Chapter 2
A Quality Framework in Closed Loop Supply Chains: Opportunities for Value Creation

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Abstract Quality issues and "uncertainties" are encountered in almost every aspect of closed loop supply chains (CLSCs). In this chapter, we analyze the CLSC processes with a focus on quality. We find that quality of returned products is the major source of uncertainty and thus a major determinant of value in CLSCs. However, we observe that there is a gap in the literature when it comes to identifying and properly defining all relevant quality dimensions and the ways in which they affect CLSC processes. In our chapter, we start with an investigation of existing definitions of quality, link them to the different stages of CLSCs, and propose a new framework summarizing the integration of quality within CLSC processes. We also relate our framework to other frameworks that can be found in the literature and show how the former may help to improve value creation in CLSCs.

2.1 Introduction

A closed loop supply chain (CLSC) is defined in [1] as "…a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time". Quality issues are encountered in almost every aspect of CLSCs: as a driver of return flows, as a marketing challenge for recovered products, and, more importantly, as an

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uncertainty of input to the recovery process. When referring to quality in the context of product recovery several terms such as “reusability”, “condition of items”, “remaining life”, “residual functionality”, and “remaining value” are encountered. For instance, Kumer et al. [2] claim that quality is one of the determinants of value creation, but they do not define quality and do not explain how quality affects value creation; Visich et al. [3] claim that the use of RFID may enhance value creation, in particular through identifying the quality levels of a product return, but quality is not defined. Zuidwijk and Krikke [4] investigate possible strategic responses to electric and electronic equipment (EEE) returns and define several scenarios with respect to product returns’ quality (“low”, “high” etc.), but do not define quality. Moreover, they mention that product returns with high quality may be brought to “as good as new” quality.

These numerous, yet often implicit, references to quality point to the necessity to properly define and structure all relevant quality dimensions of CLSCs. Only when these dimensions and their consequences are made explicit, specific targets and actions can be defined to improve supply chain performance. Hence, the main contribution of this chapter is the construction of a quality framework for CLSCs that identifies all relevant quality dimensions in the CLSC, defines them explicitly, and links these dimensions to various processes in the CLSC. Hence, the framework enables the analysis of CLSCs through a quality lens and in a structured way, as well as the discovery of new ways of value creation. Also, we hope to lay a foundation for future research, especially for the Operations Management discipline.

In the literature, several frameworks have been presented to analyze product recovery systems (e.g., [5–8]). However, to the best of our knowledge there has not been any study that developed a framework specifically from a quality point of view. To construct our framework, we start (Sect. 2.2) with discussing (returns’) uncertainty and its effects on CLSC-related processes, to establish quality as the key source of uncertainty. After that, in Sect. 2.3 we discuss how quality is traditionally defined, how the concept of “customer value” (mentioned e.g., in [9]) is built on these definitions, and how quality management principles follow from the concept of product value. Further, we employ the customer value definition to define the “return value”. In Sect. 2.4, we focus on how the traditional quality definitions apply in product recovery settings and identify which of those definitions are applicable at what stages of the CLSC. Based on this mapping we construct our framework. Then, having identified the traditional definitions of quality that apply to product recovery, in Sect. 2.5 we focus on the quality management approaches and their applicability in product recovery setting. In the last but one section, we relate our quality-based framework to earlier ones that can be found in the literature to establish a link between planning and management of product recovery and our quality framework. Finally, in Sect. 2.6 we present potential issues of future research.

2.2 Uncertainty in Product Recovery Environments

Return flows are characterized by high levels of uncertainty. When describing them, several researchers (e.g., [10, 11]) have identified uncertainties with respect to quantity, timing, and quality of returns. In this section we argue that quality is the major source of uncertainty in CLSCs. We further argue that it encompasses timing and quantity uncertainties after the receipt of the recoverables due to potential yield loss.

Categories of recovered products may differ with respect to their coordinates on the dimensions of quantity, timing, and quality. In this regard, Guide [8] argues that in recovery environments uncertainties in timing is positively correlated with uncertainties in quantity, but negatively correlated with quality uncertainty. Using Guide's examples, for remanufacturing of jet engines timing is highly predictable, whereas the condition of components is variable. On the other hand, for remanufacturing of single use cameras quantity and timing is highly uncertain, whereas quality variance is limited. Nevertheless, virtually in all applications all three sources of uncertainty are present to some degree and complicate the decision-making processes.

Timing and quantity uncertainty are linked to the product's life cycle, rate of technological change, and the willingness of end-users to return the product [12]. The condition of recoverables, on the other hand, depends on factors such as the age of product, the customer use pattern, and the nature of product (e.g., mechanical or electronic).

Along the CLSC, quantity and timing uncertainties are partially resolved at the same stage, that is, upon receipt of the recoverable items. Le Blanc [13] introduced the concept of disposer decoupling point (DDP) for CLSCs based on the customer decoupling point (CDP) concept of traditional forward supply chains. The DDP corresponds to the point in the CLSC where the "disposition route" can be actively managed, i.e., where the decisions on recovery options, timing of recovery and volume of recovery are taken. So, at the DDP not only the ownership changes hands but also the disposition route is determined.

At first glance one may mistakenly conclude that at the DDP all timing and quantity uncertainty is resolved. However, quality uncertainty may only be resolved after further testing and grading. Sometimes, quality can only be assessed during the recovery process itself. Hence, residual quantity (yield loss: how many units will ultimately be recovered?) and timing uncertainty (how long will it take to recover or decide to dispose?) still remain, even after the physical receipt of the product returns.

Consequently, a larger portion of uncertainty would be resolved at the DDP if more effort was invested there in testing/grading or in collecting information about the state of returns during use (data logging). With regard to the first option, the nature of products or the nature of testing/grading operations may exclude such an option. The returned item may need disassembly in order to assess its quality state, which may be infeasible at the point of receipt. Likewise, testing may require certain equipment or expertise which is only available upstream. On the other hand, data logging and installed base management is mainly possible for electronic products. Furthermore, such approaches do not necessarily result in a definitive conclusion regarding a product's quality state.

To illustrate, consider the recovery of leased copier equipment. Some researchers (e.g., [10, 14]) count leasing among the major success factors for effective implementations of product recovery, because through leasing firms may have a better control of return streams. However, even in the case of lease contracts the control on timing and quantity is not perfect, since the customer may opt to extend the contract. Suppose there is no such option and there are no other sources of returns. Then the firm knows exactly when and how many products will return and plan recovery activities accordingly. The condition of returned items are, however, still unknown and maybe more importantly, non-uniform, even if a lot of items come from the same installation. It may also turn out that some of the cores or components are not recoverable. In the case of component remanufacturing, inspection and testing may require disassembly, which takes place after the core is released to the shop floor. Hence, quality uncertainty carries over the other two types of uncertainties along the CLSC and onto the shop floor.

This persistent variability of the condition of returned items is the main source of complexity in product recovery systems [11]. In the same study, it is noted that, since used products serve as raw materials in such systems, planning and control are much harder than traditional systems, which primarily deal only with demand uncertainty.

In summary, quality uncertainty has a deeper impact on the CLSC and may extend the reach of the other two types of uncertainties. Therefore, as a preliminary conclusion, we put forward that research focusing on timing or quantity uncertainty issues in product recovery systems also need to consider quality uncertainty for greater relevancy of the outcomes. This calls for the development of a structured view of quality in product recovery, which is the topic of the rest of this chapter. To do so, we focus on definitions of quality in the next section. First, we present extant quality and (quality based) value definitions from the literature and subsequently relate them to the product recovery environments.

2.3 Definitions of Quality

Garvin [15] provides five definitions of quality, based on different views:

1. Transcendent: This definition refers to "innate excellence". In other words quality is not the result of a specific attribute, but rather a "state".
2. Product based: According to this view quality is a precise and measurable variable. It is a function of certain attributes of the product. The more of those

attributes the higher the quality. The product-based approach is based on performance, features, and durability dimensions of quality.

3. User based: Individuals have different needs and quality is determined by how well these preferences are satisfied. In operations management this view is represented by the "fitness for use" concept. The user-based approach is based on esthetics and perceived quality dimensions as well as more tangible dimensions such as performance and features.
4. Manufacturing based: Unlike the user-based view, which is based on subjective preferences, this view uses objective measures such as tolerances and performance standards. Any deviation from specifications implies a reduction in quality. Conformance and reliability dimensions of quality are the focus of this approach.
5. Value based: In this view quality is jointly determined by the product's conformance to specifications and the price (cost) of attaining that product.

The transcendent view of quality does not provide a tangible scale for measurement. What it lacks is provided by the product-based, user-based, and manufacturing-based views. As noted by Hopp and Spearman [16], these views are product oriented. In other words, they pertain to what is "seen" by the customer. Naturally, it is ultimately important to match what is delivered to what is required. Therefore, a basic tenet is that the product's quality should be defined from the customer's point of view.

Customers have not always been at the focal point of the quality approach. For a long time, the quality concept was rather manufacturing based and the primary concern was detection and control. Due to economic growth, whatever was produced could find a market and only after competition increased customers came into the picture [9]. Delivering what the consumer wants requires more than manufacturing excellence. As opposed to product-based (engineering) and user-based (marketing) definitions of quality that would fit the organizational boundaries, quality is in fact delivered as a result of a process; an aggregate effort from design to manufacturing and then aftersales. This view has led to the emergence of total quality management (TQM).

TQM is a system approach that works backwards and forwards along the supply chain [9]. At the heart of TQM lie the concepts of continuous improvement and "customer value". Customer value extends the value-based definition of quality by incorporating price or costs. Bounds et al. define customer value as "a combination of benefits and sacrifices when a customer uses a service or product to meet certain needs". Those consequences that contribute to meeting one's needs are benefits, while those consequences that detract from meeting one's needs are sacrifices. Thus, Bounds et al. argue that customer value concept encompasses all definitions of quality. To provide value, product designs must conform to customer needs (user-based and product-based quality), manufacturing processes must conform to the designs (manufacturing-based quality), and the product must deliver performance (user-based quality). Value is delivered to the customer during the "use process", which includes all the activities that customers go through in using a product: find, acquire, transport, use, dispose.

The value concept can be extended for product recovery situations. In [13] and [14], "value of returns" is used to define different CLSC strategies. The authors define "negative externality value" and "positive intrinsic value". Negative externality value refers to potential environment or safety risks as well as negative influences on brand image. Positive intrinsic value refers to the "built-in value" and depends on the type of return. In [13] Le Blanc argues that positive intrinsic value is related to the value in reuse for End-of-Use returns and material value for End-of-Life (EOL) returns. Therefore, these definitions are mostly based on what is left of the primary value added process. Thus, from a quality angle they are product-based definitions and not value-based ones.

In [14], a third value definition, namely the time-based value, is used. This notion is based on the time sensitivity concept introduced by Blackburn et al. [17] for commercial returns. It is built on the observation that the value of a product typically diminishes over time. Certain consumer electronics, for instance, may lose 1 % of the original sales value per week. Le Blanc [13] also acknowledges that value can be a function of time. However, unlike Krikke et al. [14], Le Blanc [13] does not present a time-based value definition, but rather argues that value of returns (positive and negative) can be time dependent.

Employing these definitions and using the concepts behind customer value, we can describe "return value" as "a combination of benefits and sacrifices when a product is used in a certain recovery option". In this way the "return value" definition encompasses acquisition of recoverables, reverse logistics activities, and recovery operations which constitute the sacrifices. For example, the existence of a collection network, mandatory take back policies, having a design that facilitates recovery operations, developing a secondary market, etc., define the sacrifices. On the other hand, the intrinsic value of the return, the natural resources saved, improved brand image, etc., define the benefits. The return value definition captures the time dependency of the returns since the recovery options that are available are a function of time. As a summary, a quality-based definition captures the most essential aspects of return value in the recovery processes.

However, the benefits and sacrifices are dependent to a great extent on the recovery option. The recovery options that can be exercised by a supply chain actor are mainly a function of *quality*, a fact that makes the latter the main determinant of return value. Moreover, in order for the value to materialize after recovery, the supply and demand should match. However, an end-user may have a different quality perception of recovered items when compared to newly manufactured items; this gives rise to additional demand uncertainty. Therefore, due to the quality uncertainty of the recoverables the definition of "return value" does not in fact possess the same operational power as "customer value".

This can be explained by the fact that the concept of customer value, which essentially is a "forward" supply chain concept, is well supported by quality definitions and procedures to translate customer needs. Therefore, it is possible to operationalize the concept by segmenting the market and measuring value for each type by marketing tools. Moreover, all the processes in the forward supply chain are tuned to control variation, thus ensuring predictability and stability.

In contrast to this, the "use process" that closes the supply chain is expected to introduce a substantial amount of variability into the chain. Although the acquisition and upstream testing can reduce the variability introduced to the recovery process, the residual variability in turn makes the return value a less useful concept for operational purposes. In other words, incomplete information about quality makes an overarching definition less effective. A similar limitation, likewise stemming from quality variability, was noted by Le Blanc [8] when trying to find out the determinants of the aforementioned DDP. The author concluded that quality information has an obvious relation with where the decoupling point should be placed but the relation is "not unambiguous", thus weakening the DDP concept.

A promising research direction, as pointed out by Krikke [18], is to analyze the "return value" from different value perspectives (see Sect. 2.6). However, since our focus is on the quality aspects of product recovery, we will turn our attention to the building blocks of the value concept in terms of quality definitions. More specifically, in the next section we will focus on the applicability of these definitions to the quality concept along the CLSC.

2.4 Quality Aspects of Product Recovery

Quality, as we have seen, takes on various roles in a CLSC (Fig. 2.1). First, quality problems can be the driver behind the return process itself, such as in warranty returns [5]. Second, the uncertain condition of recoverables introduces variances in material and product flows. Third, the recovery options are defined with respect to certain quality specifications. The perceived quality of the recovered items by the customer/user constitutes the fourth aspect.

For all categories of reverse flows the return reason can be directly related to quality aspects. Warranty returns represent a failure on the reliability dimension of quality. In commercial returns, although the product may be completely functional, there is usually a mismatch with the customer's expectation. This can happen with respect to performance or perceived quality dimensions. For End-of-Use returns the product no longer satisfies the quality expectations of the customer due to changing preferences or better products entering the market. EOL returns are again initiated by failing quality issues due to the product exceeding its technical lifetime. Hence, quality is established as the main driver of reverse streams.

Consequently, the return reason, largely driven by quality aspects, defines the available disposition routes to some extent. For example, if either "esthetics" or "perceived quality" is the lacking dimension as in commercial returns, then the return is possibly routed to direct reuse (that is restocking). If the "features" dimension of quality is lacking the return is a candidate for refurbishing or remanufacturing (e.g., copier remanufacturing). Nevertheless, since the returns are input to the forward flow, a more accurate definition of "product return" is

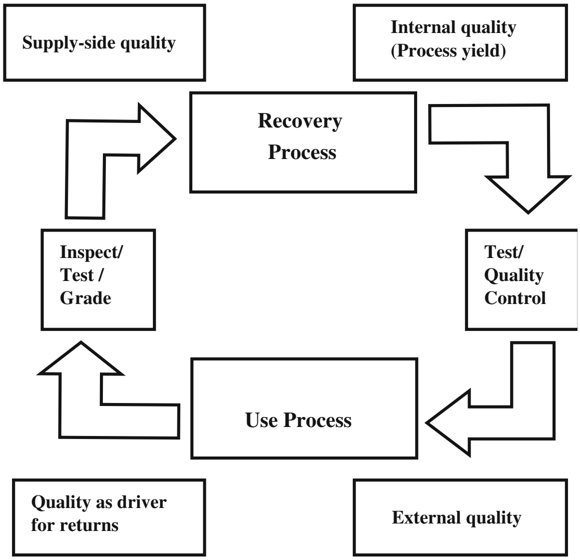

Fig. 2.1 Depiction of quality aspects in a generic product recovery network

necessary to control the input. Therefore, manufacturing or product-based views of quality with specifications and performance standards are more appropriate. In essence this means that no two items from the same return stream are alike with respect to these specifications, even if they are returned for the same reason.

In Fig. 2.1 we use the term "supply-side quality" for the unknown condition of returned items. The magnitude of uncertainty changes with respect to the type of return stream and the complexity of the product [8]. As Guide points out, as the product gets more complex, simply there are more things that can go wrong. To connect the level of uncertainty and quality as a return reason, we can use the sojourn time of a product with the customer as an explanatory link. Roughly, we can argue that if the sojourn time is relatively short, like with warranty returns, or relatively long, like with EOL returns, the quality and thus the value uncertainty is typically small. In the former, there is a quality complaint on the performance dimension, but the variance is small since the product has not been in extensive use. In the latter, product has no residual functionality or value left apart from material recycling. In between, when the length of the "use process" is more variable, End-of-Use returns pose more quality uncertainty. Without any data logging or product monitoring, it is hard to determine the condition of the product and its components. Moreover, the possibility of damage in transport is higher in the reverse chain since the products are not packaged in a uniform, proper way.

Usually the uncertainty is resolved by checking nominal characteristics and/or inspection-testing efforts. As examples, in copier remanufacturing [19] and cellular phone remanufacturing [20], there are grades defined by nominal characteristics and basic functionality of items. In commercial returns setting, this step is crucial for the decision to refund the customer. In addition, the routing of returns is a result of this

Table 2.1 Definition of product recovery options (adapted from [21])

Recovery option	Quality requirement
Repair	Restore product to working order
Refurbishing	Inspect all critical modules and upgrade to specified quality level
Remanufacturing	Inspect all modules and parts and upgrade to “as good as new” quality
Cannibalization	Recovery of components with “working order” requirements
Recycling	High for production of original parts; less for other parts

activity. In product recovery situations often firms have a number of disposition options available. These options are repair, refurbishing, remanufacturing, cannibalization, and recycling [21]. The best choice among these options is affected by the economics and the incoming quality. Therefore, inspection/testing mechanisms also function as a gateway for the recovery process options.

The third dimension of quality in product recovery systems is internal quality. In Table 2.1, each of the recovery options is defined with respect to the quality requirements to be satisfied. These definitions refer to the conformance to predefined standards and therefore are based on the manufacturing-based view of quality. Therefore, once these standards and specifications are in effect, it seems possible to apply the traditional (or primary production) quality processes to recovery situations. However, the nature of the recovery process in most cases dictates performance testing after recovery. In other words, unlike manufacturing (or primary flows) where variations of the processes are stable and controlled, due to the input variability, recovery processes may lead to “defectives” or yield loss. This yield loss may also be the result of the recovery process itself. For example, if the recovery process requires disassembly and the product is not designed to facilitate that operation damaging of the components might occur.

Therefore, after the recovery process, the specified quality requirements are checked by a “test-quality control” step. We will use the term “internal quality” for the process yield issues regarding the recovery operations (Fig. 2.1). It is worth noting that due to the uncertainty from the supply side the test/quality control procedure is essential. In other words, traditional tools such as sampling and control charts are not suitable for the recovery process as they rely on standardized, high quality inputs. Hence, each unit of the output must be checked and tested before meeting demand or reassembly.

The fourth and final quality aspect that we consider in product recovery environments is the “external quality” or the quality observed by the customer. This facet of quality in recovery systems is similar to the traditional usage in manufacturing and engineering aspects. However, there are also additional marketing and strategic issues related to external quality. First, in terms of perceived quality, recovered products or products that have recovered components are sometimes thought of as being inferior. The marketing of these products, with concerns such as market cannibalization and protecting the brand image, may require significant effort. For example, in copier remanufacturing, to convince the customers, remanufactured machines are offered with the same warranty assurances as the new ones. In tyre retreading, this negative perception together with low cost competitors from Far East results in limited use of recovery opportunities for passenger car tyres [22]. Second, if recovery is carried out by independent parties and not done properly it may tarnish the Original Equipment Manufacturer's quality reputation. The case of printer cartridges is an example. Lexmark's move into product recovery and protecting the cartridges by design changes is a result of such concern [23]. Brand protection is one of the main drivers behind car manufacturers' part recovery efforts [24, 25], preventing third parties from recovering their engines without proper quality control.

Summarizing, different definitions apply to the different roles of quality along the CLSC. These are depicted in Fig. 2.2. Returns are triggered by an overall value-based definition of quality. A returned product fails to deliver any more value to the customer. This failure can take place due to any of the dimensions of quality such as performance, reliability, esthetics, etc. Following that, at the input side of the recovery process the product-based definition of quality applies, which relies on performance, features, and durability dimensions. These dimensions, for example features of an electronic product or performance of mechanical parts, are instrumental at the testing/grading step to determine available recovery routes. In other words, the quality of return is measured along certain dimensions. At the output of the recovery process, the internal quality is measured; this time according to manufacturing definitions of quality. There are acceptable tolerances and standards that the recovered product should conform to. When it comes to the external quality or the preferences of the customer, the user-based definition of quality applies; this drives the purchase decision and the return decision. The perceived quality dimension plays a prominent role in this definition and it is more pronounced in product recovery systems than in forward supply chains.

In conventional (forward) production environments quality and quality management have been on the management agenda for quite some time. There is an established philosophy as well as tools and techniques to apply. However, the nature of product recovery environments would not allow the use of some well-known tools like statistical process control in the short run. Given the divergent structure at the "supply side" of product recovery, there is little chance to control incoming variability. This will often lead to unstable variation in the output. Since the recovered components are fed into the primary production lines or completely remanufactured products are delivered to the customers, each item is inspected and tested after the recovery operations. The need to inspect each one of the incoming items (100 % Inspection) and output is reminiscent of early stages of quality control where the focus was on detection. Even with design and process improvements, this is unlikely to change, at least soon. On the other hand, this does not affect the fact that, true to the TQM spirit, the aim and the real benefit should be controlling the variability coming from the previous stages. So at this phase of product recovery where the systems are still developing, the benefit probably lies in utilizing the problem solving and forward-thinking aspects (process thinking, continuous improvement) and organizational aspects (cross-functional management) of quality management. In the next two paragraphs, we will discuss these two aspects.

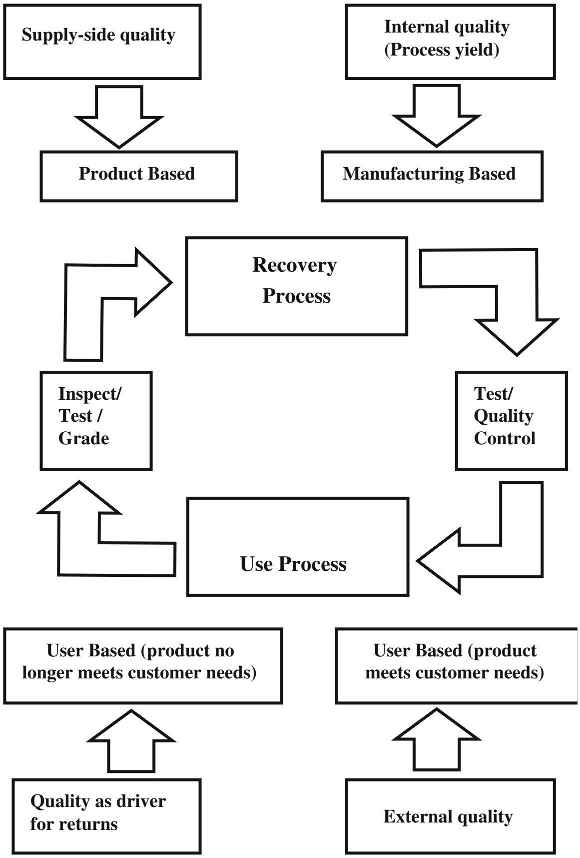

Fig. 2.2 Quality definitions along the CLSC

The process-oriented view of quality necessitates the exploration of cause and effect relationships, since quality is a result of an effort along the supply chain. In other words, controlling the quality of inputs to a process is achieved by controlling the previous process. Using this reasoning, what is delivered to the customer ultimately affects the reverse flow. For example, in [26], Klausner and Hendrickson point to the fact that power tools are generally “over-engineered” for an average user, thus recovery of certain components is highly feasible. In the automotive industry, on the other hand, the “built-in obsolescence” concept is used to limit the life of certain components. With European Union regulations holding the manufacturer responsible for EOL vehicles, thus closing the loop, such practices have a direct impact on the feasibility of recovery operations. Therefore, in the product recovery setting, the quality and the value concept should be defined both for the “use process” and the “recovery process”. Hence, the product should not only deliver value to the customer, but also should retain a “return value” that can be defined, built-in, measured, and extracted with minimal effort and uncertainty.

From an operational point of view, this closed loop view of quality calls for design improvements by feeding back recovery know-how to designers. In [23], using a resource-based view of the firm, Toffel argues that cross-functional management and continuous improvement capabilities, which are cornerstones of TQM programs, can enable organizations to transfer knowledge that has accumulated in the recovery stage to the design stage. Such approaches will undoubtedly contribute to enhanced quality throughout the CLSC and hence, better decision-making and more return value. In the next section, we turn our attention to managing the product recovery systems themselves.

2.5 Product Recovery Management and Quality Framework

In this section, we relate the quality framework of Sect. 2.4 to the planning and management of recovery systems. This way we establish a link between the quality variability and the planning of recovery systems. To do so, we employ three frameworks from the literature that deal with the planning of product recovery systems [6, 7, 8]. In [8], the characteristics of remanufacturing systems that complicate planning and control activities are discussed. In [7], Geyer and Jackson present their "Supply loop framework", which is used to determine the constraints (or inefficiencies) in the CLSC. Compared to [7] and [8] which address a wider scope of the closed loop supply, Fleischmann et al. [6] focus on the network structures for product recovery and present a classification. In this section, mainly the frameworks in [7, 8] are used to establish a link with our quality framework, while the framework in [6] will be employed in network design-related aspects.

In [8] (and also in [12]), seven major characteristics that significantly complicate management of recoverable manufacturing systems are presented. These characteristics are the following:

1. The uncertain timing and quantity of returns.
2. The need to balance returns with demands.
3. The disassembly of returned products.
4. The uncertainty in materials recovered from returned items.
5. The requirement for a reverse logistics network
6. The complication of material matching restrictions.
7. The problems of stochastic routings for materials for remanufacturing operations and highly variable processing times.

Although these factors are mainly reported for remanufacturing, they fit other types of product recovery as well. These characteristics correspond to constraints on the CLSC in the framework of [7]. A process in the CLSC is constrained if it has difficulties with the output of the upstream process. Therefore, the constraints for the "Acquisition process" (i.e., "access to the products leaving the use process") are characteristics 1, 2, and 5. The constraints for the "Recovery process"

Table 2.2 Complicating characteristics and constraints on recovery networks

Framework Guide [8]	Framework Geyer and Jackson [7]
1. The uncertain timing and quantity of returns 2. The need to balance returns with demands 5. The requirement for a reverse logistics network	Constraint on acquisition
3. The disassembly of returned products 4. The uncertainty in materials recovered from returned items 7. Uncertain routings	Constraint on recovery
2. The need to balance returns with demands 6. The complication of material matching restrictions	Constraint on secondary use

are 3, 4, and 7 and the constraints for the "Secondary use process" are 2 and 6. This mapping is summarized in Table 2.2.

To link our quality framework to the other two frameworks, we discuss the characteristics presented above to find out how they are affected by different aspects of quality, namely "Supply-side quality", "Internal Quality", "External Quality", and "Quality as a driver for returns".

1. *The uncertain timing and quantity of returns*. A return is initiated when the product does not deliver any customer value. Therefore, this characteristic is mainly related to "Quality as a driver for returns". Further, as put forward in Sect. 2.2, the quality uncertainty is the main source of uncertainty for the recovery process since it carries timing and quantity uncertainties over into the process. In this regard, this characteristic is also related to "Supply-side quality".
2. *The need to balance returns with demands.* Firms must balance the customer demand with the returns by either disposing of excess or manufacturing (purchasing) new items to be able to meet demand. Therefore, the variability of "supply-side quality" may necessitate acquisition management activities which in turn are aimed at influencing the flow from the (primary) use process. On the other hand, the lack of an efficient secondary market can constrain the CLSC as noted in the framework of Geyer and Jackson [7]. The "External Quality" aspect of our framework is closely related to the dynamics of the secondary market as explained in the previous section.
3. *The disassembly of returned products.* In [8] this characteristic is discussed as a (re-)manufacturing step before the release of parts to the shop floor only. Fleischmann et al. [6] interpret it in a broader sense to denote all operations for determining whether a given product is reusable and in which way. Using the latter view, the "Supply-side quality" in our framework is related to this characteristic in terms of the level and method of testing required and its location (centralized or decentralized).
4. *The uncertainty in materials recovered from returned items.* This characteristic is directly related to the "Internal Quality" aspect. In other words, it is related to the yield from the recovery.

Table 2.3 Complicating characteristics and Constraints on Recovery Networks

Quality Aspect	Quality Definition	Framework Guide [8]	Framework Geyer and Jackson [7]
Quality as driver for returns	User-Based (product no longer meets customer needs)	1. The uncertain timing and quantity of returns 2. The need to balance returns with demands	Constraint on acquisition
Supply side	Product based	5. The requirement for a reverse logistics network	
Internal quality	Manufacturing based	3. The disassembly of returned products 4. The uncertainty in materials recovered from returned items 7. Stochastic routings	Constraint on recovery
External quality	User-based (product meets customer needs)	2. The need to balance returns with demands	Constraint on secondary use

5. *The requirement for a reverse logistics network.* This characteristic encompasses how products are collected from the end-user and brought to the recovery facility. In their analysis of product recovery networks, Fleischmann et al. [6] note that in traditional production/distribution systems, destination of flows are known with certainty whereas in product recovery networks the routes are dependent on quality and distinguish three types of networks in their analysis: bulk recycling networks, assembly product remanufacturing networks and re-usable item networks. Especially for assembly product remanufacturing networks, the quality of the collected product leads to centralization/decentralization of testing and inspection activities. In this sense this requirement for a reverse logistics network and its design is related to both “Quality as a driver for returns” and “Supply-side quality” aspects.
6. *The complication of material matching restrictions.* This characteristic is specific to the cases where product recovery is serial number-specific. For instance, in aircraft engine recovery certain engine parts need to be recovered as a set. This characteristic does not have a direct relation to quality uncertainty.
7. *The problems of stochastic routings for materials for remanufacturing operations and highly variable processing times.* As Guide [8] points out, variable quality translated as variable processing times make resource planning, shop floor control etc. more difficult. Therefore, this characteristic is related to the “Internal Quality” aspect.

To summarize, out of the seven complicating characteristics reported in [8], six of them are related with the quality uncertainty. In Table 2.3, these relationships are summarized.

Moreover, Table 2.3 establishes a link between definitions of quality and complicating characteristics, and constraints of product recovery networks. As such it gives a comprehensive overview of how the challenges encountered in the CLSC link to the various quality dimensions. Hence, Table 2.3 provides management with powerful handles to actually act on the challenges through quality improvements.

2.6 Conclusions and Future Research

In this chapter, we have analyzed product recovery systems from a quality point of view. We have established quality uncertainty as the main source of variability in product recovery systems. Managing better the quality (uncertainty) in the recovery systems will lead to more efficient CLSC and better use of recovery options. To this end, the framework presented in Sect. 2.4 provides the necessary building blocks and structure by identifying applicable definitions of quality. Furthermore, the link between our quality framework and the existing frameworks in the literature, as established in Sect. 2.5, outline the scope and impact of quality in product recovery systems. Our framework clearly shows that problems and inefficiencies due to quality issues downstream can often be explained through quality management issues upstream in the CLSC. Hence, instead of planning capacities to deal with uncertainties and lack of quality in the recovery process, managers should analyze the processes further upstream to avoid these issues in the first place. The suggested framework can help managers to analyze potential quality bottlenecks in a structured way. Likewise, researchers should investigate the impact of this approach in terms of logistics costs and value creation.

One future line of research can be the in-depth analysis of the impact of quality on the complicating factors as described in Guide's framework [8] and the constraints of Geyer and Jackson's framework [7]. This could be done along different dimensions such as different types of returns (EOL, End-of-Use, commercial, and warranty returns) and different product types (electronics, automotive etc.). Another important line of research is to analyze the "return value" from different perspectives, for instance as coined by Krikke [18] (sourcing value, environmental value, customer value, and informational value), to quantify the impact of quality and quality uncertainty on value creation. For this, however, a proper framework needs to be developed, defining the value dimensions and assigning proper constructs to measure value along these dimensions.

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