and 5.4:

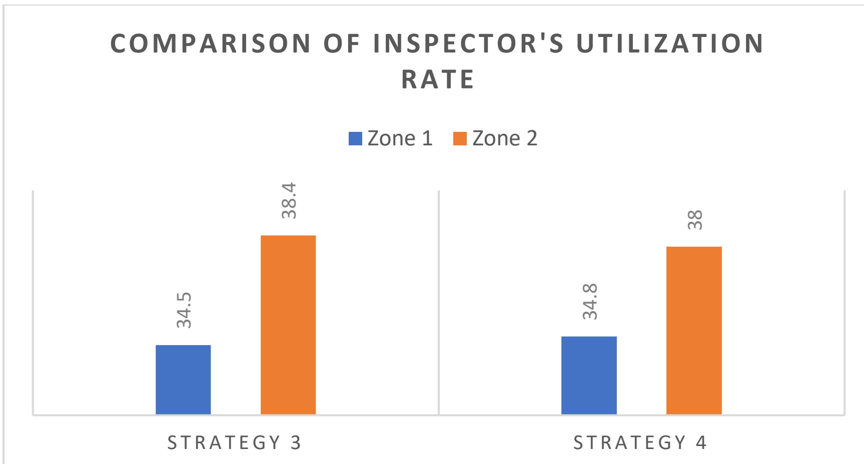

Chart 5.3: Comparison of inspector’s utilization rate at 14% of the demand level

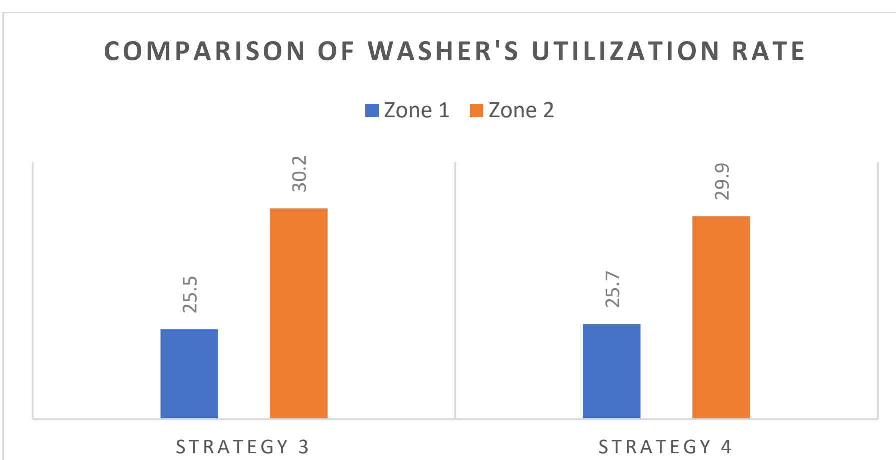

Chart 5.4: Comparison of washer’s utilization rate at 14% of the demand level

As the shared equipment moved from the lender to the borrower for inspection and cleaning, the utilization rates of inspectors and washers in zone 2 decreased slightly, and accordingly, the utilization rates in zone 1 increased. This is because more equipment will be inspected and cleaned at the facility in the borrower's zone. Overall, there is no significant impact on overall efficiency wherever the equipment inspection process is performed due to sufficient redundancy of inspectors and washers in both zones. Therefore, it will be more based on fair considerations, such as "who uses, who maintains", if Strategy 4 is chosen. Otherwise, it will be based on cost considerations to choose Strategy 3 because choosing Strategy 4 will result in more transportation costs between the two regional warehouses.

5. Under Strategy 5: Centralized

Region	L1	L2	L3	L4	L5	Avg.
Local/total fulfillment %	96.0	95.9	95.9	96.0	96.0	96.0

Table 5.18: Results under Strategy 5 at 14% of the demand level

As shown in Table 5.18, with resources continuing to be centralized, Strategy 5 did not improve overall fulfillment performance compared with strategies 3 and 4. However, the performance was still better than the baseline model. This result indicates that although the resource pooling strategy can play a role in smoothing the randomness of demand in various regions, fulfillment does not necessarily continue to improve while resources continue to be centralized.

Chart 5.5 shows the comparison of fulfillment rates under all strategies at this high demand level:

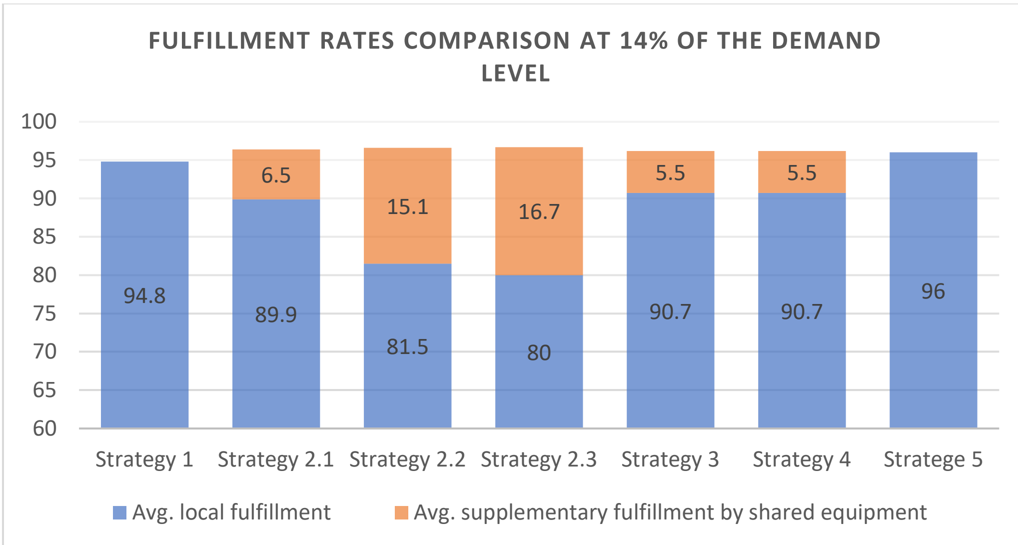

Chart 5.5: Comparison by ratios at 14% of the demand level

As demand increases to 14% of the potential annual demand level, pooling equipment can still improve the overall fulfillment rate. The average total fulfillment rates are 96.4%, 96.6%, 96.7%, 96.2%, 96.2% and 96.0%, under Strategies 2 to 5, respectively. However, the increase in demand level had pushed equipment usage to almost the limit under each strategy. In this situation, maintaining a certain level of self-sufficiency while lending equipment to others is difficult because the equipment is always busy, and fewer units could be available.

We can find that the performance of local fulfillment was harmed most under Strategies 2.2 and 2.3. The performance of local fulfillment was gradually improved with increased equipment centralization, as shown under Strategies 3, 4 and 5. However, Strategies 2.2 and 2.3 showed better results in total fulfillment rates. Therefore, it is a trade-off to consider: whether it is necessary to sacrifice local self-sufficiency levels to improve overall performance.

Once again, the shared equipment travelling mileage as another factor also needs to be considered.

Strategy	Number of Transshipment Equipment	Total Travelling Mileage
2.1	255	7,726
2.2	548	18,113
2.3	677	15,919
3	2,034	61,062
4	2,034	61,023
5	2,400	56,051

Table 5.19: Comparision of the travelling mileage at 14% of the demand level

As shown in Table 5.19, the three derivatives of Strategy 2 still show the shortest total travelling mileage. In addition, under rule 2.1, the local fulfillment performance was least jeopardized; thus, the shared equipment transhipments were less frequent, and the total travelling mileage was the shortest compared with the other two rules.

Considering the above factors, Strategy 2 shows the most flexibility and capability to increase the overall fulfillment rate with shorter shared equipment travelling mileage, even though the situation and interaction across all regions became more complex at 14% of the demand level.

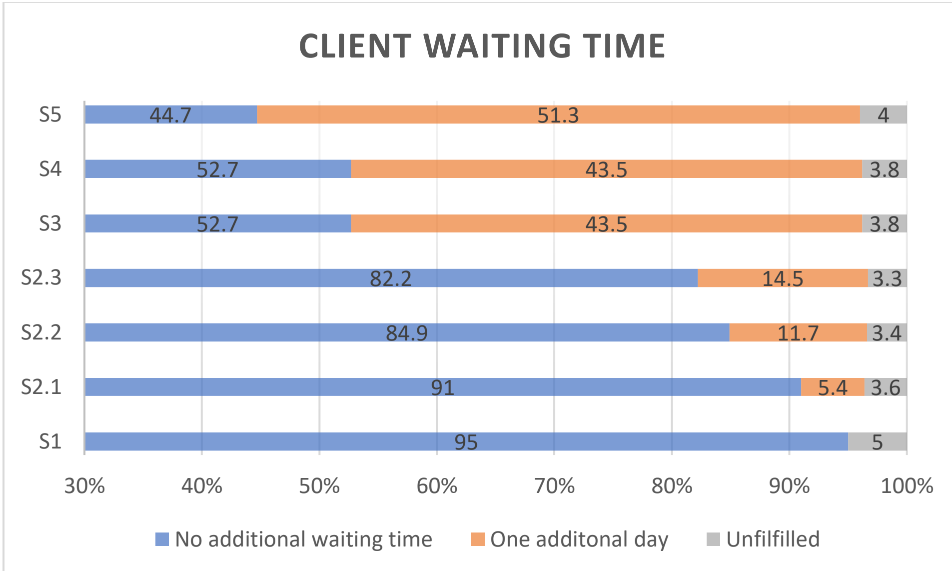

Chart 5.6: Percentage of additional waiting time under the five strategies at 14% of the demand level

As shown in Chart 5.6, at 14% of the demand level, the number of patients who have to wait longer to receive the equipment increased significantly under the three derivatives of Strategy 2 compared with 12% of the demand level. However, this kind of significant change did not show under other strategies. In particular, this change is more significant to be observed under the second and third rules than Strategy 2.1, which shares the same network structure with Strategies 2.2 and 2.3. This is because, under Strategy 2.1, Each region is more inclined to prioritize limited equipment resources to meet local needs. This difference indicates that even if the network structure is the same and other conditions, including the total amount of resources, remain the same, implementing different rules may lead to significantly different results.

5.2.3 At 15% of the demand level

The purpose of continuing the test at the 15% demand level is to evaluate whether the sharing and pooling strategies can improve the system's performance to some extent in the case of extremely high demand but limited resources.

Strategy	Fulfilled Local Orders (Half-Width)	Fulfilled Shared Orders (Half-Width)	Unfulfilled Orders (Half-Width)
1	4,545 (3.4)	-	427 (6.0)
2.1	4,149 (5.9)	437 (5.0)	398 (6.6)
2.2	3,683 (9.9)	901 (9.6)	397 (6.8)
2.3	3,570 (10.9)	1,014 (10.8)	395 (7.0)
3	4,119 (7.0)	444 (5.8)	417 (7.0)
4	4,116 (6.6)	445 (5.5)	423 (7.1)
5	4,560 (3.3)	-	426 (6.8)

Table 5.20: Fulfillment performance under the five strategies at 15% of the demand level

The fulfillment performances under each strategy at 15% of the demand level are shown in Table 5.20. The three derivatives of Strategy 2 still showed statistical differences compared with our baseline model in terms of unfulfilled orders, but within these three derivatives, there is no statistical difference. However, we observed the overlaps in confidence intervals in terms of unfulfilled orders under Strategies 1, 3, 4 and 5. That means the performances under the three physical resource-pooling strategies measured by unfulfilled orders did not show significant improvement compared with the baseline model. Due to higher demand, more frequent equipment transshipment between the regional warehouse and local service point caused more equipment in transit, which caused more transportation delays – we can also observe this change in Table 5.21 and Chart 5.8. This may diminish the advantage of equipment centralization. We will analyze the impact of transportation delays in the following section.

As shown in Chart 5.7, the harm to local fulfillment performance appears to worsen at 15% demand levels. The margin of benefit that the network gains from resource sharing and pooling is also shrinking compared with the change in the average total fulfillment rate at 14% of the annual demand level: the difference between the highest performance strategy and the baseline model at this level is 1.5%, while at 14% level, the difference is 2%. The three derivatives of

Strategies 2 still showed better total fulfillment performance than the baseline model and under other strategies. Testing at this level shows that inventory pooling and resource sharing can still improve overall fulfillment performance to a certain extent when redundancy capacity is extremely limited at every site. In addition, we still need to keep the statistical differences in mind when we obtain the information from the above analysis.

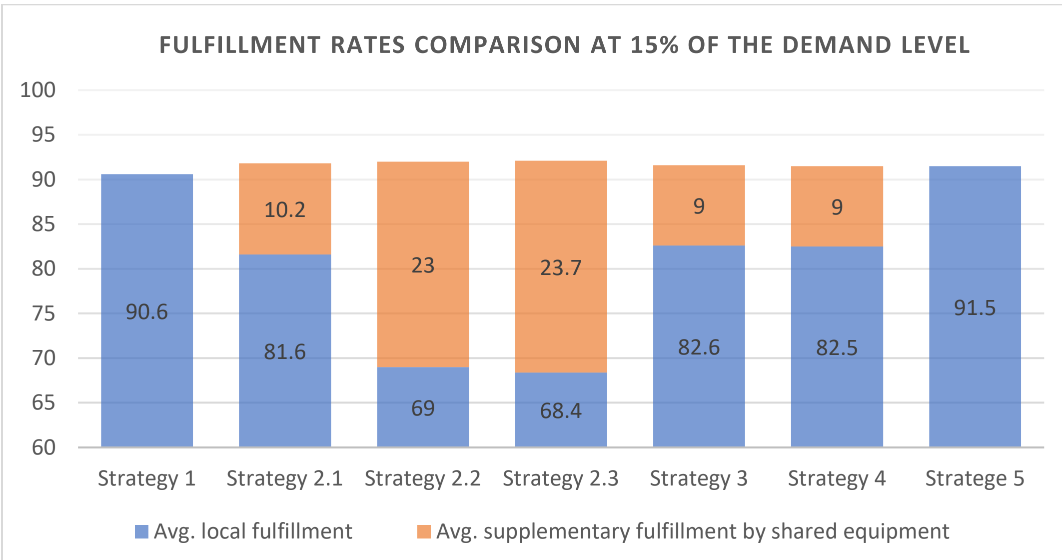

Chart 5.7: Comparison by ratios at 15% of the demand level

Strategy	Number of Transshipment Equipment	Total Travelling Mileage
2.1	434	12,890
2.2	901	29,108
2.3	1.014	25,076
3	2,196	62,973
4	2,194	62,867
5	2,465	57,590

Table 5.21: Comparision of the travelling mileage at 15% of the demand level

Summarizing the information in Chart 5.7 and Table 5.21, the three derivatives of Strategy 2 still show the advantages at 15% of the demand level both in higher fulfillment rate and less equipment transaction mileage.

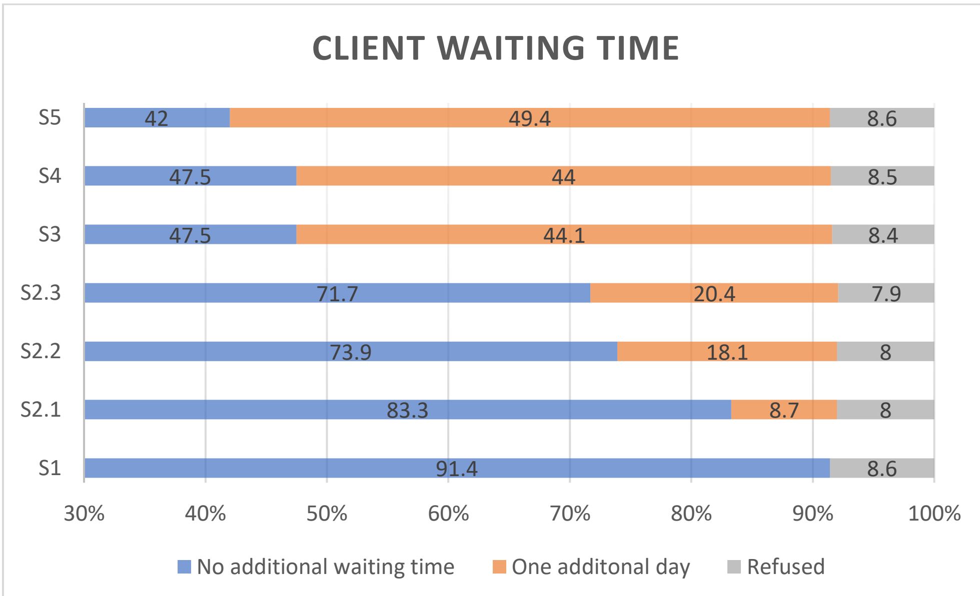

Chart 5.8: Percentage of additional waiting time under the five strategies at 15% of the demand level

As shown in Chart 5.8, the number of patients waiting longer for the equipment increased under every strategy compared with the results at 14% of the demand level. However, Strategy 2.1 still provides the possibility to serve patients faster than other strategies at this demand level.

5.3 The impact of transportation time on the fulfillment rate

The cost of distance and time for equipment transshipments is unavoidable when physically pooling and centralizing the health equipment inventory. We need to find a method to identify the impact caused by longer travelling mileage in a centralized network and measure how much this impact affects the fulfillment rate in each region.

Thus, we made the following assumptions to diminish the travelling mileage of equipment transshipments between the regional warehouses and service points:

1. All clients need to pick up their booked equipment from the regional warehouse in their zone or the other zone's warehouse if the equipment is shared.

2. Clients return the equipment to the original site after finishing their rehabilitation treatments.

3. All clients can pick up their booked equipment on the same day once they receive the notice and return the equipment immediately after finishing their treatments.

These assumptions will diminish the time delay in the equipment transshipment between warehouses and service points without further changes in the network structures. Considering the Euclidean distance between the warehouses and any service point is no more than 53.85 km (even if the actual route will be slightly longer), the same-day round trip to pick up or return the equipment is reachable for clients. This adjustment will accelerate at least two days per service cycle by removing the transportation time.

While this change in the service process is achievable, it will impact the customer experience. Therefore, the purpose of this change is limited to assessing the impact of the additional waiting time caused by equipment transshipment on fulfillment performance compared with the original process.

We applied this change to three derivatives of Strategy 2 and Strategies 3, 4 and 5 at the 15 % demand level. Table 5.22 shows the fulfillment performances by diminishing equipment transshipments under each strategy at 15% of the demand level. Unlike before the adjustment, the performances in terms of unfulfilled orders under Strategies 3, 4 and 5 showed significant statistical differences compared with the baseline model, and by diminishing equipment transshipment, their performances were closer to the three derivatives of Strategy 2 – no statistical difference among these strategies. Chart 5.9 provides an intuitive comparison of these changes in terms of total fulfillment.

Strategy	Fulfilled Local Orders (Half-Width)	Fulfilled Shared Orders (Half-Width)	Unfulfilled Orders (Half-Width)
1	4,545 (3.4)	-	427 (6.0)
2.1	4,159 (5.8)	429 (4.9)	388 (6.6)
2.2	3,710 (10.3)	888 (10.1)	380 (6.8)
2.3	3,591 (10.9)	1,007 (10.7)	382 (7.0)
3	4,180 (7.0)	421 (6.0)	381 (6.5)
4	4,172 (6.6)	426 (5.6)	387 (6.6)
5	4,601 (3.5)	-	388 (6.6)

Table 5.22: Fulfillment performance without transportation delay at 15% of the demand level

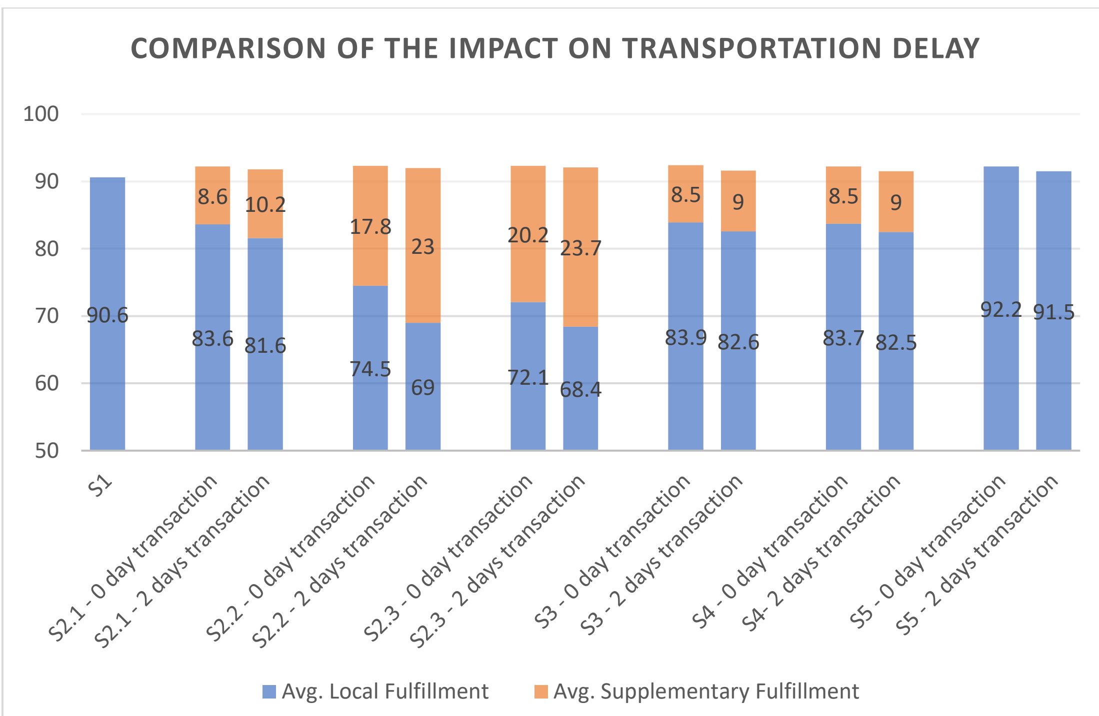

Chart 5.9: Impact of transaction delay on fulfillment performance at 15% of the demand level

As shown in Chart 5.9, comparing the initial scenarios, we observed that the modified approach without transportation delay performed better in terms of local and overall fulfillment performance under each strategy. This kind of improvement can be more significantly observed under Strategies 3, 4 and 5. Referring to the information in Chart 5.8, this difference in impact is better explained: this adjustment could affect up to 49.4% of the requests in the physical resource pooling (centralized) networks, while only at most of 20.4% of the requests were affected in the virtual resource pooling (or decentralized with sharing policy applied) network structures. Therefore, the impact of transportation time is more pronounced in the case of physical resource pooling. We can notice that Strategies 3 showed better performance of total fulfillment rate. Furthermore, the fulfillment increased most under the three physical resource pooling strategies: Strategies 3, 4 and 5, as shown in Table 5.23. In contrast, the fulfillment performances under the three derivatives of Strategy 2 only show slight increases. This difference indicates the impact of transportation times on the implementation of physical inventory pooling strategies since those pieces of equipment in transit are also counted as busy equipment. Furthermore, although strategy 4 is the same as strategy 3 in the deployment of network layout, the additional transportation of shared equipment between patients' places and the borrower's regional warehouse due to implementing different sharing rules resulted in a lower fulfillment rate.

Strategy	Avg. Total Fulfillment Rate % (Without Transshipment)	Avg. Total Fulfillment Rate % (With Transshipment)
S2.1	92.2	91.8
S2.2	92.3	92.0
S2.3	92.3	92.1
S3	92.4	91.6
S4	92.2	91.5
S5	92.2	91.5

Table 5.23: Comparison between the average total fulfillment rates without transportation delay with the original scenario at 15% of the demand level

5.4 The effect of improving maintenance efficiency on overall performance

The other part of the entire flow that the service provider can adjust is the inspection and cleaning process. As we mentioned before, the processing time to clean one piece of equipment can be reduced from 1.5 hours to less than 10 minutes by adopting a wheelchair washer. Furthermore, each wheelchair washer can process 2 to 4 wheelchairs or other types of equipment of similar size, and almost all types of health equipment can be cleaned and disinfected by a wheelchair washer. A wheelchair washer can significantly lighten the labour intensity and improve maintenance efficiency. However, the extent to which the overall performance is affected by adopting this expensive wheelchair washer is more important to measure, especially when limited resources face a high demand level.

Considering the high price of acquiring a wheelchair washer, we only applied this change under Strategy 5 at 15 % of the demand level and kept other processes of the entire flow unchanged.

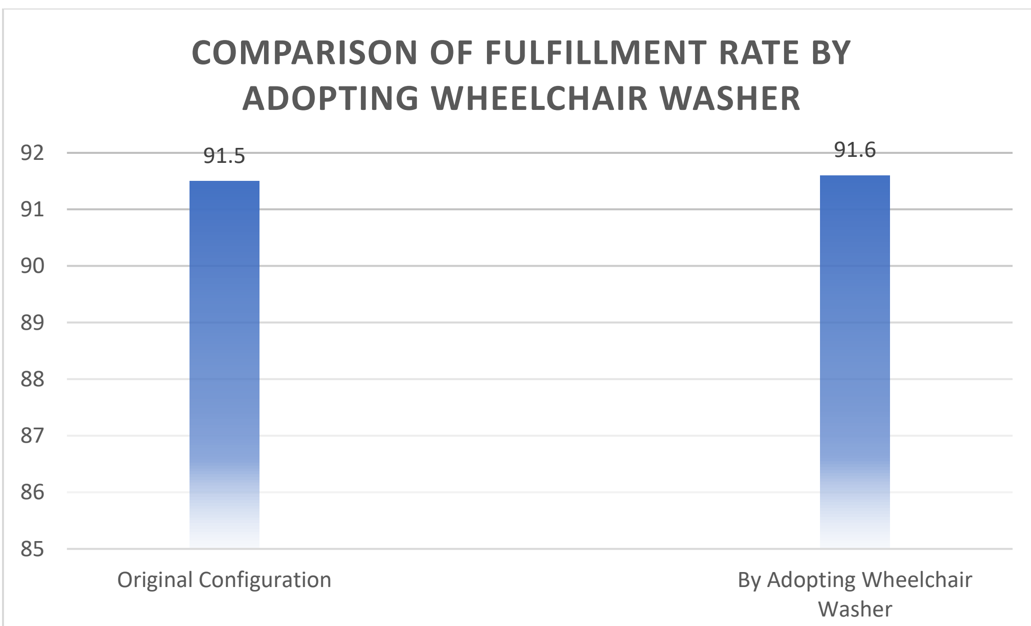

Chart 5.10: Comparison of fulfillment rate by adapting Wheelchair washer under strategy 5 at 15% of the demand level

The fulfillment rate did not show a notable improvement by adapting the wheelchair washer, as shown in Chart 5.10. We can find that the wheelchair washer was on standby most of the time – the utilization rate of the wheelchair washer was only around 6.8% during the entire simulation period. Therefore, adopting the wheelchair washer might not be economical in terms of cost.

5.5 Summary of the observation

Generally, resource-sharing and pooling strategies that we tested can achieve better performance measured by fulfillment rate compared with the initial network configuration at all the demand levels we tested. However, several trade-offs need to be considered:

1. Decentralized inventory combined with appropriate resource-sharing policies achieved better overall fulfillment performance in most scenarios compared with physical resource pooling strategies. However, the price is that the performance of local fulfillment is inevitably compromised, and this damage is progressively worsened as demand increases but total resources have not increased.

2. Physically pooling inventory in fewer locations usually generates more even fulfillment performance across regions that benefit from unified inventory management. On the other hand, centralized inventory also leads to more frequent equipment transshipments and longer transportation miles between warehouses and demand points. Frequent equipment transshipments reduce fulfillment efficiency and increase transportation costs.

3. More patients will wait longer until they receive their equipment, as resources are pooled in a few locations. Decentralized inventory combined with appropriate resource-sharing rules always performed better than centralized inventory if measured by the waiting time between the client request being received and the client receiving the equipment.

4. Based on the above two points, storing resources locally and allowing resource-sharing across regions might be the better strategy to systematically improve fulfillment performance and benefit from a shorter total transportation distance. In addition, this strategy can provide more

flexibility to match any two locations when seeking shared resources by choosing different resource-sharing rules with the same network layout.

5. When resources had been highly utilized, improving a certain step's efficiency only had a limited effect on the overall performance of the whole process. In this case, we improved the efficiency of the inspection and maintenance process by introducing advanced equipment. However, the overall performance of the system had not improved significantly.

6. Even in the same network structure, implementing different resource-sharing rules may generate significantly different results. Therefore, clarifying the primary goal of providing this service might be necessary. For example, for the service provider, which goal is more important: getting the most patients to receive the equipment they need faster or serving as many clients as possible with limited resources?

Chapter 6. Conclusion and Study Limitations

Our study covered the entire workflow of the health equipment rental service. We focused on the internal and external uncertainties from the service provider's perspectives. In addition to paying attention to the impact of different network configuration strategies on service levels, we also focused on the differences in performance due to implementing different resource-sharing rules under the same network layout. Furthermore, the impact of transportation time due to geographic distance on service levels under different strategies is another focus of our study.

However, some elements may limit the precision of our findings. First, the potential demands in each region were assumptions based on limited data and information. Since the demand in each region is not in a simple proportional relationship with the region's population, it may also be affected by other factors such as the population's average age, local medical conditions, etc. Therefore, it will be helpful to cover more abundant data in future research.

Second, we regarded all types of health equipment as a family to facilitate modelling. However, in reality, the types of donated equipment received by service providers are often not complete. Therefore, in fact, patients are more likely not to get the correct type of equipment they really need, thereby causing increased unmet needs.

Third, in our models, all requests were on a first-come, first-served basis. This assumption helps generate a relatively stationary demand pattern. In practice, however, some physicians may prefer to book rehabilitation equipment for their patients in advance, while others may not book the equipment until their patient is close to discharge. Therefore, an order that arrives first does not necessarily mean more urgent. In follow-up research, it may be possible to focus on exploring a reasonable order processing mechanism and cover more demand patterns.

Forth, the results and conclusions obtained in our study are based on the particular case. For example, the specific geographical location of the selected regions, the relative distance between the regions, and the population of each location could affect the final conclusion. On the other hand, our model is universally applicable to be adapted to other case studies by only changing specific parameters.

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Appendix

1. Weighted utilization rate- the simple rate*(total fulfilled orders/total orders)

Strategy	S1	S2.1	S2.2	S2.3	S3	S4	S5
Utilization %	75.6	75.6	75.6	75.6	75.5	75.5	75.6

Table A.1: Weighted utilization rate of health equipment at 12% of the demand level

Strategy	S1	S2.1	S2.2	S2.3	S3	S4	S5
Utilization %	80.0	82.3	82.9	83.0	82.7	82.7	82.7

Table A.2: Weighted utilization rate of health equipment at 14% of the demand level

Strategy	S1	S2.1	S2.2	S2.3	S3	S4	S5
Utilization %	78.9	80.6	80.8	80.8	80.6	80.6	80.4

Table A.3: Weighted utilization rate of health equipment at 15% of the demand level

2. Fulfillment performance in each region under the five strategies at 15% of the demand level

Strategy 1:

Region	L1	L2	L3	L4	L5	Avg.
Local / Total Fulfillment %	91.0	89.2	90.2	89.5	93.2	90.6

Table A.4: Fulfillment performance under Strategy 1 at 15% of the demand level

Strategy 2.1:

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	79.5	80.2	80.5	81.2	86.7	81.6
Total fulfillment %	91.9	92.1	90.6	92.4	92.2	91.8

Table A.5: Fulfillment performance under Strategy 2.1 at 15% of the demand level

Strategy 2.2:

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	62.5	65.1	63.4	70.9	83.1	69.0
Total fulfillment %	92.0	92.0	92.0	92.1	92.0	92.0

Table A.6: Fulfillment performance under Strategy 2.2 at 15% of the demand level

Strategy 2.3:

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	66.2	65.6	59.7	73.8	76.9	68.4
Total fulfillment %	92.2	92.0	92.0	92.0	92.1	92.1

Table A.7: Fulfillment performance under Strategy 2.3 at 15% of the demand level

Strategy 3:

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	82.5	82.7	82.5	82.6	82.9	82.6
Total fulfillment %	91.6	91.7	91.6	91.7	91.6	91.6

Table A.8: Fulfillment performance under Strategy 3 at 15% of the demand level

Strategy 4:

Region	L1	L2	L3	L4	L5	Avg.
Local fulfillment %	82.6	82.5	82.4	82.5	82.7	82.5
Total fulfillment %	91.5	91.5	91.4	91.6	91.5	91.5

Table A.9: Fulfillment performance under Strategy 4 at 15% of the demand level

Strategy 5:

Region	L1	L2	L3	L4	L5	Avg.
Local /Total fulfillment %	91.4	91.5	91.4	91.4	91.5	91.5

Table A.10: Fulfillment performance under Strategy 5 at 15% of the demand level