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Modeling for Designing a Value Loop : A Wheelchair Allocation Application

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Abstract. This paper deals with the modeling of the wheelchair allocation context in the Province of Québec (Canada), managed and supervised by a public insurer, for the design of the related value loop. A value loop is a supply chain integrating reverse logistics activities, referring to recovery, processing and redistribution. The modeling aims at identifying the potential network entities (sites, products, end-users) and characterizing achievable network performances in terms of capacities, costs and service levels. It leads to the grouping of products and end-users for defining tractable design models, while reflecting network dynamics. Through the modeling, various uncertainty factors related to this dynamics are identified and characterized. Their impacts are assessed with design decisions. Several issues rose within the wheelchair context led to modifications to current modeling approaches. Notably, end-users represent both demand and return sources with distinct service levels. Product volumes, depending on their state and network conditions (demand and return volumes, network capacities and operating costs), can be directed toward one or many processing alternatives. Processing deals with product repair, disassembly for part refurbishing and disposal. Reusable products obtained from these activities are designated as valorized products. They are considered as supply alternative to new products. Repair costs depend on valorized part availability. Uncertainty factors affect such availability and thus design decisions. However, benefits of an appropriate integration of reverse logistics activities are perceived through the design decisions.

Keywords. Reverse logistics, supply chain, design and modeling, product grouping, demand zone, forecast.

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1 Introduction

It is common knowledge that the definition of mathematical model parameters requires major efforts prior to the optimization process. Parameters must be carefully defined to accurately represent the studied system, while sufficiently reducing the problem size.

Designing logistics networks involves deciding on site location (e.g.: factories, warehouses) and defining their mission, notably by specifying product types handled by sites. Decisions are made among sites and resources (human resources and equipment) presented as a potential network. They generally rest on anticipated demand and capacity constraints, while meeting an economic objective function. Prior to the resolution of such models, information on potential network capacities, cost drivers and service level targets serve to group end-users in geographical demand zones and products in families. They are used to represent distinct consolidated product flows. Bills of materials are defined to detail how products are processed. They specify the relative quantities of part families (raw materials, components and assembly modules) required in finished product assembly. Several approaches are proposed in the literature for the modeling of such supply chains (Shapiro, 2001). Although more and more mathematical programming models are proposed for designing value loops, which integrate reverse logistics to supply chains, few of them suggest guidelines for their modeling (Chouinard *et al.*, 2007). Most of these models are deterministic, whereas it is well known that reverse logistics is characterized by a high level of uncertainty.

This paper deals with the modeling of the wheelchair allocation context in the Province of Québec (Canada), managed and supervised by a public insurer, for the design of the related value loop. It takes into account the fact that end-users represent both demand and return sources and that product volumes, depending on their state and network conditions (demand and return volumes, network capacities and operating costs), can be directed toward one or many processing alternative. Processing deals with product repair, disassembly for part refurbishing and disposal. Reusable products obtained from these activities are designated as valorized products. Such reengineering is addressed to improve accessibility to products and services, taking into account valorized products, while reducing operating costs.

The paper is organised as follow. First, details about the studied case are given. The considered modeling framework is then presented and illustrated with modeling approaches adapted to the case. Random factors are identified and characterized through the process. Their impacts are evaluated according to the design decisions. Finally, conclusion and future research directions are presented.

2 Studied case

2.1 Network

The RAMQ is a government agency which manages several health programs in the Province of Quebec, such as the mobility aids program that includes wheelchairs. It currently mandates thirteen rehabilitation centres notably for wheelchair (finished products) allocation and maintenance. Since June 2000, the RAMQ requires that these centres recover unused finished products from end-users. Recovered finished products can be repaired for reallocation, and disassembled for part refurbishing. Reusable processed products (finished products and parts) are designated as valorised products. Recovered products that are not valorised are disposed. More than one processing alternative may be considered according to product states, site capacities, network operating costs and needs for valorised products.

2.2 Products

Finished products are identified under three wheelchair categories: manual wheelchairs (MAW), motorized wheelchairs (MOW) and positioning bases (PB). About sixty finished product models are currently in circulation. New models are regularly introduced on the market, at a three-year interval, following the RAMQ homologation and invitation to tender process. Finished products are personalized to suit the end-user's condition by adding specialized equipment and choosing adapted parts from each related categories, such as leg rests, arm rests, etc. Finished products are made up of more than forty different part categories. For significant part categories, up to five different part versions are proposed. Manufacturers have their own technologies. Usually, parts of a specific finished product are not compatible with others, even for a same manufacturer.

2.3 End-users

Finished products are used free of charge by admissible end-users, according to the RAMQ criteria. Final decisions regarding the finished product selection are made by end-users, according to suggestions from occupational therapists. Replacements can occur when end-user or product condition has sufficiently deteriorated, again, according to RAMQ criteria.

Depending on product availability, both new and valorised products may be used to fulfil demand. Valorised products meet lower quality standards compared to new. Some end-users are admissible to valorised finished products only, according to RAMQ criteria. Others have the alternative of valorised ones to take advantage of a shorter delivery delay (Vincent *et al.*, 2003). Valorised parts can also be used to reduce repair costs.

Recovery usually occurs following product replacement or end-user death, which may require collection by rehabilitation centres by means of a private vehicle fleet or with recourse to logistics service providers.

End-users generally go to neighbouring rehabilitation centres, in order to quickly access services. The Province of Quebec is divided into 18 socio-sanitary areas. Demographic statistics are made public for these areas and are detailed for smaller territory divisions, called districts or "*centres locaux de services communautaires*" (CLSC). There are more than 160 districts. Relevant health statistics about districts are provided by the Ministry of Health and Social Services of Quebec (MSSSQ, 2005).

2.4 Current local operating context

The thirteen rehabilitation centres currently operate on an autonomous basis. Centres are self-financed from RAMQ lump sums. A recent study conducted by the RAMQ shows that valorisation can improve finished product availability to end-users while reducing expenditures (Côté *et al.*, 2003). For the period from June 15, 2000 to March 31, 2002, the RAMQ saved about 3.8 million dollars from a total budget of 54.3 million dollars using valorised products. However, since recovery, processing and redistribution are carried out by the centres that allocate the wheelchairs, reallocation possibilities are decreased.

2.5 Logistics network redesign

A logistics network design process is undertaken to locate sites used for collection, processing and storage, and to define their mission. These location-allocation decisions are simultaneously dealt with defining the strategic proportions of product flows to direct toward processing alternatives (**Figure 1**): finished product repair, disassembling for part refurbishing or disposal. The resulting repaired finished products and refurbished parts, designated as valorised products, are stored to partly or completely fulfil the anticipated network demand. New products are delivered on demand by established suppliers. A mathematical programming model is available to deal with such decisions (Chouinard *et al.*, 2008; 2007). It aims at maintaining or increasing service levels and reducing operating costs with greater availability for valorised products.

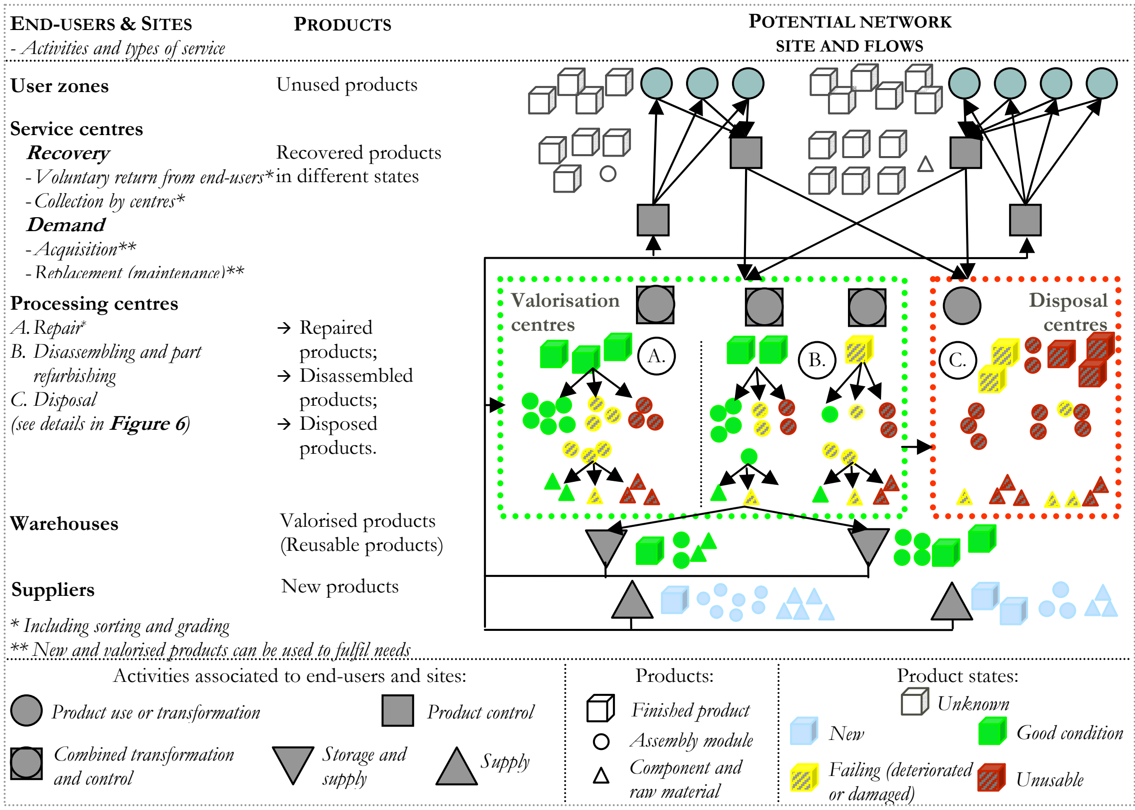

Figure 1: Potential network sites and flows.

3 Methodological framework

The work presented in this paper is part of a methodological framework for designing value loops. **Figure 2** summarizes this from model parameter definition to the model solution and validation. Emphasize is put on the definition of the model parameters. **Table 1** presents the main characteristics of this step.

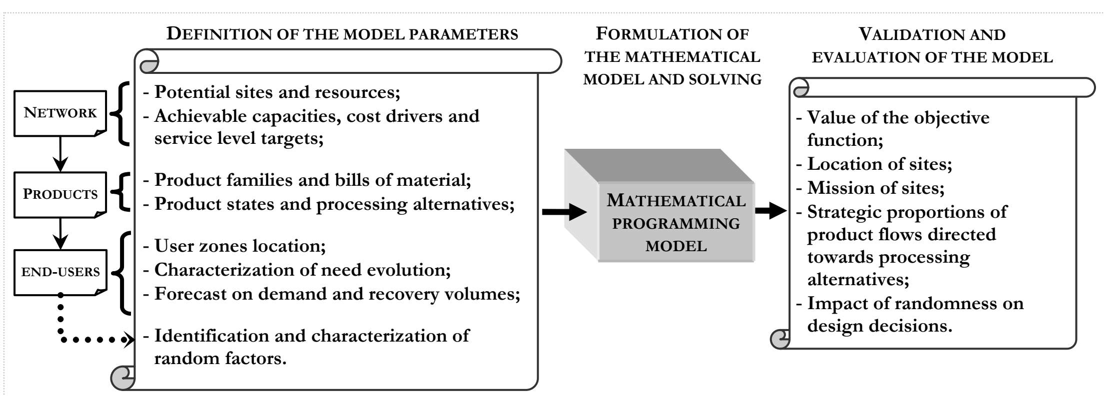

Figure 2: Methodology for designing value loops.

Modeling approaches are proposed in the literature, mainly concerning supply chains. However, different issues are raised in modeling key parameters for design value loops (**Table 1**). Some approaches from the literature and difficulties they could lead to, according to the considered value loops, are identified in the following sections. The tackled approach is then detailed.

3.1 Network

Potential network entities and interrelations are defined in this section.

3.1.1 Potential sites and resources

The potential network is defined by considered sites and resources, such as handling resources and transport modes, to support operations. Current approaches proposed for the identification of potential sites and resources (Punniyamoorthy and Ragavan, 2003; Brown and Gibson, 1972) can be used in a value loop context. All possible options are evaluated and compared, under established criteria (raw material and labour availability, proximity of end-users, etc.), to retain the ones that can best serve the organisation. Such approaches have now to take into account the site capability to support reverse logistics activities.

The current role of rehabilitation centres as regards demand fulfilment is not put into question in this work, but some of them are considered as potential sites for collection with use of private vehicle fleet or logistics service providers. All these centres refer in the text to service centres, but are differentiated according to the types of services they can provide: 1) Demand: 1a) Acquisition; 1b) Replacement. 2) Return: 2a) Voluntary return from end-users (including replacement); 2b) Collection by centres.

Some current rehabilitation centres have modified their operations to increase their valorisation (repair and disassembling) and storage capacities, and some adjustments may still be made to a certain level according to current resources. Most of these centres are located in high density population areas. These centres are considered as potential valorisation centres and warehouses. Specific third parties are considered for disposal.

Table 1: Issues in modeling value loops.

	Parameters	Characteristics	Interest	Issues raised in designing value loop
Network	Potential sites and resources	- Recovery and processing centres, and warehouses in addition to current supply chain sites; - Resources used through the network (handling and transportation systems, etc.).	- Identify the potential network entities.	- Reverse logistics network can be dedicated or integrated to a current supply chain; - Reverse logistics activities can be partly or completely outsourced; - Reverse network can be centralized or decentralized; - Reverse logistics processes can be operated in one site or distributed between many sites.
Network	Achievable capacities, costs drivers and service level targets	- Costs (acquisition, transportation, handling, processing, holding); - Benefits; - Service level in terms of distance or product volumes; - Capacities and constraints.	- Define the potential network flows; - Define achievable network performance; - Define limits of flows.	- Reverse logistics and supply chain processes can share or not same resources or resources; - Activities can be realized under economy of scale and scope; - Processing costs can depend on product state and on retained processing alternative; - Quality, cost drivers and service level target for valorised products can differ from new; - Unit product value can depend on retained processing alternative and on considered supply sources to repair products (ex.: use of valorised product at lower cost instead of new); - Different holding costs can be considered for recovered, valorised and disposed products, according to opportunity costs.
Products	Product families and bill of materials	- Generic product function for organisation processes and end-users needs or requirements (demand, recovery and processing profile); - Product impacts on organisation costs and benefits; - Disassembling and (re)assembling sequence and involved part quantities.	- Represent particular product paths through a network, which could be supplied by specifics sites in response of specifics needs, from end-users and network processes.	- Products can be used to fulfil demand from end-users or processing centres, to repair products; - Products can have different economical and environmental impact on network costs and benefits throughout their lifecycle; - New and valorised products can be substituted or not to fulfil demand; - Disassembling can result in products in various states; - Technical, commercial and environmental feasibilities can occur in product recovery, processing and redistribution.
Products	Product states and processing alternatives	- Product processing alternatives (repair; refurbishing; remanufacturing; disassembling for part recovery; recycling; clean disposal); - Product proportions assigned to processing alternatives according to expected product volumes states.	- Reflect product flows to be directed toward processing alternatives.	- One or many processing alternatives can be considered for recovered products; - Different potential value recovery can result from processing alternatives (decrease of production load, revenue from selling recovered product, use of valorised product at lower cost instead of new).
End-users	User zones location	- Location of demand and return sources.	- Reflect end-users accessibility to products and services.	- User zones can represent a demand source, a return source or both of them; - User zones can be assigned to distinctive service and recovery centres; - Service levels can differ for demand and return; - Products can intervene within demand and return and require distinct service levels.
End-users	Characterization of need evolution	- Procurement conditions (sales or renting; contract terms; product type and state); - Return conditions (guarantee; unused products following users' dissatisfaction or product dysfunction; product end of lifecycle); - Processing conditions (product aesthetics, age and wear or technical quality); - Demographic statistics and product fleet characteristics.	- Characterize conditions under which product flows are initiated.	- Different end-users and product characteristics can influence product flows; - Product flows can vary according to site practices. - Product flows can vary according to evolution and dispersion of needs from end-users.
End-users	Forecasts on demand and return volumes	- Demand and return volumes on future horizon periods according to demographic and product fleet changes.	- Estimate expected end-users needs dispersion and profile as for product and services.	- End-users needs can evolve differently according to characteristics of user zones in terms of population, end-users and product fleet.
	Identification and characterization of random factors	- Randomness on return, processing and demand volumes.	- Represent possible variation on product flows.	- Product flows depend on product capacity to meet specific end-user needs as well on conditions of use and maintenance to which they are subjected.

3.1.2 Achievable capacities, cost drivers and service level targets

Site capacities, cost drivers and service level targets are defined to characterize the achievable network performance and to determine the potential links between network entities.

Achievable network performance parameters are generally defined through fixed and variable costs, which define the use of potential network sites and resources according to expected maximum service levels and capacities. They are estimated from transactional data or established through simulation, according to new organisation policies and strategies.

Estimating such parameters is of great concern in designing value loops, especially for processing and holding costs. They can depend on product states and on valorised product availability, as parts for finished product repair, which influence product unit value.

In this industry, the valorised product unit value can be estimated as low as 20% of an equivalent new one (Fleischmann *et al.*, 2003). In a customization context, unit value depends on modifications brought to products, according to end-user's needs. Choice for valorised finished products would generally be considered when few additional changes are required, thus avoiding unnecessary costs. Failed or unusable parts are replaced by new or valorised ones before or after knowing exact needs from end-users (Chouinard *et al.*, 2005). They would be replaced as early as possible in order to restore product appearance and functionality, and thus increase reallocation potential.

Annualised holding cost rates generally range from 20% to 40% of the stored product value. In the case where recovered, valorised, new and disposed products may be stored, different holding cost rates can be evaluated according to the related opportunity costs (Teunter *et al.*, 2000).

FIXED COSTS

Fixed costs for operating potential sites and resources are estimated in the studied case from data collected in current sites or given by the considered logistics service providers and third parties.

SERVICE LEVELS AND TRANSPORTATION COSTS

Service levels and transportation costs for private vehicle fleets are estimated based on average distances between sites and end-users. Distances are obtained from a commercial geographical information system, which take into account the transportation infrastructure. Other transportation costs are given by logistics service providers. End-users are assigned to the nearest service centre in a demand context, to reflect service accessibility, but are not assigned to specific service centres in a collection context, since such assignment is part of design decisions. Only the links between end-users and service centres that respect the established service levels for recovery are evaluated. Proximity of sites is also considered to define potential product flows. In particular, valorised product flows between warehouses and service centres are considered only if they ensure a shorter delivery delay compared to supply with new products.

PROCESSING COSTS

Disassembling and (re)assembling costs are currently standardized in valorisation centres for all part categories of the three wheelchair categories to encompass all product states (Zwingmann and Aït-Kadi, 2006). They are used to characterize valorisation alternatives, except for disposal for which costs are given by third parties.

The valorised product unit value used is that estimated by Diallo and Aït-Kadi (2005) and Côté *et al.* (2003). It includes sorting and grading, processing and administrative costs. It considers that failed and unusable parts are replaced on finished products before storage to restore product appearance and functionality. When only valorised parts are used, the resulting finished product unit value is estimated at about 12%, 7% and 10% of an equivalent new one, respectively, for manual, motorized wheelchairs, and positioning bases. The estimated average unit value is at about 20%, 13%, 15% respectively when both new and valorised parts are used. As for valorised parts, unit value is evaluated at about 15% of equivalent new ones. Up to 80% of these values are related to parts acquisition, disassembling and (re)assembling (Côté *et al.*, 2003). The remainder is related to additional repair (finished products) and refurbishing (parts) costs, which include cleaning and disinfecting (13%), and technical control (7%). This cost portion is applied as additional processing costs, with part acquisition, disassembling and reassembling costs, when repair or refurbishing occurs.

HOLDING COSTS

In this paper, only valorised products are stored to fulfil anticipated demand. The annualised holding cost rate is estimated to an average of 30% of valorised product unit value (Cloutier, 2004), including opportunity costs calculated from repair and refurbishing costs. It is used to evaluate holding costs in warehouses. The previously identified valorized product unit values are then used to define different operating contexts used to evaluate their impacts on design decisions.

3.2 Products

Potential network entities and interrelations are notably characterized through the product grouping, which aims at reflecting suitably network needs and resource consumption.

3.2.1 Product families

Products are grouped in families to reduce the design problem size. They are defined for a proper representation of network needs for products requiring similar resources and path into a network, and thus having comparable impacts on network performance.

Several methods are proposed to group products into families: single criterion or multi-criteria approaches. A multi-criteria approach, based on ABC classification with the use of the Analytic Hierarchy Process (AHP) (Flores *et al.*, 1992) or clustering methods (Ramanathan, 2006; Ernst and Cohen, 1990), can notably be considered. For supply chains, grouping usually rests on the following criteria (Martel, 2004): service level, seasonality, risk; production, storage and handling resources; distribution channels; means of transportation. The integration of reverse logistics to current supply chains can require other relevant criteria.

Distinct families can be defined for supply chains and reverse logistics. However, this would complicate subsequent design decisions. A same product can be involved in one or many network activities (design, production, distribution, maintenance, recovery, processing and redistribution) and can have different impacts through its lifecycle (**Figure 3**). Links between products can also occur during activities (part replacement) and product substitutability with new or valorised products can be allowed. Designing a new value loop may require the use of lifecycle analysis techniques, such as Life Cycle Cost (LCC) or the Life Cycle Assessment (LCA) (Wenzel *et al.*, 1997), to get a detailed portrait of product lifecycle impacts on organisation costs and benefits.

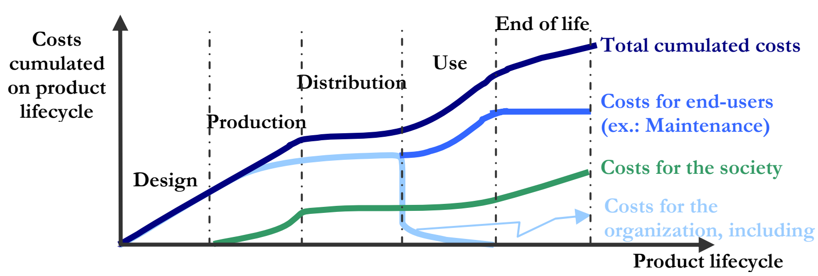

Figure 3: Cost structure through product lifecycle (Alting, 1993)

In this paper, the grouping of products into families is made according to two main characteristics:

- Needs and requirements coming from network activities and end-users:
  - -Product category or class (e.g.: electronics product, television, etc);
  - -Service level, seasonality and risk related to product management;
  - -Technical, commercial and environmental feasibilities to recover, process and redistribute products;
- Potential economic impacts on design decisions:

-Activities related to design decisions;

-Recovery and (re)distribution channel and resources used in activities (production, handling, etc.).

These two main characteristics are considered through an ABC classification. They are measured by volume (needs and requirements) and cost (potential economic impacts) percentages calculated from transactional data. They are detailed, as enumerated, for a greater representation of organisation responsibilities through the product lifecycle.

Volume and cost percentages are tackled by simultaneously and separately considering all activities that are part of design decisions (distribution, maintenance, recovery, etc), while focussing on products which have a significant impact on such decisions. Finished product families and their related part families have to be identified to take into account disassembly and (re)assembly.

Product categories are used here to refine the product grouping into families. Categories having a significant impact on design decisions (class A) suggest the possible grouping of their related products into families within each related category. Categories with less impact on design decisions (class C) can be neglected. Other categories (classes B & C) are each considered as a family or grouped with other similar or complementary categories to form a family.

For the studied case, volume and cost percentages related to finished products are measured with regard to the following activities: initial acquisition (value paid to the suppliers, transportation and handling); adjustments (product dimensioning and personalization); maintenance; transportation (collection of unused products); valorisation (repair). As for parts, activities only refer to: initial acquisition (value paid to the suppliers, transport and handling). Disassembling, (re)assembling and refurbishing costs are not detailed in the database for parts. An ABC classification of products and product categories is carried out with regard to these activities, while considering common service levels, resources and recovery and (re)distribution channel for all products.

The ABC classification allows the validation of the current product categories and contributes to target those which have a significant impact on design decisions. Three finished product families and approximately five part families for each are thus identified (**Figure 5**). No specific models are grouped to form families, since products regularly change and most of the costs are common to all products in a given category. Categories are not grouped with others since none of them are complementary. Such a definition supposes that all products in a family are substitutable. Although reality is somewhat different, this approach leads to a suitable approximation of network operations.

3.2.2 Bills of materials

Bills of materials (BOM) are used to define product family disassembly and (re)assembly sequence, and the relative involved quantities.

Bills of materials could be considered through the product family definition, as for inventory control contexts (Srinivasan and Moon, 1999). For supply chains, bills of materials present a given assembly sequence. However, the possible product disassembly and (re)assembly require the consideration of possible technical, commercial and environmental feasibilities (Fandel and Stammen, 2004).

For the studied context, bills of materials are defined by the links between product categories, which now refer to a restricted number of product families (**Figure 4**). No technical, commercial or environmental constraint is related to the disassembly and (re)assembly sequences (**Figure 5**). Parts can be replaced by either new or valorised ones.

Figure 4: Exploded view of most manual wheelchair generic parts.

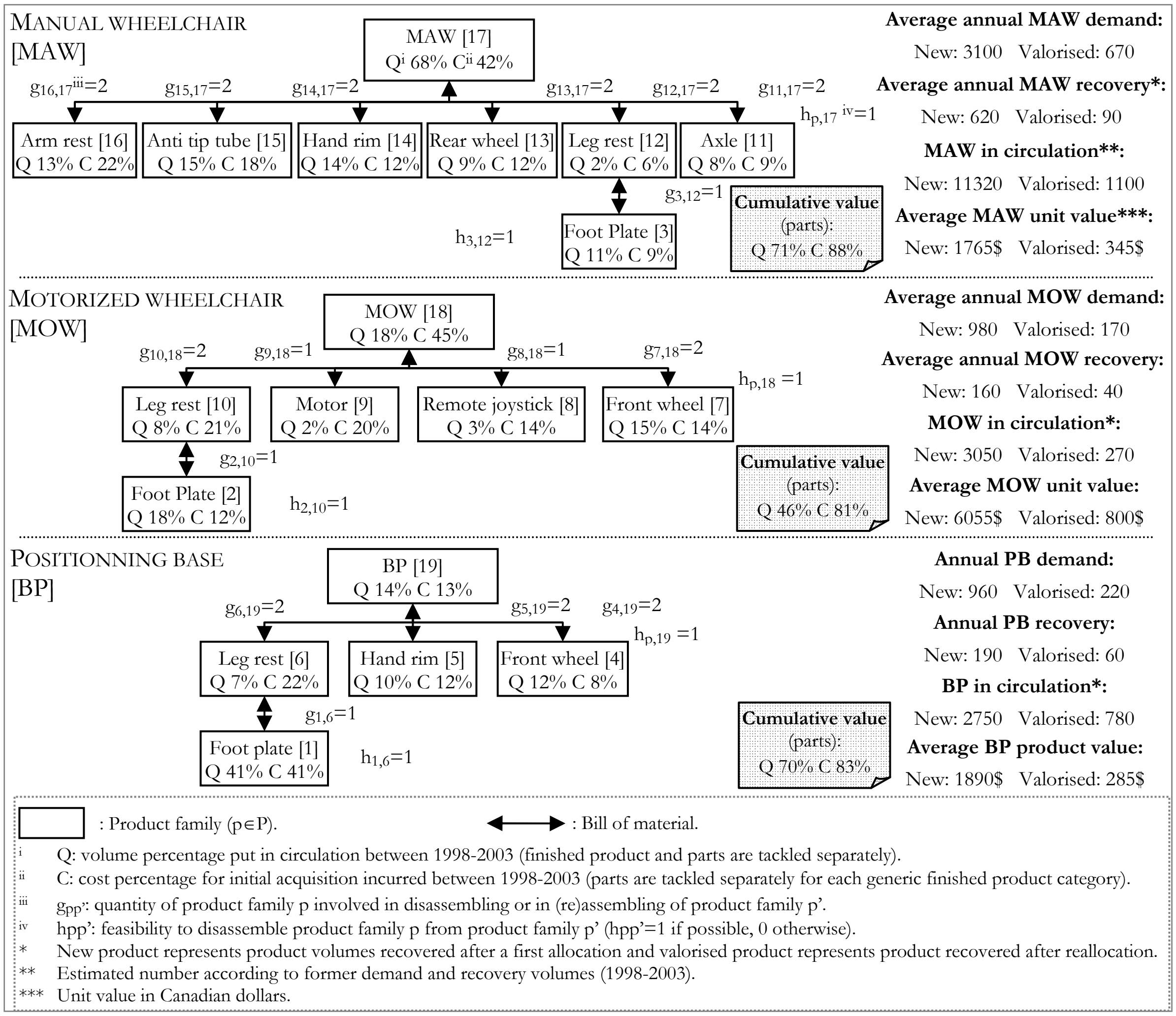

Figure 5: Bills of materials and product families resulting from an ABC classification.

3.2.3 Product states and processing alternatives

Product states are used to set proportions of product flows to direct to processing alternatives.

Many recovery, processing and redistribution strategies may be considered by organisations. Three steps are generally required to define such strategies (adapted from Teunter, 2006): 1. Determine all possible disassembling and (re)assembling sequences and processes; 2. Determine all possible recovery, processing and redistribution alternatives, and the associated costs and revenues, including those of their related parts; 3. Determine optimal recovery, processing and redistribution strategies.

Several authors deal with the first and third steps with a view toward process planning (Inderfurth and Teunter, 2001). At a strategic level, especially for designing value loops, some approaches are suggested to define how recovered product flows are directed toward processing alternatives.

Proportions of product flows to direct toward processing alternatives are generally fixed *a priori*. Krikke (1998) proposes a method to determine such proportions. A dynamic stochastic programming algorithm is used to fix proportions while maximizing processing profits, without explicitly considering network needs or requirements and capacities. It rests on conditional recovery probabilities established according to historical data on recovered product states. Teunter (2006) proposes an adapted version of this method. It considers several disassembling processes (e.g.: destructive or non-destructive) and allows partial product disassembling. Conditional recovery probabilities are established according to product states and disassembling processes.

Fleischmann (2001) uses a lower bound on recovered product volumes to dispose and which allows the model to fix the optimal proportions of product to remanufacture, in an as-new state.

Barros *et al.* (1998) and Listes and Dekker (2005) refer to different kinds of recovered product volumes, which may be considered as recovered product volumes in different states. Then, a given recovery, processing and redistribution strategy is fixed for each of these states.

In this paper, five states are used to define product flows:

1. Unknown: $s = 0$;
2. New: $s=1$;
3. Good condition: $s=2$:

   Which implies that the products can be repaired (finished products) or refurbished (parts) and thus lead to valorised products;
4. Deteriorated or damaged: $s=3$:

   Which implies that the products can be disassembled;
5. Unusable: $s=4$:

   Which implies that the products are to be disposed.

Products are recovered in an unknown state ($s = 0$). The states are determined after a sorting and grading step ($s = 2$, $s = 3$ & $s = 4$) at the level of service centres. It is considered that no new products ($s = 1$) are recovered. Unusable products ($s = 4$) are transferred to disposal centres. Other products ($s = 2$ & $s = 3$) are transferred to valorisation centres. Portions of these products may be directed toward one or many processing alternatives. Processing alternatives may be considered according to product states (**Figure 6**).

In valorisation centres, finished product in good condition ($s=2$) can be repaired. Their failed and unusable parts ($s=3$ & $s=4$) are disassembled and replaced. Parts in good condition ($s=2$) are refurbished and cleaned before reassembling. Finished products and parts in good condition or failed ($s=2$ & $s=3$) can also be disassembled. Parts in various states (*s=2*, *s=3* & *s=4*) can thus be recovered. Only parts in good condition (*s=2*) can be refurbished. Resulting repaired and refurbished products are designated as valorised products.

Valorised products (*s=2*) are then transferred to warehouses. Other products from valorisation centres (*s=3* & *s=4*), notably those that cannot be further disassembled in repair alternative to replace unusable parts, are transferred to disposal centres.

Two sets of proportions are used to define product states in the network and to direct product flows toward processing alternatives. The first set is used to define products in good condition and thus upper bounds for flows to direct toward repair or refurbishing. The second specifies unusable products and thus lower bounds for flows to direct toward disposal. The proportions of flows to direct toward disassembling are obtained according to these two bounds. Products can be directed toward a lower processing alternative according to both network needs and capacities.

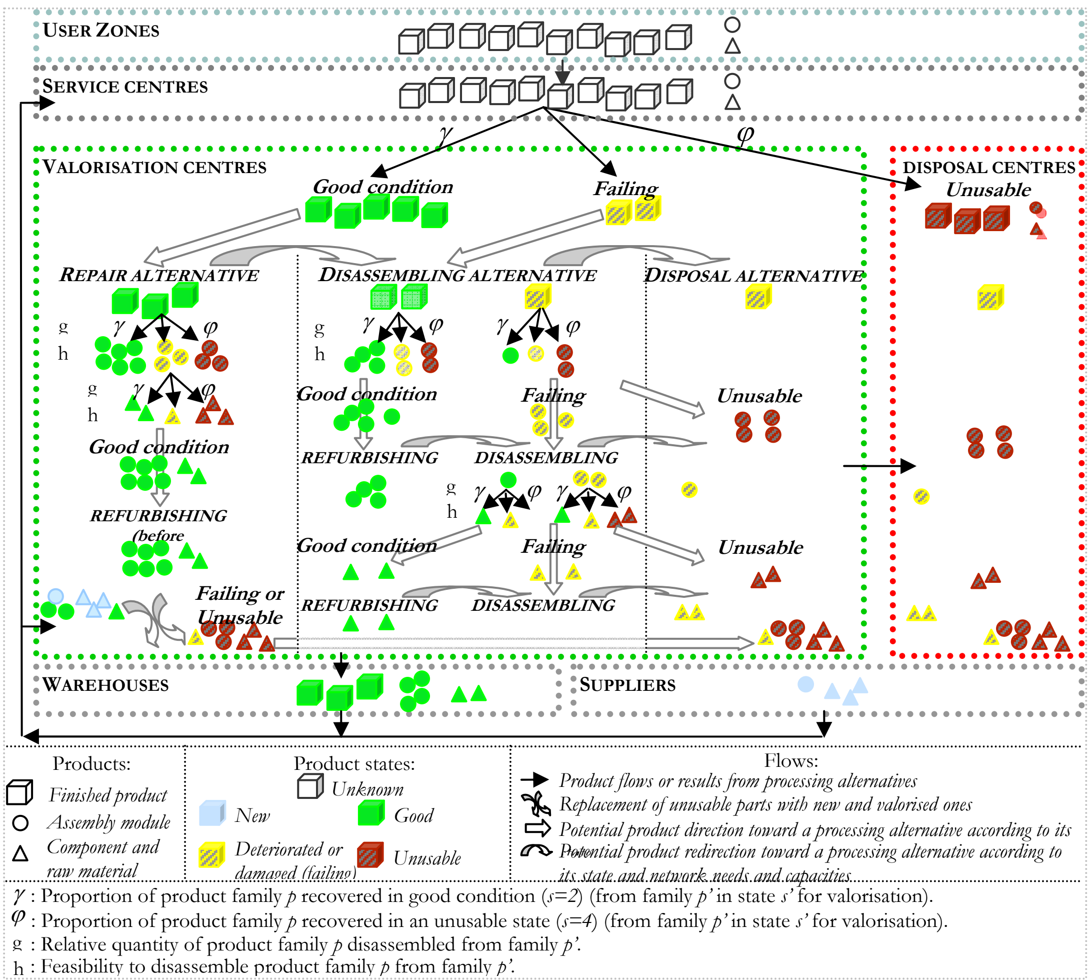

Figure 6: An example of product flow directed toward processing alternatives.

The definition of proportions is based on historical observation regarding to finished product states made at the time of sorting and grading (2000-2003), on both a monthly and yearly basis. No clear evolution of these proportions has been noted over time for each finished product family. Variation on proportions has been represented by converting the monthly proportions in probability distribution functions with use of a commercial statistical analysis tool. The Gamma and Weibull distribution best represents the wheelchair context in the Province of Quebec for the three finished products families, with a goodness of fit around 80%. Since no data have been collected concerning parts, probability distribution functions are derived from proportions of the related finished product family. They are used to represent probabilities of recovering parts in different states, according to the disassembled product state (section 3.4).

3.3 End-users

End-users are considered in the location and forecasting of demand and return volumes. Their characteristics are taken into account to reflect needs evolution while decreasing impacts they can have on design decisions:

- Positioning errors (Hillsman and Rhoda, 1978):
  - Accurate estimation of transportation costs for aggregated end-users compared to the transportation cost met when end-users are served individually;
  - Inappropriate end-user allocation to sites and erroneous site location due to aggregated demand (return) volumes rather than individuals.
- Demand (return) forecast errors:
  - Accurate forecasts with sufficient amount of data allowing a proper representation of demand (return) evolution according to population, end-users, products and service characteristics.

3.3.1 User zones location

Geographical areas designated as user zones are considered to locate consolidated demand and return volumes, in order to reduce the problem size. They serve to estimate service levels, according to distance between end-users and service centres, and are used to locate these centres for collection (section 3.1.2). They are also used to estimate transportation costs, occurring with use of different means of transport for collection. User zones are defined according to current end-users identified with historical data (1998-2003).

User zones are usually defined using clustering methods. Guidelines are given in the literature to control location, size and number of zones (Ballou, 1994, 1992; House and Jamie, 1981). They notably suggest the number of zones to define and the minimal proportion of total demand to distribute between each of them. A zone centroid is then calculated by weighting end-user's latitude and longitude coordinates according to its demand proportion (demand associated to an end-user coordinate/total demand in the considered user zone).

Attention must be focused on the fact that zones can represent both demand and return sources, which can or cannot be considered into distinct zones. They can even be distinguished according to the initiated service type (replacement, collection, etc.) and the involved product families, which can be both characterized by distinct service level targets and cost drivers.

In this paper, user zones are used to represent both demand and return sources for all product families. The service levels are known for all service types associated to demand and return and are the same for all product families. The zones are defined and assigned to a specific service centre on the basis of service levels associated to demand, but can be assigned to a distinct service centres with respect to service levels associated to return through design decisions (section 3.1.2).

The clustering method advocated in this work uses successively Kohonen Neural Networks, also called Self-Organising Map (SOM), and K-means clustering algorithm (Canetta *et al.*, 2005). Groupings are made according to end-user coordinates, and distance between them and service centres. End-user coordinates are obtained from a commercial geographical information system using the first three postal code characters. Several end-users can thus have the same coordinates.

In this approach, data are initially standardized using the W-normalization index (Milligan and Cooper, 1988). Ten user zones are imposed as a maximum for the algorithm for each service centre, following a study completed by Ballou (1994). Löbler's performance index is used to evaluate quality of groupings (Löbler, 1996). This index is calculated according to the number of clusters. A suitable number of zones are defined according to the greatest relative progress of this index. Sixty-two user zones are defined for the studied case, which represent between three to eight user zones for each current service centres as regard demand (**Figure 7**).

A zone centroid is calculated by weighting end-user coordinates with the proportion of products in their possession (number of finished products in circulation associated to an end-user coordinate/ total number of finished products in circulation in the considered user zone). It could also be calculated by weighting end-user coordinates with the proportion of the population possessing wheelchairs (population possessing wheelchairs associated to an end-user coordinate/ total population in the considered user zone). Centroids are calculated without distinguishing product families. Both approaches underline in some way the potential demand and return importance of each end-user in a zone, by moving centroid closer to end-users with high amounts of products in circulation. However, it does not consider demographic changes (death, moving, etc.). It is tackled through forecast on demand and return volumes (section 3.3.3).

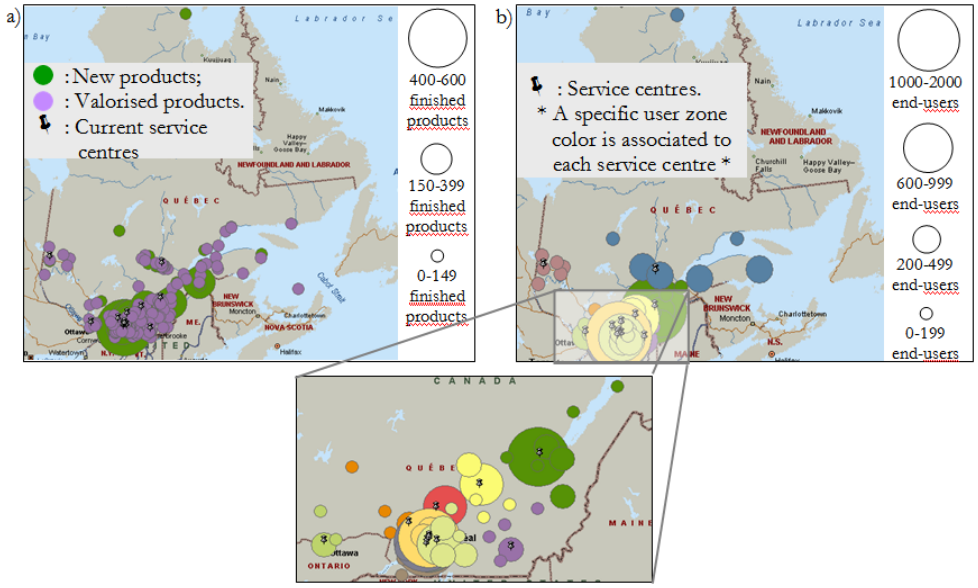

Figure 7: a) New and valorised products in circulation; b) User zones locations.

3.3.2 Characterisation of needs evolution

Various factors influencing return, processing and demand volumes are identified in this section. They are used to reflect, on a yearly basis, needs evolution according to characteristics of the defined user zones in term of population, end-users and products in circulation. They are determined from former transactional data on demand and return volumes (1998-2003), sorting and grading data (2000-2003) and demographic statistics (MSSSQ, 2005).

Characterization of needs evolution is generally obtained through data visualization and statistics. Scatterplot and bivariate statistics, such as correlation coefficients, can be used to this end (Makridakis *et al.*, 1998).

IDENTIFICATION OF INFLUENCING FACTORS

Several factors influencing needs evolution have been identified for the studied context in the previous sections. They mainly refer to products and service types which initiate demand and returns. Others are tackled here. These factors are used to identify whether products and end-user characteristics can affect needs, notably with an ageing population and prolongation of product lifecycle. Correlation coefficients [R_{XY}] are calculated for each finished product family to represent how end-user's age and gender or product state at the time of allocation and age at the time of recovery [X] can influence return, processing and demand volumes [Y].

Return, processing and demand volumes are correlated with end-user and product family characteristics (**Table 2**). User's gender brings little variation to the observed values. Correlation is lower for valorised finished product demand, since allocation depends on the RAMQ criteria. They are mainly allocated to less active people and, consequently, to older people. Correlation is also lower for product replacement, which depends on the RAMQ cost limits on product adjustment. End-user age influences return, especially following death which represents a great proportion of collection done by current service centres (MAW≅60%, MOW≅30% and BP≅50%). Return is characterized by the inverse relation between product age and return volumes. Return volumes are higher for newly allocated products.

Average duration of use (time between allocation and return) is estimated at about four years for MAW and MOW, and two and a half years for PB. The average product lifecycle (time between the first allocation and its disposal) is estimated at about seven years for MAW and MOW and five years for BP. Product volumes directed toward processing alternatives are also correlated with product age. As product age increases, the proportions of product directed toward repair and disassembling decrease and proportions of product directed toward disposal increase. Currently, disassembled products are mainly used to repair products in valorisation activities. Contrarily to MAWs and MOWs, BPs are generally allocated to less active people and require fewer adjustments to restore products appearance and functionality after recovery. Part replacements associated to BPs thus increase according to product wear and age, and require parts of the same generation. Consideration of product age, in addition to end-user age, disaggregates data too much, so that both influences cannot be evaluated simultaneously.

Table 2: The correlation coefficient [R_{XY}] of: a) user age and demand volumes, for acquisition and replacement, according or not to user gender; b) user age and return volumes, according to the product state at time of allocation; c) product age and return volumes, according to the recovery motivation; d) product age and return volumes, according to the product state at time of allocation; e) product age and processing volumes.

a)

			CORRELATION COEFFICIENT [R_{XY}]											
			DEMAND - Acquisition						DEMAND - Replacement					
PRODUCTS			MAW		MOW		BP		MAW		MOW		BP	
			New	Valo.	New	Valo.	New	Valo.	New	Valo.	New	Valo.	New	Valo.
END-USERS	Age	Men & Women	0.50	0.41	0.32	0.13	0.49	0.46	-0.23	0.28	0.04	0.28	0.10	0.40
		Men	0.44	0.28	0.33	0.09	0.53	0.40	-0.30	0.20	0.03	0.29	-0.26	0.25
		Women	0.49	0.39	0.33	0.10	0.49	0.49	-0.05	0.27	0.18	0.22	0.36	0.34

b)

		Correlation coefficient [R_{XY}]					
		Return					
Products		MAW		MOW		BP	
		New	Valo.	New	Valo.	New	Valo.
End-users	Age	0.48	0.41	0.38	0.30	0.52	0.42

* Database used does not distinguish the recovery motivation.

c)

		Correlation coefficient [R_{XY}]		
		Return		
Recovery motivation	Products	MAW	MOW	BP
Death	Product age	-0.66	-0.73	-0.73
Unused	Product age	-0.66	-0.47	-0.58

* Data from a database centred on product sorting and grading, which does not distinguishes product state at time of allocation.

d)

	Correlation coefficient [R_{XY}]					
	Return					
Products	MAW		MOW		BP	
	New	Valo.	New	Valo.	New	Valo.
Product age	-0.76	-0.48	-0.76	-0.65	-0.62	-0.64

* Estimated product age according to the collected date of first allocation, which does not distinguish the recovery motivation (end-user death or once product unused, which include replacement or voluntarily return).

e)

	Correlation coefficient [R_{XY}]								
	Processing - Repair			Processing - Disassembling			Processing - Disposal		
Products	MAW	MOW	BP	MAW	MOW	BP	MAW	MOW	BP
Product age	-0.95	-0.87	-0.90	-0.81	-0.66	0.46	0.92	0.93	0.66

According to such information, user age and product age are used to reflect respectively evolution of demand and return volumes, and processing volumes. User gender and product state at time of allocation are considered at a later stage to evaluate differences in network site practices.

No seasonality has been observed. The correlation coefficients notably vary little over the years.

Characterization of practices in service, recovery and processing centres

The identified influencing factors are used to denote practice differences between sites. Site practices are distinguished through proportions for specific combination of influencing factors. The following figures (**Figure 8** to **Figure 11**) present the yearly average demand, return and processing proportions obtained from all current service centres and a specific centre, used in later examples. End-user ages are presented here using a ten year age bracket.

a)

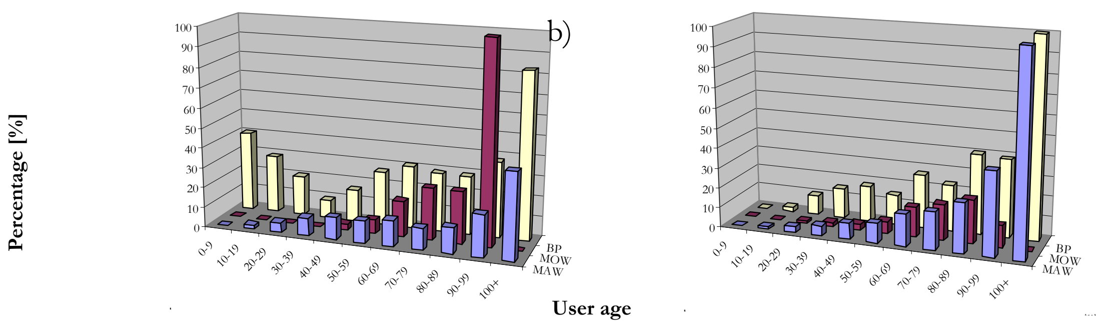

Figure 8: Percentage of total demand satisfied through valorised finished products for each ten year end-user age bracket: a) Acquisition; b) Replacement.

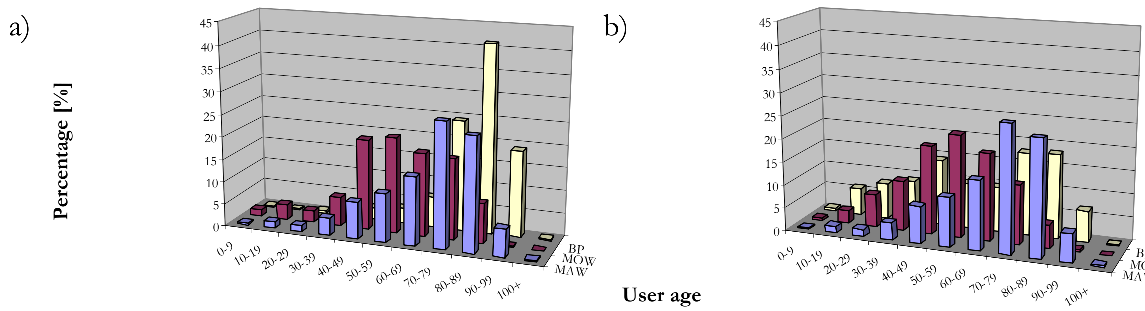

Figure 9: Percentage of the total demand associated to each ten year end-user age brackets: a) Acquisition; b) Replacement.

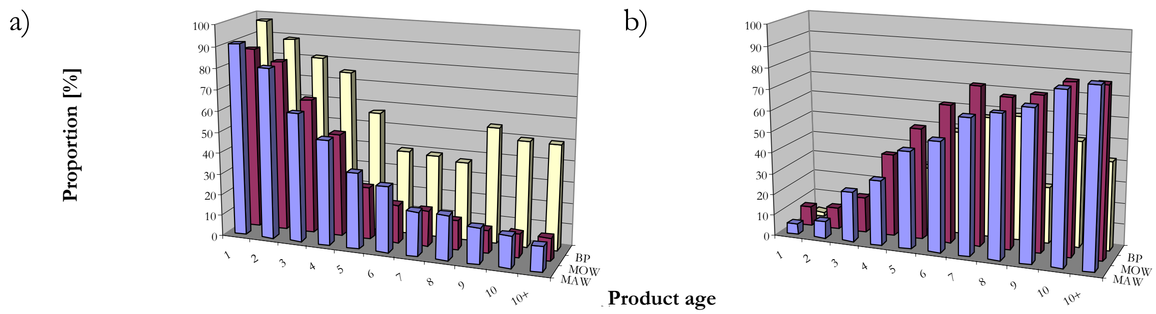

Figure 10: Proportion of recovered finished product directed toward processing alternatives according to product age: a) Repair; b) Disposal.

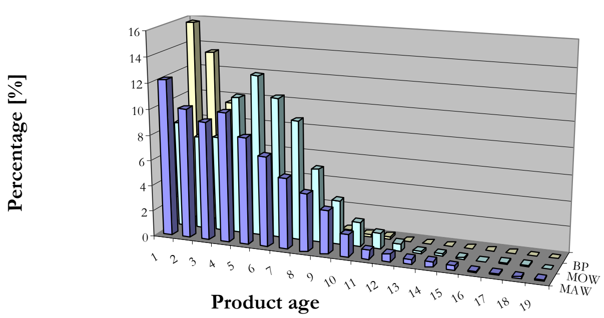

Figure 11: Percentage of the total recovered finished product according to product age.

Such information can be useful to identify if supplier's proximity and employee's confidence in valorised products can influence site practices. Average proportions of valorised product allocated in service centres vary between 2% and 32%. The average for the Province of Quebec is about 16% (MAW≅12%, MOW≅12%; BP≅26%). It varies according to the end-user age bracket. However, proportions of end-users whom are only admissible to valorised products cannot be obtained from historical data. No conclusion can thus be drawn on the will of current service centres to allocate valorised products. As for proportions of finished products directed toward processing alternatives according to their states, they are globally known for all current service centres put together, but are individually known for only some centres, which use a sorting and grading decision support tool. Differences have been noticed according to finished product ages between centres that use this tool or not. However, average proportions between centres vary little regardless to product age (example for Repair: MAW≅54%, MOW≅42%; BP≅81%). Such results show that current service centres have similar practices as for sorting and grading.

END-USER AND PRODUCT AGE BRACKETS

In order to facilitate the later forecast stage, end-users and finished product age brackets are defined.

An empirical rule is used to define appropriate end-user age brackets. Five age brackets are defined: 0-39; 40-59; 60-69; 70-79; 80+. Each bracket accounts for about 20% of current end-users (10% if considering gender). Since a maximum of 8 user zones are associated to current service centres, a minimum of about 1% (10%/8 zones) of end-users is then distributed to related zones for each age-gender combination. This value is arbitrary, but ensures a minimum of data for the later forecast stage and to evaluate the related errors.

Product age brackets for finished product families are defined according to distinctive product lifecycle stages, which present specific proportions of recovered products (**Figure 11:** Percentage of the total recovered finished product according to product age.**Figure 11**) and of products directed toward processing alternatives (**Figure 10**). Three product age brackets are retained here: 0-2; 3-6; 7+. The first bracket is related to finished product families recovered inside the average half duration of use. The second bracket is related to families recovered before the average lifecycle and after the average half duration of use. The last age bracket is specifically related to finished product families recovered after the average lifecycle. The average durations of the three finished product families are considered here.

End-users and product age brackets can be used to present proportions as shown in previous figures (**Figure 8** to **Figure 11**).

CHARACTERIZATION OF USER ZONES

The retained influencing factors are used to reflect need evolution and dispersion according to user zone characteristics in terms of population, end-users and products in circulation. Such characteristics are measured through proportions of end-users and products in circulation that meet the considered influencing factors on a yearly basis.

Table 3 presents the proportions of end-users and population with wheelchairs, without consideration of product families, according to their age and gender. Demographic statistics are obtained according to district codes (section 2.3) related to user zones. This is an estimate, since the district codes covered by zones were not validated at the time of this work. The number of products in circulation is estimated from demand and return volumes occurring between 2000 and 2003.

The characteristics of the user zones vary significantly. Some zones are in rural areas, which are confronted with an exodus of young people toward urban areas. Others include healthcare institutions. These characteristics are represented by the density of the population with a loss of mobility (**Table 3**).

Table 3: User zone characteristics measured by a) proportions of end-users and b) population having wheelchairs for a specific service centre.

a)

Age	PROPORTION OF CURRENT END-USERS WITH WHEELCHAIR									
	Men					Women				
	Zone 37	Zone 38	Zone 39	Zone 40	Total	Zone 37	Zone 38	Zone 39	Zone 40	Total
0-40	0.54%	1.09%	1.16%	3.29%	6.08%	0.49%	1.24%	0.87%	2.30%	4.90%
40-60	0.62%	1.34%	1.34%	5.24%	8.53%	0.74%	1.71%	1.68%	5.17%	9.30%
60-70	0.59%	1.16%	0.59%	3.29%	5.64%	0.30%	0.96%	0.79%	4.30%	6.36%
70-80	1.71%	1.36%	0.96%	6.95%	10.98%	0.84%	2.03%	1.61%	8.33%	12.81%
80 +	1.48%	1.53%	0.45%	5.98%	9.45%	1.16%	5.39%	1.73%	17.68%	25.96%
Total	4.95%	6.48%	4.50%	24.75%	40.68%	3.54%	11.33%	6.68%	37.78%	59.32%

b)

Age	PROPORTION OF POPULATION WITH WHEELCHAIR									
	Men					Women				
	Zone 37	Zone 38	Zone 39	Zone 40	Total	Zone 37	Zone 38	Zone 39	Zone 40	Total
0-40	0.07%	0.08%	0.04%	0.27%	0.10%	0.07%	0.09%	0.03%	0.20%	0.08%
40-60	0.15%	0.19%	0.09%	0.80%	0.26%	0.18%	0.23%	0.11%	0.72%	0.28%
60-70	0.63%	0.57%	0.16%	1.49%	0.63%	0.33%	0.44%	0.20%	1.71%	0.66%
70-80	3.09%	1.03%	0.42%	4.42%	1.92%	1.30%	1.19%	0.56%	4.04%	1.76%
80 +	7.80%	3.66%	0.67%	12.27%	5.37%	3.25%	6.66%	1.30%	16.89%	7.32%
Total	0.37%	0.26%	0.09%	1.08%	0.37%	0.27%	0.45%	0.13%	1.54%	0.52%

3.3.3 Forecast on demand and return volumes

Demand and return volumes are forecasted for each user zone according to changes with user zone characteristics in terms of population, end-users and products in circulation.

Different forecast approaches are proposed in the literature. Some deal specifically with return. They use the probability of a return after a demand (Toktay *et al.*, 2004; Toktay, 2003; Kelle and Silver, 1989). In healthcare systems, forecasts are often based on demographic statistics. Forecasts are done on incidence rates, rather than on a specific number of occurrences. Incidence rates represent ratio between the number of occurrences and the size of the associated population over a given horizon period, according to the user zone characteristics. Forecasts can be made through projections based on age-period-cohort models, Bayesian age-period-cohort models or functional data analysis (Erbas *et al.*, 2005). Occurrences for future periods are then calculated by multiplying forecasted rates with predicted size of the associated population for the same period. The predicted size of a population is usually calculated by government forecasting agencies, with use of sophisticated models (Ahlburg, 1987).

For long-term forecasts, used for logistics network design, simple models based on time series are usually advocated (Makridakis *et al.*, 1998). Forecasted volumes are often considered as deterministic. When stochastic models are taken into account, random factors are represented as dependant, through discrete scenarios, or as independent with the use of specific distribution function. Normal or Lognormal distributions usually represent random demand. In designing value loops, the randomness of demand and return volumes is usually considered through a limited number of discrete scenarios (Listes, 2007; Listes and Dekker, 2005).

For the studied case, forecasts of the demand and return volumes for finished products are made with time series by considering the previously identified influencing factors and consequently the user zone characteristics. They are evaluated for each service type, except for replacement. Forecasts on part families are not detailed in this paper, but are made with traditional simple linear regression.

For the sake of comparison, forecasts (f_t *and* F_t) on a yearly basis (t) deal here with both demand and return volumes ($F_t=[D_t, R_t]$) and rates ($f_t=[d_t, r_t]$) (rate = volume/size of the associated population or number of products in circulation for a given set of characteristics). Since products in circulation cannot be completely deduced from historical data, user zone characteristics are only defined according to the size of the associated population. The population is characterized by the Ministry of Health and Social Services of Quebec (MSSSQ, 2005) according to the district demographic statistics given on an annual basis until 2026. Forecasts are made by considering time (t) or the size of the associated population (p_t) as independent variable: [$f_t(t)$, $F_t(t)$] (volume and rate); [$F_t(p_t)$] (volume).

Forecasts deal with each finished product family and service type separately, except for replacement. They were carried out by separating, or not, sections of data that are set according to the end-user age and gender, product age at the time of recovery and state at the time of allocation (new and valorised), which thus reflects different combinations of the identified influencing factors.

Forecasts are calculated for both user zones and service centres. Two forecasting strategies are considered in this paper. One consists in establishing forecasts at the level of current service centres, which are then distributed to each of their related zones. The other consists in establishing forecasts directly at the level of user zones.

Forecasts are done using simple linear regression models. A specific model is used for each considered zone and site, each service type, each product family and each combination of influencing factors (end-users and products in circulation characteristics). These approaches are illustrated below for the case of a specific service centre for manual wheelchairs.

First strategy

Forecasts are first determined at the level of the current service centres and are then distributed to their related user zones, while considering their characteristics. The distribution is made proportionally to the number of end-users and products in circulation for a given set of characteristics that correspond to the influencing factors considered for the forecasts (forecast factors) and, depending to the approach, to differentiate the forecasts (specification factors). The considered approaches are summarized in **Figure 12**.

Proportions used to differentiate forecasts according to the specification factors are assumed to be the same for all time periods (2000-2003). They are estimated as an average annual value. The numbers of end-users and products in circulation for a given set of characteristics are those previously determined according to the historical data for the latest time horizon period (2003).

An example of demand forecasts for acquisition (approaches 1.1 and 1.2), with time set as an independent variable ($d_t(t)$), is presented in **Table 7**. It represents the average forecasts between 2000 and 2003. The results show the sum of the demand for new and valorised products and all end-user characteristics in the zones.

Second strategy

Forecasts are directly calculated at the level of the user zones, by considering the zone characteristics. The considered approaches are summarized in **Figure 12**.

The results for the manual wheelchair acquisition and collection obtained from a specific service centre are presented in **Table 7** to **Table 9**. They relate to forecasts with time ($D_t(t)$, $R_t(t)$, $d_t(t)$) or the size of the associated population ($D_t(p_t)$) as an independent variable. Results present the sum of demand for new and valorised manual wheelchairs, without distinguishing the end-user and product characteristics. Rates are converted as volumes by multiplying them with the appropriate size of the associated population.

DISCUSSION ON FORECAST ERRORS

Observation of the mean absolute errors (MAE) shown in **Table 7** to **Table 9** indicates that the consideration of the user zones and service centres affects forecast errors. Errors are generally higher in zones because of greater data dispersion. However, errors in zones are reduced by establishing forecasts directly at the level of zones, thus reflecting their specific evolution, rather than by distributing forecasts of current service centres to their related zones.

Forecasts established on disaggregated data according to the characteristics of the population, end-users and products in circulation also lead to increased forecast errors (not represented in the tables). Forecast errors are accentuated for valorised product demand and for returns. This can suggest that the stationary state has not yet been reached. Forecasts for such situations are also affected by the fact that few data are currently available for some service centres and user zones.

Forecasts on demand and return rates or with the use of the size of the associated population (p_t) as an independent variable bring few changes in errors.

Long term forecasts detailed and realized according to the user zone characteristics in terms of population, end-users and products in circulation can bring useful details on needs evolution and dispersion. They can be of great interest to evaluate policies or strategies, notably for sorting and grading according to product age and end-user admissibility to valorised products through age categories. Such forecasts however rest on a high amount of data over several horizon periods.

Gains in accuracy obtained from the application of one of the suggested forecast approaches cannot be determined at this point. Forecasts have to be evaluated over several horizon periods to get conclusive remarks about the quality of the approaches, notably through the use of other statistical measures. Approaches also have to be compared with those considered in healthcare systems.

3.4 Identification and characterization of random factors

Parameters reflecting randomness on return, processing and demand volumes are defined in this section, while considering observations made throughout the modeling. Some specifications are first made for the modeling of the demand and return volumes.

Return volumes, as regards collection, are defined at the level of user zones to support service centre location decisions and to evaluate the resulting transportation costs. Demand volumes (acquisition and replacement) are established at the level of current service centres, since their locations are not put in question in such a case.

Demand volumes for valorized products are determined through design decisions according to lower bounds, defined as proportions of the total forecasted demand. Two cases are considered here. The proportions are given by average values met in current service centres, for each finished product family, or fixed at zero.

Return volumes are not estimated from forecasts, since a steady state has probably not yet been reached. The current return volumes are then adjusted according to the growth rate of demand, since the growth rate of products in circulation can not be estimated from historical data.

In a first investigation of the network design decisions, no distinction is made for forecasts considering user zone characteristics in terms of population, end-users and products in circulation. Average forecast errors of the order of 15% to 35% noted for service centres or user zones are used to denote randomness on demand and return volumes (**Table 4**), while assuming the forecast errors are normally distributed with zero mean.

Table 4: Normally distributed demand and return volumes.

	Dist. fct	MAW	MOW	BP	Parts
Demand (acquisition and replacement)	$N[\mu_D, \sigma_D]$	σ_D/μ_D □ 15%	σ_D/μ_D □ 30%	σ_D/μ_D □ 35%	σ_D/μ_D □ 25%
Return (collection only)	$N[\mu_R, \sigma_R]$	σ_R/μ_R □ 30%	σ_R/μ_R □ 30%	σ_R/μ_R □ 30%	σ_R/μ_R □ 25%

Randomness of product states are represented through the two identified sets of probability distribution functions (section 3.2.3). The first set defines the states of recovered products at the level of service centres. Function parameters of this set are defined for finished product families by the average practices of current service centres. This approach reflects the desire for sorting and grading standardization. No function is assigned to part families, since it is considered that parts recovered at service centres are unusable. The second set of functions defines the states of recovered parts at the level of valorisation centres, following finished product repair and part disassembling and refurbishing alternatives. No data were available at the time of this work to define such proportions. Functions defining the proportions are derived from the related finished product families. The states of parts disassembled from products in good and failed conditions are given respectively by functions defined from data on finished products with ages below and above average half duration of use. No further consideration of product characteristics (age category, state at time of allocation) is considered in the definition of product states. Service and valorisation centres are represented by distinct functions to reflect their independent operating context.

Table 6 summarizes the distribution functions used to establish product family states. The Gamma and Weibull distributions are chosen because of their goodness of fit for the studied case.

To reflect the variability on valorised product accessibility and specifically the variability on valorised product unit value, design decisions are evaluated under two average unit values. The first reflects the use of valorized parts only to repair recovered finished products and the second considers the use of both new and valorised products, which leads to lower and higher unit values for valorised finished products (section 3.1.2).

Probability distribution functions are used to define scenarios for return, processing and demand volumes, by considering four different operating contexts according to the proportions of demand fulfilled with valorised products and their unit values (**Table 5**). Scenarios are defined outside of the optimization procedure with the Monte Carlo sampling methods for the identified distribution functions. The negative values given by these functions are considered as equal to zero. The combination of proportions that define product family in good and unusable conditions is corrected, if needed, to ensure their sum is lower or equal to 1.

Table 5: Characteristics of the operating context.

DEMAND FOR VALORISED PRODUCTS (% of demand, as for acquisition and replacement)								UNIT VALUE OF VALORISED PRODUCTS (% of unit value of new products)							
Imposed minimal demand proportions				**No minimal demand proportions**				**Lower value** (repair with valorised parts)				**Higher value** (repair with new and valorised parts)			
MAW	**MOW**	**BP**	**Parts**	**MAW**	**MOW**	**BP**	**Parts**	**MAW**	**MOW**	**BP**	**Parts**	**MAW**	**MOW**	**BP**	**Parts**
13	13	26	0	0	0	0	0	12	7	10	15	20	13	15	15

Table 6: Average and standard deviation [μ,σ] for proportions [%] defining states of product volumes with use of Gamma and Weibull distribution functions.

	DIST. FCT	FINISHED PRODUCT FAMILIES			PART FAMILIES					
					Dis. from prod. in good cond.			Dis. from prod. in failed cond.		
		MAW	MOW	BP	MAW	MOW	BP	MAW	MOW	BP
Repair	Weibull $W[\alpha,\beta]$ or Gamma $G[\alpha,\beta]$	*G* μ : 54 σ : 4	*G* μ : 41 σ : 7	*G* μ : 81 σ : 3	*W* μ : 90 σ :10%	*G* μ : 89 σ :13	*W* μ : 88 σ : 9	*W* μ : 33 σ : 7	*G* μ : 20 σ :20	*G* μ : 46 σ :43
Disposal		*W* μ : 36 σ : 4	*W* μ : 46 σ : 7	*W* μ : 13 σ : 3	*G* μ : 3 σ : 3	*W* μ : 4 σ : 3	*G* μ : 1 σ : 1	*W* μ : 53 σ : 7	*W* μ : 60 σ :15	*G* μ : 69 σ :26

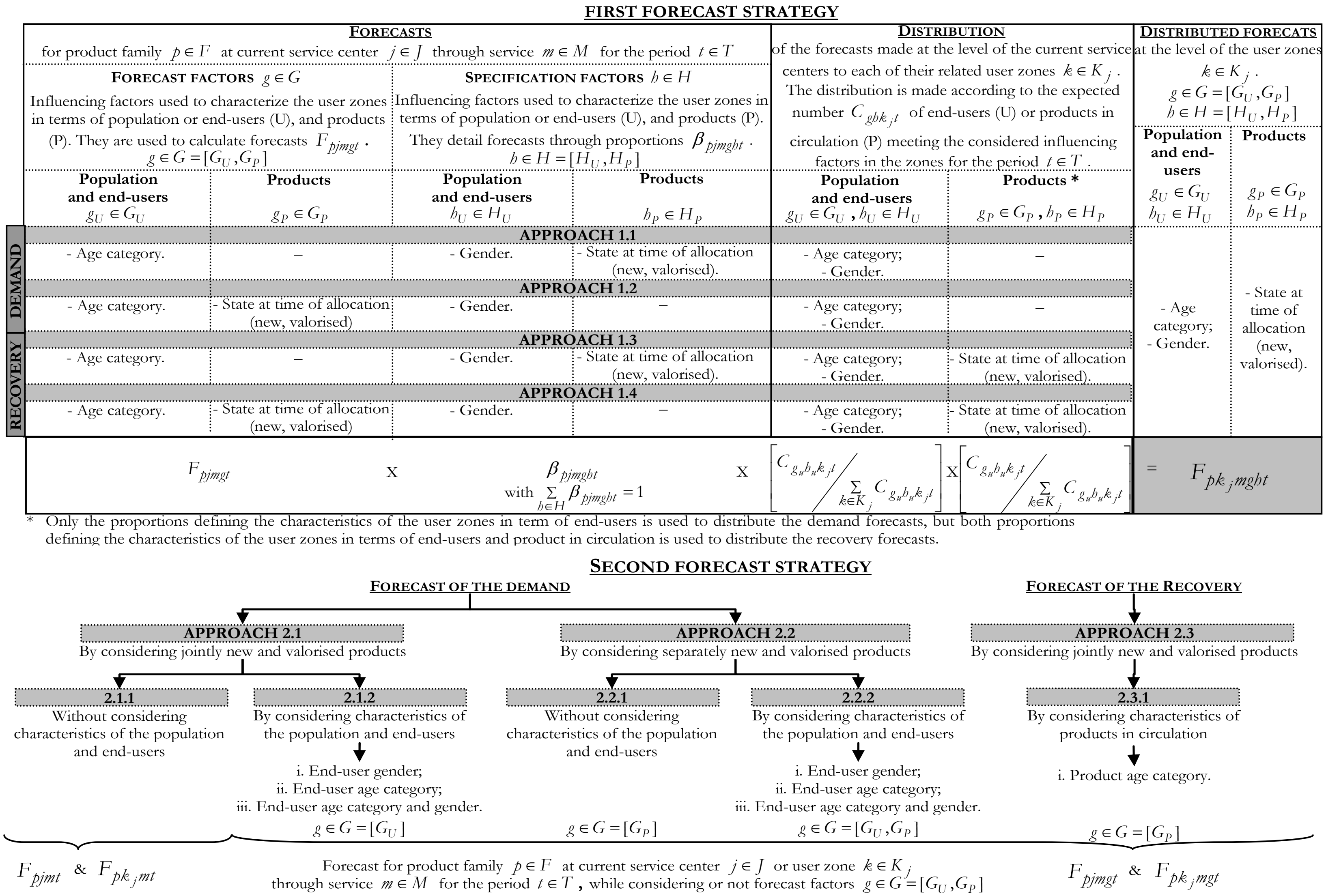

Figure 12: Forecast strategies.

Table 7: Average (2000-2003) annual demand and mean absolute error in a context of acquisition for a current service centre and its related user zones using the first forecast strategy: a) use of time period as independent variable.

a)

	Approach 1.1.						Approach 1.2.					
	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones
Average	40	80	46	294	460	460	49	106	84	220	460	460
MAE	3	10	3	12	5		7	25	35	67	5	

Table 8: Average (2000-2003) annual demand and mean absolute error in a context of acquisition for a current service centre and its related user zones using the second forecast strategy: a) volume with time as independent variable; b) volume with the size of the associated population (p_t) as independent variable; c) rate with time as independent variable (rate is converted in volume).

a)

	Approach 2.1.1.						Approach 2.1.2.i. (user gender)						Approach 2.1.2.ii. (user age)						Approach 2.1.2.iii. (user age and gender)					
	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones
Average	42	81	49	288	460	460	42	81	49	288	460	460	42	81	49	288	460	460	42	81	50	288	460	460
MAE	0	4	1	9	5	5	0	4	1	9	5	5	0	4	1	9	5	5	0	4	1	9	5	5

	Approach 2.2.1.						Approach 2.2.2.i. (user gender)						Approach 2.2.2.ii. (user age)						Approach 2.2.2.iii. (user age and gender)					
	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones
Average	42	81	49	288	460	460	42	81	49	288	460	460	42	81	49	288	460	460	42	81	50	288	460	460
MAE	0	4	1	9	5	5	0	4	1	9	5	5	0	4	1	9	5	5	0	4	1	9	5	5

b)

	Approach 2.1.1.						Approach 2.1.2.i. (user gender)						Approach 2.1.2.ii. (user age)						Approach 2.1.2.iii. (user age and gender)					
	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones
Average	42	81	49	288	460	460	42	81	49	288	460	460	42	81	49	288	460	460	42	81	50	288	460	460
MAE	0	3	1	9	8	8	0	2	1	9	8	8	0	3	0	10	8	8	0	3	0	10	9	8

c)

	Approach 2.1.1.						Approach 2.1.2.i. (user gender)						Approach 2.1.2.ii. (user age)						Approach 2.1.2.iii. (user age and gender)					
	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones
Average	42	81	49	288	460	460	42	81	49	288	460	460	42	81	49	288	460	460	42	81	50	288	460	460
MAE	0	4	1	9	6	8	0	4	1	9	6	8	0	4	1	10	7	9	0	4	2	10	8	8

Table 9: Average (2000-2003) annual returns and mean absolute error in a context of collection for a current service centre and its related user zones using the second forecast strategy: a) volume with time as independent variable.

a)

	Approach 2.3.1.						Approach 2.3.2. (product age)					
	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones	Zone 37	Zone 38	Zone 39	Zone 40	Sum	All zones
Average	14	25	14	107	159	159	14	25	14	107	159	159
MAE	1	3	5	7	16	16	1	3	5	7	16	16

4 Impact of randomness on design decisions

Uncertainty impacts on design decisions are evaluated by comparing results from a deterministic and stochastic model developed for the studied case (Chouinard *& al.*, 2008, 2007). A first investigation is made while considering that each current rehabilitation centers proceed to the collection of their allocated products.

The stochastic model is solved with a heuristic approach based on the Sample Average Approximation (SAA). It deals with $M = 16$ scenario samples of size $N = 100$. This approach requires the evaluation of obtained designs with a much larger sample of size $N' = 400$. An optimality gap is estimated with the approach. Samples are defined from the Monte Carlo sampling methods (section 3.4). The deterministic model deals with average values of random factors. Solving these models leads to two potential designs (**Table 10**), one identified by both models (solution 1) and one by the stochastic model only (solution 2). This solution suits best to the studied case since it has the lower objective function value and is less sensitive to considered uncertainty factors (**Table 11**). It is referred to here as the robust design.

Table 10: Designs obtained with the stochastic and deterministic models.

	Number of processing centres (valorisation centres) [8 potential proc. centres, including 4 valo. centres]	Number of warehouses [6 potential warehouses]
Solution 1*	6 (4)	4
Solution 2	5 (3)	3

* Solution also identified with the deterministic model.

Table 11: Costs statistics (million $) of the identified solutions.

	$\hat{f}_{N'}(\overline{Y})$	Std dev	Min	Max	Optimality gap [% of $\hat{f}_{N'}(\overline{Y})$]
Solution 1	21.75	0.62	19.98	23.21	0.11
Solution 2	21.68	0.52	20.00	23.11	0.09

The robust design suggests the use of one less processing centre and warehouse. This decision affects proportions of products directed to processing alternatives, and consequently proportions of demand fulfilled with valorized products (**Table 12**). It decreases accessibility to valorized finished products, but increases accessibility to valorized parts. Such accessibility can affect unit product value and operating costs (section 3.1.2). According to the considered operating contexts, an increase of two thirds of the valorized finished product unit value leads to an increase of about 0.7% of the objective function value. Proportions of demand fulfilled with valorized products have also impacts on design decisions. In this work, model decisions aim at increasing demand fulfilled with valorized products (finished products & parts), since their unit value is lower. According to the operating contexts, imposing minimal proportions of demand to be fulfilled with valorized products leads to an increase of less than 0.02% of the objective function value. In a context where only new products are used to fulfil demand and that recovery and processing products are not considered, the objective function value is however increased by 20%.

Table 12: Proportions of demand volumes fulfilled with valorised products and proportions of recovered product volumes directed to processing alternatives for the identified solutions.

Solution	% of demand for valorised products								% of recovered product volume repaired						% of recovered product volume disposed					
	MAW		MOW		BP		Parts		MAW		MOW		BP		MAW		MOW		BP	
	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
1	32.7	1.2	34.5	2.2	57.2	3.5	10.4	5.3	74.8	2.9	77.3	4.1	89.6	2.8	0.0	0.0	1.0	3.2	0.0	0.1
2	26.8	1.0	29.4	1.3	47.7	2.9	25.6	6.6	61.5	2.4	65.9	3.6	74.8	2.4	0.0	0.0	1.2	3.9	0.0	0.1

5 Conclusion

The modeling of the wheelchair value loop in the Province of Québec (Canada), managed and supervised by a public insurer, is presented in this paper. It aims at defining the related potential network entities, as potential sites and resources, products and end-users. They are used to properly represent network dynamics according to achievable performance levels in terms of capacities, costs and service levels. The modeling is tackled while considering needs evolution with population, end-users and products in circulation characteristics.

Different random factors are identified and characterized through this approach. They relate to demand, return and processing volumes, specifically according to recovered product states. Different operating contexts are defined to represent possible changes of valorized product accessibility, depending on the organization policies or strategies. They are represented by demand proportions to be fulfilled with valorized products and by valorized product unit values, used for the estimation of holding costs. Impacts of these uncertainties and operating contexts are evaluated through design decisions obtained from a deterministic and stochastic model. They suggest that product accessibility vary with recovered products states and network conditions (demand and return volumes, network capacities and operating costs). Significant benefits can be perceived with a proper integration of reverse logistics to the current supply chain.

The suggested modeling approaches rest on data obtained by the organisation. Data availability and integrity are of great concern for such approaches. Restricted data can limit the network analysis and characterization. Lower data integrity can increase randomness in estimates and forecasts.

Methods and tools are to be proposed to support the modeling of value loops for which data are not available or unusable, especially following changes in organisation policies and strategies to support the product lifecycle. Such methods and tools may notably rest on simulation.

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