Unlocking the Potential of Data in Circular Manufacturing: Opportunities for data sharing and stakeholders' collaboration

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Abstract: Circular manufacturing represents a transformative approach to production and consumption, emphasizing resource conservation, waste reduction, and the creation of sustainable, closed-loop systems. It is clearly a competitive advantage and a market opportunity for manufacturers. However, implementing circular strategies and closed loop systems requires seamless flow and sharing of data across different stages of the product lifecycle from design to production, and End of Life. Therefore, disparate systems, incompatible data structures, and data silos present a challenge for the integration and harmonization of data from different sources for circular manufacturing. Additionally, the lack of system interoperability limits the ability to gain a holistic view of the circular manufacturing process, hindering effective decision-making and optimization. This research paper aims to investigate the nature of data sharing for circular manufacturing, focusing on the strategies employed and the pivotal role of sharing data between stakeholders within these strategies, from a product lifecycle perspective. A literature review is performed on the use of data from each lifecycle stage of the product for closed loop manufacturing, as well as the participation of the stakeholders within the circular manufacturing practices. The outcome of the review is a discussion on the collaboration opportunities available for manufacturing companies, focused on exchanging and sharing data, that will support the implementation of circular manufacturing. This work presents the role of each actor along the product lifecycle in supporting circular manufacturing activities data provider (passive engagement), data receiver, or implementer of circular activities (active engagement).

1. Introduction

Manufacturing has an immense effect on the environment and how people use natural resources. As society's ability to create products has evolved, so have societal expectations for managing the effects of manufacturing processes. The traditional 'make-use-dispose' economic model is being replaced by closed loop models [1] enabled by Circular Manufacturing (CM). The core tenet of CM, or circular business models within manufacturing, is the maximization of resource retention in the economy. This is made feasible by using items for a longer period of time and by restorative processes that reuse, remanufacture, and recycle waste products, by-products, and other resources to bring them back into the economy [2]. Historically, environmental, and societal restrictions have been implemented in a reactive manner to limit the detrimental effects of the manufacturing sector. Producers have recently tried more proactive strategies to restrict consequences by anticipating them during the planning and production phases [3]. Accordingly, the value of data, and their use in predictions, decision making, and optimization, has been an important topic of research and industrial attention for circular economy and closed loop manufacturing. Within circular economy literature, a restriction to the successful implementation of CM practices has been the lack of data and information, and the lack of their exchange [4]. Previous articles addressed these gaps by focusing on specific technologies or protocols to enable data sharing, such as blockchain [5], or on analyzing the needed data for various circular economy topics [6], [7]. However, a study on the needed relationships and collaboration between different stakeholders to enable data sharing for CM is missing. Accordingly, this paper intends to address the data and information gap within CM by conducting a literature review to analyze the active involvement of stakeholders of the product lifecycle within various CM strategies, as well as the data and information needed from each stakeholder for CM implementation. The objective is to discuss the needed collaboration between the stakeholders to support the implementation of CM strategies, as well as analyze the role of each stakeholder as data supplier and data receiver for CM strategies. The article addresses CM strategies and stakeholders of small scale products as well as industrial assets from a product lifecycle perspective [8].

The circular strategies addressed within this paper have been chosen from past reviews to provide a comprehensive view of the strategies discussed in literature within the manufacturing industry. They are: Recycling [9]; Remanufacturing [9]; Reuse [9]; Disassembly [9], [10]; Design for maintainability, durability, repairability, and correct disposal [6], [9]; Servitization [10]; Resource efficiency and cleaner production [10]; Design for cross-model compatibility [6]; Reverse logistics & closed-loop supply chain [9]; Waste management [10]; Industrial symbiosis [10]; refuse [11], [12]; rethink [11], [12]; reduce [11], [12]; Refurbish [6], [12]; Repair [6], [12].

The article is structured the following way, as seen in figure 1. Section 2 presents the methodology of the literature search and review carried out. Section 3 reviews the stakeholders within the product lifecycle and their involvement in CM strategies. Section 4 presents the data and information requirements for CM practices. Section 5 draws upon the presented information from section 3 and section 4 to discuss the data and information sharing opportunities within CM. Finally, section 6 presents the conclusion and future avenues for research.

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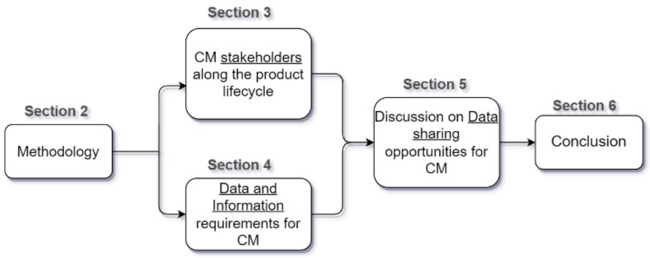

Fig. 1. Structure of the paper

2. Methodology

This paper presents a review of the literature addressing the needed data and information for CM and the dependent involvement of stakeholders. The search for papers was carried out on Scopus as it is the largest database that contains articles from several well-known publishers, hence provides inclusive results [13]. The search and review is conducted from a product lifecycle perspective, analyzing the articles addressing data collection, data management, or data sharing for circular activities along the Beginning of Life (BOL), Middle of Life (MOL), End of Life (EOL), or throughout all stages of the product lifecycle [14]. Within this article we highlight the perspective of considering assets as complex products operating within a complex systems where multiple stakeholders intervene, and hence have the same lifecycle stages as a product lifecycle made up of BOL, MOL, and EOL [8].
Accordingly, the search methodology consisted of the following search string followed by a snowball sampling of relevant articles.

TITLE-ABS-KEY ((data OR information OR knowledge) AND (shar* OR exchange) AND (bol OR "beginning of life" OR mol OR eol OR "end of life" OR "middle of life") AND ("circular manufacturing" OR "closed loop" OR circular))

Articles that were written in any other language than English have been excluded to ensure readability by all authors. The chosen subject area has been constrained to 'Engineering' and 'Business, Management, and Accounting'. No limitation was placed on the year of publishing of the articles. 31 articles resulted from the search on Scopus. For the choice of papers for the review, the unit of analysis is on the Micro level (products, companies, consumers) [15] resulting in the articles displayed in Table 1, divided according to the lifecycle stage they address. As seen from Table 1, the area of investigation of this article is a challenge that has not yet been studied enough as the low number of papers demonstrate.

Table 1 Chosen papers for review

Product Lifecycle Phase	References
BOL	[6], [9]–[12], [16]–[18]
MOL	[6], [9], [12]
EOL	[10], [11], [16], [19], [20]

3. Overview of the current circular manufacturing stakeholders along the product lifecycle

The participation and collaboration of numerous stakeholders from the product value chain (such as suppliers, industrial manufacturers, etc.) and systems is necessary for the successful implementation of CE strategies as each stakeholder only has knowledge of particular technology and activity [21]. An example mentioned in [21] highlights the importance of tight cooperation built on the exchange of data models between the recycling company and the manufacturing or maintenance company, to support the recycling of the old components discarded from the upgrade activities that could be made much easier by having the inspection results. Therefore, the first step of mapping out the needed collaborations is to map out the stakeholders within each product lifecycle stage and discuss their involvement and activities in the various CM strategies. The following sections discuss the stakeholders and their roles within CM for each lifecycle stage.

3.1. Stakeholders in the BOL

The BOL is made up of the design and the manufacturing activities, and this is where most of the static data and information about the product is generated [16]. The stakeholders involved in this phase, as seen from table 2 in column Stakeholders, are the suppliers, designer, and the manufacturer. Depending on the type of industry, the designer and manufacturer could be within the boundaries of the same company or of separate companies. For example, in the cosmetics industry the company that designs the formula and packaging of the product is different than the company that manufacturers these parts, while in the automotive and computer sectors Original Equipment Manufacturers are typical, and they have a specific role of designing and assembling parts. For the manufacturer, they could be the product manufacturer or the parts manufacturer. In table 2 the role of each stakeholder along the product lifecycle is mapped against the CM strategy they can implement, or lead, according to the reviewed literature. Industrial Symbiosis is a strategy that all stakeholders from the BOL can participate in by trading resources, byproducts, and scraps. This strategy tries to encourage collaboration between businesses in order to achieve shared objectives of environmental and financial sustainability [10]. Therefore, designers, manufacturers, and suppliers can benefit from understanding what materials they can gain from other companies.

The following are the roles of the BOL stakeholders in the circularity strategies:

1. **Designer:** Designers have the largest role in circularity compared to other stakeholders along the value chain, with being responsible for strategies such as:
   - *Design for X* (including Design for maintainability, durability, repairability, correct disposal [9], design for cross-model component compatibility [6], and design for ease of disassembly [10]): Products need to be manufactured using materials and methods that allow the correct EOL treatment of the product in a circular manner, and that starts at the design process. This allows the fulfilment of closed loop manufacturing [11] and paving the way for the downstream stakeholders to be able to carry out disassembly and

maintenance in a more effective and sustainable manner.

- *Refuse, Rethink, Reduce:* These strategies encourage designer to avoid or reduce the use of virgin materials for the product [11] hence reducing the waste and encouraging industrial symbiosis.

Accordingly, companies carrying out the design process need to have the awareness on circularity principles and be equipped with data and information about the whole product lifecycle to be able to optimize the design iterations to increase the level of circularity of the product, from a design perspective.

2. **Manufacturers** are responsible for the production and assembly of the product. According to the reviewed articles they can adopt the following circularity strategies:
   - *Resource efficiency and cleaner production* [10]*:* Resource efficiency is requiring manufacturers to produce products and packaging with less materials, while cleaner production is focusing on sustainable methods of using energy and water for the production process, such as the reliance on renewable energy sources;
   - *Refurbish* [12] *and Remanufacture* [12]*:* Both refurbishing and remanufacturing are strategies that require the manufacturer to acquire back used products and restoring and transforming them up to a certain level in case of refurbishment or to be good as new in case of remanufacturing.

3. The role of the **supplier**, within the reviewed articles, is visible in *Resource efficiency and cleaner production* [10], where suppliers could focus on reducing resource use such as water and energy, as well as employ sustainable methods for obtaining or sourcing the materials.

3.2. Stakeholders in the MOL

The MOL is made up of logistics, maintenance, and usage stages. Accordingly, as seen from table 2 the stakeholders involved are the logistics company (Transporter), customer, and the service provider such as maintenance providers.

The following are the roles of the stakeholders within the MOL phase in circularity strategies:

1. **The logistics** company can have an active role in *Reverse logistics* [9].
2. **The service provider** can be involved in the *Repair strategy* [6], [12] : The maintenance service provider can provide repair activities to the asset or product by knowing information about the expected lifetime and repair history.
3. Research on the role of the **customer** during the usage phase has been missing from the reviewed articles.

3.3. Stakeholders in the EOL

In a closed loop supply chain, managing the products EOL is crucial. Firms have to regulate the process of disassembly, as well as the various material and product movements in a closed cycle. This translates into adding a loop to an established supply chain following the EOL stage [22]. In a linear value chain, the EOL would be composed of the disposal activities, however in closed loop manufacturing the EOL is made up of the activities that give the product, parts, and materials a second life such as recycling, disassembly, re-manufacturing, etc. The stakeholders involved in the EOL stage are re-manufacturer, recycling facility, and waste disposal facility. The following are the roles of the stakeholders within the EOL phase in circularity strategies:

1. The **Re-manufacturer** is responsible for *remanufacturing* activities [19] that involves giving a used product a second life and restoring it to be as good as new. The re-manufacturer could also be the original manufacturer.
2. The **Dismantler** has an active role in *waste management* activities [10] .
3. The **Recycling facility** is responsible for *recycling activities* [16] by converting the waste materials into new materials or new products.

Table 2 Stakeholders and their roles in CM in the BOL, MOL, and EOL

Product Lifecycle	**Stakeholders***	**CM strategy actively involved in**
BOL	Supplier	Resource efficiency and cleaner production [10]; Industrial Symbiosis [10]
	Designer	Design for X [9], [11], [12] (including Design for maintainability, durability, repairability, and correct disposal [9]); Easily disassembled products [10]; Design for cross-model component compatibility [6] ; refuse [11], [12]; rethink [11], [12]; reduce [11], [12]; Industrial Symbiosis [10]
	Manufacturer	Resource efficiency and cleaner production[10]; Refurbish [6], [12]; Remanufacture [6], [12]; Industrial Symbiosis [10]
MOL	Transporter	Reverse logistics [9]
	Customer	
	Service Providers	Repair [6], [12]
EOL	Re-manufacturer	Remanufacturing [19]
	Recycling Facility	Recycling [16]
	Dismantler	Waste Management [10]

*Extended from [23], [24] and [9]

4. Data and Information requirements for Circular Manufacturing

The need for data collection and data exchange in support of CE has been discussed in several research articles [7], [25], [26]. In this section, the literature articles have been reviewed to synthesize the data needed for each CM strategy, and the stakeholder responsible for providing this data. The following strategies have not been addressed in section 4 and section 5 due to the lack of information on them in the reviewed articles refuse; rethink; reduce; refurbish; repair.

4.1. Data requirements from BOL

The BOL is the stage from which most data is generated and required for facilitating optimized CM strategies implementation. It can be seen from table 3 that out of the eleven discussed CM strategies, ten strategies could benefit from data and information generated from the BOL phase, emphasizing the importance of data and information collection, storage, and sharing from this phase. Product related data is the dominant type of data needed, such as the Product architecture and the Bill of Materials (BOM) [10] needed for 'Disassembly', and the Testing reports [18] needed for the 'Design for maintainability, durability, repairability, and correct disposal'. These forms of data and information can be described as static data (i.e. data/information that remain the same after its collection) and take on formats such as

- Documents. For example the testing reports [18];
- Pictures. Such as for product components [19] ;
- And CAD files, for CAD/CAM models [19].

Process related data such as the availability of spare parts [6] is needed for 'Reuse' and the 'Design for maintainability, durability, repairability, and correct disposal' strategies, and information about inventory [10] for 'Remanufacturing'. A full list of all the data needed from the BOL stage can be found in table 3.

4.2. Data requirements from MOL

The analyzed articles discussed the use of the data generated from the MOL in six CM activities, namely 'Design for maintainability, durability, repairability, and correct disposal'[6], [9] , Servitization [10], Reverse logistics & closed-loop supply chain [9], Remanufacturing [9], Waste management [10], and Industrial symbiosis [10]. Most of the data needed from the MOL is usage data such as Service log, location, running hours, utilization, external environment [6], product conditions [10], and quality of returned products [6]. Additionally to the usage data, 'Servitization' strategy requires business and marketing data such as Customer demand, needs, requirements, and competitor's actions [10]. However, as stated earlier, research has been lacking on the data needed from MOL phase, specifically on manufacturing companies as users of industrial assets.

4.3. Data requirements from EOL

Data from the EOL is needed either to support EOL activities or to be shared back with the BOL and MOL stakeholders to support the design, production, and use of the next generation of the product for more circular EOL treatment. For example, information about the recycling process [12]**,** Waste characteristics [12]**,** product analysis [12]**,** and Current technologies for sorting/separating materials [20] are needed to support Recycling activities.

While failure time and modes [18] data could be shared with the designers for Design for X activities.

5. Discussion on Data sharing opportunities for CM strategies

The information discussed in section 3 and section 4 have been mapped together in this section to synthesize the opportunities and gaps for data sharing and collaboration in CM. The data presented in section 4 for each CM strategy has been numbered and mapped in table 4 in a material flow matrix. This matrix outlines the flow of the data by having along the vertical axis the stakeholders as the source of the data, and along the horizontal axis the stakeholders as the sink of the data. Within the matrix are also the CM strategies that are enabled by the sharing of the data and collaboration between the stakeholders. For example: looking at the manufacturer as the sink of the data, it can be noticed that the manufacturer could benefit from receiving information about the Product type (3) and Component information of other product models (19) from the designer, to carry out waste management or design for cross model compatibility activities. Accordingly, the matrix allows the visualization of the flow of the data from-and-to the stakeholders in the product lifecycle, as well as the analysis of the strength of collaboration between stakeholders needed for each CM strategy. It also allows the visualization of the areas that have not yet been discussed in literature and that need to be reinforced.

The matrix also allows the visualization of how stakeholders can passively be involved in circularity activities by sharing data generated during their processing/activities. Passive involvement means that stakeholders can facilitate the correct implementation of CM strategies by sharing data about the product, process, or business activities with other stakeholders, instead of actively implementing the strategy. Figure 2 shows an example of the passive involvement of manufacturers and designers in the recycling process in a simplified IDEF0 representation, where it can be seen that the recycling facility is responsible for implementing the recycling activities of transforming waste as input into recycled products as output. However, data from the manufacturer about the waste characteristics and from the designer about the product type could be used as control information to guide the recycling facility during the recycling process and aid in more accurate decision making.

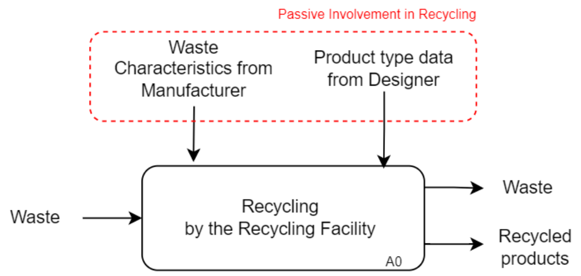

Fig. 2. *Passive Involvement in Recycling*

Mapped along the diagonal are the data that could be generated by each stakeholder for internal use and *active implementation* of the CM strategy. Most of the active participation of the stakeholders in CM strategies is focused within the BOL stage, where:

- the **supplier** needs to generate data related to status of product, machines used, energy used, and carbon footprint [10] to use for implementing 'Resource Efficiency';
- the **designer** needs the 'product type' data for waste management, Component information of other models [6] for the Design for cross-model compatibility, and the testing reports [18] for Design for X strategies;
- and the **manufacturer** needs the product type data and circularity level [10] for remanufacturing and waste management strategies, data related to status of product, machines used, energy used, and carbon footprint [10] use for implementing 'Resource Efficiency and cleaner production', Component information of other models [6] for the Design for cross-model compatibility, inventory of the returned product [10] for 'Reverse logistics & closed-loop supply chain', and the Types and quantities of resources consumed, types and quantities of waste and by-products produced [10] for 'industrial symbiosis'.

The active involvement of the MOL stakeholders in CM has not received attention from researchers. This might be due to the perceived higher importance of the BOL stage for circular activities. Currently in literature, the data generated from stakeholders of the MOL is used by them only for the implementation of industrial symbiosis that requires the participation of almost all actors along the product value chain.

Along the EOL

- The **recycler** needs Waste characteristics and product analysis data [11] for recycling activities;
- The **remanufacturer** needs to produce and record data related to the amount of WIP, the production plan, resource status, scheduling, remanufacturing activities for each product type, and resources to perform these activities [10] for remanufacturing activities;
- And the **disposal facility** needs to keep data on the waste type and quantity and internal storage capacity [10] for waste management activities.

Above the diagonal are the data and information that could be shared downstream the product value chain, while **below the diagonal** are the data that is to be shared upstream. Sharing the data downstream the value chain ensures that the stakeholders involved in the current lifecycle of the product are able to utilize the data in efficient implementation of their circularity strategies. On the other hand, sharing the data upstream the value chain contributes to ensuring that the next lifecycle of the product is optimized and improved for a higher circularity level. Accordingly, both upstream and downstream sharing of data are important and needed for closed loop manufacturing.

Considering data sharing upstream, the map shows that:

1. A large amount of the needed data by other stakeholders is generated from BOL stage (i.e. from suppliers, designers, and manufacturers), further highlighting the importance of the BOL activities in CM.
2. Moreover, it shows that the manufacturer produces the largest amount of data that can be shared with other stakeholders, while also benefiting the most from receiving data for implementation of the strategies. Hence, the manufacturer holds an important role in generating, storing, and managing the production process and product data to be able to share it with other stakeholders.

Considering data sharing downstream, the map shows that:

1. Most of the data generated throughout the product lifecycle needs to be shared back to the manufacturer and the designer, hence they are the stakeholders that have the highest role in receiving the data and information of the product or process from other stakeholders to increase the circularity level of the product in future lifecycles.
2. Little to no information is available in research articles on how the MOL stakeholders could benefit from receiving information or data from the EOL stakeholders on how to use, maintain, ad transport the product in a manner that enables EOL treatment and decision-making.

6. Conclusion

This study set out to explore the nature of data sharing for CM, focusing on the pivotal role of stakeholders in sharing data within CM strategies, from a product lifecycle perspective. In the pursuit of this, a literature review has been conducted on the active participation of stakeholders in CM strategies, as well as the data needs for each strategy from a product lifecycle perspective.

Subsequently, a data sharing and collaboration matrix has been drawn to synthesize the opportunities for data sharing and exchange between stakeholders. Resulting from this matrix are the data the stakeholders need to generate for active implementation of the CM strategies, the data that needs to be shared upstream within the product lifecycle and the stakeholders involved in producing and receiving this data, as well as the data that needs to be shared downstream the product lifecycle to enhance the circularity of the next generation of products and the stakeholders involved in producing and receiving this data.

Reflecting on the scope of this study, certain limitations must be highlighted. This study had a focus on manufacturing companies without specifying an industry. Data and information requirements are likely to be different across industries, and while there is a share of similarities, it leads to the question of their generalizability. The presented discussion is based solely on scientific literature, therefore there is the need for further practical and empirical research.

Several avenues for future research can be outlined. First, in terms of data and information requirements, it is important to examine cross-industry similarities and discrepancies. This would both expand on the study's findings and materialize the needed collaborations. Second, it is considered relevant to study the drivers and potential challenges for stakeholders to share their data. Third, the results of this paper could used to study and quantify the impact of sharing data on CM strategies to have a better understanding of the value of data sharing for CM. Fourth, the technologies and standards needed to enable data sharing within CM could be studied.

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9. Appendix

Table 3 Data needed for CM strategies from Product Lifecycle Phases

Strategies	BOL	MOL	EOL
Recycling [9]	Product type[3], quality[4], functionalities[5] and architecture[6] [10] Waste characteristics, product analysis[8] [10], [12] BOM[9], model[10], original manufacturer and properties[11], components and components specifications[12] [10]		Information about the recycling process[1] [12] Waste characteristics, product analysis[8] [12] Current technologies for sorting/separating materials[37] [20]
Disassembly [9], [10]	Product architecture[6], BOM[9] [10] , product components[12], 3D CAD model[34] [19], BOM[9], disassembly technologies[13] [10]		Tasks to disassemble and time needed[2] [10]
Design for maintainability, durability, repairability, and correct disposal [6], [9]	Testing reports[36] [18] Availability of spare parts, service manual, guidelines for non-destructive disassembly, installation guidelines[14] [6]	Service log[24] [6] Location, running hours, utilization, external environment[25] [6]	Failure time and modes[35] [18]
Servitization [10]		Customer demand, needs, requirements, and competitor's actions[7] [10]	
Resource efficiency and cleaner production [10]	Product characteristics [10], [12] and type[3], final status of product[15], machines used[16], energy used [7], carbon footprint[18] [10]		
Design for cross-model compatibility [6]	Component information of other models[19] [6]		
Reverse logistics & closed-loop supply chain [9]	Design, perishability, complexity[20] [10] Inventory of returned products[21] [10], hazardous material composition[22] [10]	Service log[24] [6] Type, quantity, time, lifecycle stage, and quality of returned products[26] Usage data[27] [6]	
Remanufacturing [6] [9]	Product model[10], type[3], architecture[6] [10] Original manufacturer and properties[11], components[12] [10]	Product conditions[28] [10]	Amount of WIP, production plan, resource status, scheduling, remanufacturing activities for each product type, resources to perform these activities[30] [10]
Reuse [9]	Product functionalities and their location[5] [10] Availability of spare parts, service manual, guidelines for non-destructive disassembly, installation guidelines[14] [6]		
Waste management [10]	Product type[3], components, component material type and sourcing[12], product quality[4], circularity level[23] [10]	Product lifecycle stage, location in the supply chain, end-user consumption, delivery modes[29] [10]	Waste type and quantity, internal storage capacity[31] [10]
Industrial symbiosis [10]	Types and quantities of resources, waste and by-products that can be utilized by other companies[32] [10] Types and quantities of resources consumed, types and quantities of waste and by-products produced[33] [10]		

Table 4 Stakeholders collaboration matrix and data exchange

Source of data \ Destination of data	Suppliers	Designer	Manufacturer	Logistics Provider	Maintenance Provider	User	Recycler	Remanufacturer	Disposal Facility
Suppliers	15, 16, 17, 18, 33 (RE) (I)	15, 16, 17, 18 (RE)	15, 16, 17, 18, 32 (RE) (I)	32 (I)	32 (I)	32 (I)	32 (I)	32 (I)	32 (I)
Designer		3, 19, 36 (WM) (DCr) (RL)	3, 19 (WM) (DCr)			5 (R)	3, 4, 5, 6 (R)	3, 6, 10 (R)	3, 5, 6, 9, 34 (R) (D)
Manufacturer	32 (I)	15, 16, 17, 18, 19 (RE) (DCr)	3, 23, 3, 15, 16, 17, 18, 19, 21, 33 (WM) (RM) (RE) (DCr) (RL) (I)	32 (I)	14, 14, 20, 22, 32 (Dx) (Ruse) (RL) (I)	14, 14, 20, 21, 22,32 (Dx) (Ruse) (RL)	8, 9, 10, 11, 12, 14, 32 (R) (Dx) (I)	9,11, 12, 13, 14, 32 (D) (RM) (DCr) (Ruse) (I)	9, 12, 13, 14, 23, 32 (D) (WM) (Ruse) (I)
Logistics Provider	32 (I)		32 (I)	33 (I)	32 (I)	32 (I)	32 (I)	32 (I)	32 (I)
Maintenance Provider	32 (I)	24 (Dx)	24, 32 (Dx) (RL) (I)	32 (I)	33 (I)	24, 32 (Dx) (I)	32 (I)	32 (I)	32 (I)
User	32 (I)	25, 26 (Dx) (RL)	25, 26, 27, 32 (Dx) (RL) (I)	32 (I)	25, 32 (Dx) (I)	33, 32 (I)	32 (I)	28, 32 (RM) (I)	29, 32 (WM) (I)
Recycler	32 (I)	1, 2, 37 (R) (D)	1, 2, 32 (R) (D)	32 (I)	32 (I)	32 (I)	8, 33 (R) (I)	32 (I)	32 (I)
Remanufacturer	32 (I)	2 (D)	2, 32 (D)(I)	32 (I)	32 (I)	32 (I)	32 (I)	30, 33 (RM) (I)	32 (I)
Dismantler	32 (I)	2, 35 (D)	2, 32, 35 (D) (I) (Dx)	32 (I)	32 (I)	32 (I)	32 (I)	32 (I)	31, 33 (WM) (I)

RE = Resource Effeciency ; I = Industrial Symbiosis; R= Recycling ; WM= Waste Management ; DCr = Design for Cross Model Compatability ; Dx = Design for X ; RM = Remanufacturing; RL= Reverse Logistics ; D = Dissassembly ; Ruse = Reuse