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Product-service-systems for heavy-duty vehicles – an accessible solution to material efficiency improvements?

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Abstract

Previous research has investigated transitions of individual firms to PSS business. It has identified barriers and enablers and specified organizational capabilities needed. However, the transition to PSS has seldom been approached from a product-chain perspective. In addition, previous research has indicated the need for more assessments of environmental gains related to PSSs. This study aims at contributing to these perceived knowledge gaps by means of a case study. Questions posed include: Does the study's case company and one of its suppliers have the capabilities needed to adopt a PSS business model? and Could a PSS really contribute to material efficiency in their product-chain?

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1. Introduction

There are growing societal concerns about the intensity of natural resource use and the environmental burdens associated with it. At the societal-level, the dependency of today's economy on material throughput is often noted as a fundamental problem. At the firm-level, a manufacturer's revenue is often entirely dependent on selling materials in the form of products. Presented as potential solutions to such material dependency, product-service-systems (PSS) are touted ways to reduce a firm's reliance on material throughput. By changing a firm's focus from delivered product to delivered function, use, or result, PSS is thought to lead to reduced material use. Based on this reasoning, proponents of the functional economy promote a transition to more PSS-based business [1].

Previous research has investigated transitions of individual firms to PSS business. It has identified barriers and enablers and specified organizational capabilities needed [2]. Research has seldom, however, assessed such capabilities to adopt (or respond to) PSS in a product chain. Such research is absent despite literature's emphasis on the importance of value chain relationships for PSS [2-4].

The research literature has also presented much theoretical discussion indicating that PSSs should lead to better environmental performance. However, empirical, quantitative results are few and far between. As two rare examples, Lindahl et. al. 2014 and Lelah et. al. 2011 use life cycle assessment to calculate environmental impact reductions related to PSS cases [5, 6]. Although there are a number of other studies that document environmental impact reductions related to remanufacturing in PSS, e.g. Kerr & Ryan 2001 [7], such studies evaluate the environmental benefits of only one key activity (remanufacturing). They do not, however, explicitly assess the effects of the PSS as a whole. The need for more assessments of environmental gains related to PSS and more empirical case studies has been expressed by several authors [5, 8, 9].

The case study presented in this paper aims to contribute to the noted research needs and to the understanding of (1) PSS capabilities in the product chain, and (2) the potential

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environmental benefits of PSS. Questions posed include: Do manufacturers and their suppliers have the capabilities needed to adopt a PSS business model? *and* To what extent could a PSS lead to increased material efficiency in the product-chain?

2. Business models and organizational capabilities

A business model is a description of how the firm creates, distributes and capture value [10]. In a linear business model (LBM), virgin material is used to create products which are sold to a customer and disposed of at the end of the product's useful life. In a circular business model (CBM), the material is instead reused either as recycled material or as used product components. For such a business model, retaining maximum value added is of importance and hence, direct reuse is preferred to remanufacturing which is preferred to recycling [11].

One major challenge with implementing CBM is the reverse flow of products [12]. One solution to this issue is for the producer to retain ownership of the physical products, instead offering a PSS that provides use, function, or result of the product [13]. Enacting such an offering requires servitization of the business, which can in itself be challenging [14].

Regardless of the business model, a firm's competitiveness is dependent on its organizational capabilities [15]. Tangible and intangible resources antecede organizational capabilities by influencing the organization's skills and knowledge base, technical systems, managerial systems, norms and values and thereby affecting the profile of an organization's capabilities [16].

A company that only utilizes LBM likely lacks some capabilities needed to successfully offer a PSS [17, 18]. Capabilities that are key to a PSS include:

- *Remanufacturing:* Create lower cost structure by retaining value-added from manufacturing through for example reuse, refurbishing and remanufacturing.
- *Value chain management:* Manage the additional value chain complexity by (e.g) utilizing the supplier network, retaining value-added of subsystems and components.
- *Reverse logistics:* Manage the additional complexity of logistics in return flows.
- *Asset management:* Create higher revenue by optimizing use of assets against customer-pool requirements and maximizing uptime.
- *Flexible offerings:* Create higher competitiveness by providing dynamic PSS-offerings following individual customer's changing needs.
- *Product design:* Maximize profitability from products-as-assets by designing them to retain value and contribute in PSS-offerings for long times.

3. Material efficiency and material flow analysis (MFA)

According to theory, a PSS is supposed to lead to increased material efficiency, which is defined by Worrell et. al. (1995) as "the amount of primary material needed to fulfill a specific function" [19]. According to this definition, material efficiency for a product is increased if the material needed to make the product is decreased and/or if the function delivered is increased. Based on this relationship, there are many ways to increase material efficiency. Material needed may be reduced by designing the product with less material or another material (product design), by improving raw material extraction and production processes or by increasing recycled material input. Function delivered, on the other hand, can be increased by altering product: (1) design and/or component choice, (2) use, (3) installation and maintenance, (4) reuse (and remanufacturing), and (5) material recycling [19, 20].

4. Method and data sources

The research questions were approached with a case study of T-Co, an international truck manufacturer and one of its suppliers, C-Co, which delivers components that are used in many subsystems to include the engine, gearbox and wheel-end. Researchers wanted to know – what would T-Co do differently if they were to sell truck function and retain truck function throughout the truck's lifecycle? How would C-Co be able to provide products and services to T-Co in the new reality? Do the companies have the capabilities needed to enact a truck PSS? How would changes made by the companies affect the material use required to deliver truck function?

In order to answer these questions, researchers conducted interviews and performed two types of assessments. A review of the firms' capabilities to adopt PSS (capability assessment) was conducted using the Business Model Canvas [21] while Material Flow Analysis (MFA) [22] was used to assess the potential effects of PSS on material efficiency.

4.1. Interviews

Semi-structured interviews were the primary data collection activity for both assessments. Researchers identified interviewees with help from company representatives. In the end, interviewees included 12 personnel from T-Co and two from C-Co. T-Co interviewees had roles in the following areas: regional vehicle sales (1), aftermarket sales and planning (to include remanufacturing business) (4), product development (5), remanufacturing operations (1), and reverse logistics (1). From C-Co, the two interviewees identified included one regional sales manager and one product development manager.

All interviews started with the premise: T-Co sells function and retains truck ownership during the entire truck lifecycle. Interviewees were asked what actions would have to be (or could be) taken if such a PSS were to be initiated. From there, researchers asked questions specific to the objectives of the two assessments (described in 4.2., 4.3). Interviews were conducted in 1-2 hour time slots. All interviews and a workshop (described below) were recorded. Eleven practitioners were interviewed individually, ten in-person and one over-the-phone.

In addition, one two-hour workshop was arranged to discuss what wheel-end design possibilities may be relevant if a PSS for trucks were to be implemented. Three practitioners participated: T-Co's wheel-end expert and the two practitioners from C-Co.

After interviews, researchers listened to recordings, made comprehensive notes, and sent follow-up questions or data requests to interviewees when needed. After all interviews had been completed, researchers reviewed interview notes and identify overall trends.

4.2. PSS capabilities assessment

The two companies' capabilities for PSS were assessed using the Business Model Canvas. The "canvas" depicts a business model as 9 separate building blocks: Customer Segments, Customer Relations, Channels, Value Proposition, Key Activities, Key Resources, Key Partners and finally Cost Structure and Revenues Streams [21]. For this study, Cost Structure and Revenue Streams were not assessed. Hence, the focus was placed on organizational capabilities (networks and resources), not the financial aspects (revenues and costs).

Interviews were thus focused on learning about the current state related to these first seven building blocks and how these building blocks could facilitate PSS implementation. As a complement, capabilities identified in section 2 – remanufacturing, value chain management, reverse logistics, asset management, flexible offerings, and product design – were considered of special interest. From interview data gathered, the companies' business model capabilities for PSS were evaluated as being existing or not existing.

4.3. Material flow analysis (MFA)

Material flow analysis (MFA) is an established method used to systematically map and qualify flows and stocks in a system. It is commonly used for assessing flows of commodities or potential pollutants through regions or economies. The basic steps of MFA include: (1) identifying materials of interest, (2) determining scope and system boundaries, (3) identifying activities or processes of interest, (4) estimating transfer coefficients between activities or processes, and (5) calculation of flows and stocks [22].

Researchers wanted to measure material efficiency in a way that was relevant to the product chain of the two companies and that allowed for accuracy in material quantification. Three component types were chosen as the inputs to the system (materials of interest): one wheel-end component type (*w*), one gearbox component type (*g*), and one engine component type (*e*). All three components are primarily made of steel and are supplied to T-Co by C-Co or one of C-Co's competitors.

Using MFA, data from the material efficiencies were evaluated for the components in two systems: the *current state* (how flows are now) and the possible *modified PSS-state (*how flows could possibly be). The *PSS-modified state* presented in this paper was formed using relatively conservative estimates, assessing changes that appear to be within reach without radical redesign.

The system of interest included the following activities: vehicle manufacturing, use, maintenance-repair, service supply, remanufacturing, dismantling, material (scrap) handling, steel recycling metallurgy and slag handling. The country of Sweden formed the geographical system boundaries and an estimate of export was also included. Material flows were to be depicted for one year through the system. Together, the trucks represent a fleet of a fixed amount of truck function, i.e. the fleet always delivers the same amount of function.

Data collection involved obtaining data for both the current *state* and *PSS-modified state*. Thus, interview questions for the MFA were pointed towards technical and operational changes to the truck system:

If a PSS were to be adopted, would (and could):
- truck design or use life be changed?
- component design be changed?
- truck assembly be altered?
- use and maintenance be altered?
- reuse and remanufacturing be facilitated?
- recycling opportunities be improved?

In what ways and in what magnitude could these aspects (above) be changed?

Data was collected to allow for estimation of truck and component use life as well as transfer coefficients for the activities mentioned earlier. A differentiation was made between *maintenance-repair* and *remanufacturing*, where remanufacturing means that cores are repaired or rebuilt to new specifications. Transfer coefficient estimates for activities *material handling*, *steel recycling* (alloyed and carbon) and *slag handling*, as well as an estimate of truck *export* were taken from (Diener and Tillman 2014; submitted).

From interview and product data, material inputs and transfer coefficients were estimated. Input included components in new trucks and as replacement parts. New truck input was estimated by multiplying the number of new trucks introduced into the system each year (approximately 2000) with the weight of the studied components (of each type) in each new truck.

Replacement part input was estimated based on the number and weight of components that need to be replaced in a year minus the number that are supplied via reuse. Yearly replacements needed for wheel component (*w*) was based on specified component use life (km) and truck yearly driving distance (km). A figure for yearly replacements needed for gearbox and engine components was based on an estimate of how many gearboxes and engines are repaired or remanufactured in a given year. For estimating the potential amount of gearbox and engine remanufacturing for the *PSS-modified state*, the estimated failure frequencies for gearboxes and engines (how many are expected to fail in a population) was compared to the estimated current quantity of gearbox and engine remanufacture and repairs. Reuse was based on adding components reused after dismantling to components reused in conjunction with repair and remanufacturing (repair-reuse). Repair-reuse of components was based on the number of engines and gearboxes repaired or remanufactured multiplied with the percentage of components reused after engine or gearbox repair or remanufacturing.

Both *current* and *PSS-modified states* were assumed to deliver the same amount of function (km). The amount of function delivered by the fleet is approximately 360Mkm. This is estimated based on the entire T-Co fleet in Sweden (30,000 trucks) multiplied by the average truck yearly driving distance, 120,000 km [23].

The results from the MFA were then compared to assess to what extent material efficiency differs in the two states.

5. Results and Discussion

5.1. Current capabilities according to the Business Model Canvas

T-Co and some of their customer segments are already today well-equipped for PSS. Remanufacturing at T-Co has been ongoing since 1945. T-Co itself has six remanufacturing plants, where its focus is on engines and gearboxes, but where it also handles a number of other products. T-Co also has a well-developed supplier network for component remanufacturing.

Regarding asset management, dealers and maintenance entities record and utilize individual vehicle use and maintenance data to best serve individual customers. However, such data is used sparingly together. Practitioners indicated that a PSS would allow T-Co to better collect, aggregate, and apply such data for improving product design, maintenance and even remanufacturing.

Logistics for manufacturing, delivery of trucks, spare part distribution, as well as reverse logistics for core remanufacturing has been in place for many decades. These same logistics systems could be used in a PSS. In addition, interviewees indicated that reverse logistics for remanufacturing is easily scalable in size.

Like many of its competitors, T-Co already has many different offerings in the form of direct sales, varying levels of service contracts, lease contracts and shorter-term rental contracts. This variety is in response to varying market and customer demands. Customers are increasingly interested in truck use flexibility and business risk reduction and hence, lease and rental contracts. In addition, T-Co has many customers that choose trucks for quality and reliability. Many customers value truck function and uptime over truck ownership. Thus, not only has T-Co developed some capability in selling and managing PSS-like contracts, there is an increasing market demand for such services.

Product design at T-Co is conducted in conjunction with a prioritization activity that includes aspects such as cost, new production, compatibility with former designs, modularity, ease of maintenance, and remanufacturing. Although aspects like design for remanufacturing are not currently prioritized highly, a move towards PSS would change the relative importance of this and other attributes. Most importantly is that the prioritization activity exists and already considers many important attributes.

C-Co also appears to have the organizational capability to handle such design prioritization. In addition, C-Co has tangible resources in terms of R&D organizations and manufacturing facilities that can together design, manufacture and remanufacture products suitable for PSS-offerings. C-Co also has some intangible resources required, such as expertise in material, application, production, remanufacturing, sales and service, and machine maintenance. C-Co has technologies and designs that could be hypothetically adapted to the new truck PSS, such as condition monitoring sensors and equipment enabling preventative maintenance, and precision measurement for maintenance activities. C-Co offers alternative constructions for enhanced performance, reduced size and weight, and use life. Finally, C-Co already offers product remanufacturing for other vehicle types (rail and aerospace) and already provides components to some PSSs offered by other OEMs.

Despite the capabilities for implementing PSS, potential challenges were also identified for T-Co. First, T-Co already has a small fleet management and rental operation. However, an enhanced asset (fleet) management would have to be developed, in order to optimize asset use and maintenance. Second, although a strong dealer and maintenance network exists, a new system of compensation would likely have to be constructed. Revenues would come totally in the form of rental and lease payments and those funds would have to be distributed in a way to stimulate dealer and maintenance service partners to sell as well as to compensate them for truck service costs.

Despite some limitations, both case companies showed to have most of the basic capabilities required to run a PSS despite the fact they both currently operate under a linear business model paradigm. A move to primarily PSS offerings would undoubtedly be challenging for both companies – their capabilities and infrastructure has been structured for product sales for many decades. Nevertheless, in the event that customers demand more function and performance offerings, both companies are well prepared. Many capabilities that take many years to develop are already in place, albeit to a limited degree.

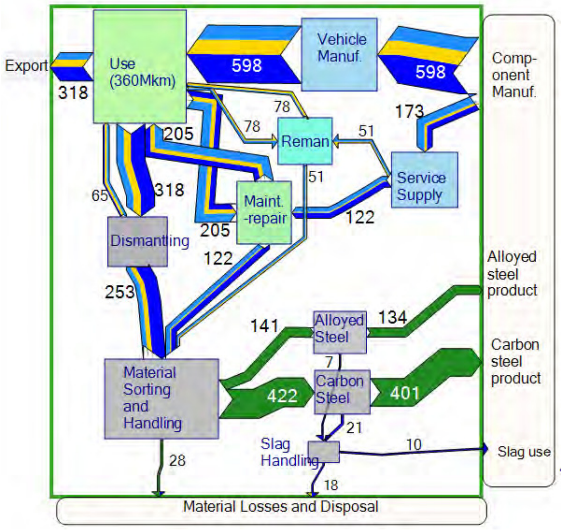
5.2. Potential material efficiency

The material flows of the selected wheel (w), gearbox (g), engine (e) components for the current state and the PSS-modified state are shown in Figure 1 The components that enter the system go to vehicle manufacturing is a weight ratio of estimated to be 2:1:1. (*w:e:g*). Transfer coefficients for the activities vehicle manufacturing and aftermarket distribution were assumed to be 100%, since component damage in assembly or overstock/distribution losses are said to be negligible.

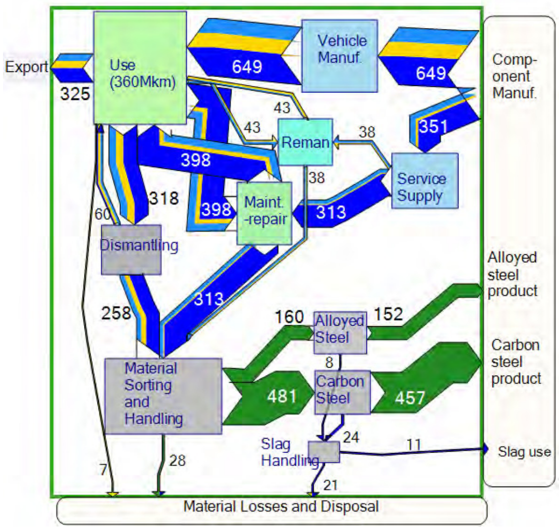
From use, components are sent to export, maintenance (repair), remanufacturing (where they are re-worked to new specifications), or to dismantling. No wheel components (w) are currently repaired or remanufactured. It is estimated that approximately 2% of the engines and 1% of the gearboxes in the fleet are repaired on a yearly basis, while around 0.5% and 0.4% are remanufactured, respectively. During engine or gearbox repair, components are commonly only replaced as needed. It is assumed that 25% of the components in engines and gearboxes (e and g) are replaced during repair. When it comes to remanufacturing, some engines and gearboxes (cores) are discarded before remanufacturing. During engine remanufacturing, 100% of the studied engine components (e) are replaced. During gearbox remanufacturing, 75% of the studied components (g) are replaced. From dismantling, 33% of gearboxes and engines and 5% of wheel components (w) are salvaged for reuse.

Considering the *PSS-modified state*, the introduction of PSS would lead to a number of changes to material flows. First, interviewees indicated that a slight truck size reduction could be made if T-Co owned the fleet, as customers show a tendency to purchase larger and more-equipped trucks than might be needed. Second, as some customers do not follow preventative maintenance schedules, interviewees indicated that there is a sizable potential to improve the fleet's uptime. Based on these two indications, a nominal 2% material reduction to the (new truck) input is assessed. Interviewees indicated that many more gearboxes and engines would likely be remanufactured by T-Co and that remanufacturing would likely take the place of some of the current maintenance-repair activities. In addition, it is estimated that there are more gearboxes and engines that could be repaired or remanufactured than are currently done. A remanufacturing manager also indicated that it would likely be possible to replace less of the studied components (*g and e*) during remanufacturing. Thus, for this assessment, remanufacturing is estimated to be doubled for both gearboxes and engines and replacement of components (*e and g)* is decreased by 25%.

Regarding the wheel component (w), interviewees indicated that component *w's* use life could be increased by either making the component more robust (by adding material) or by making specifications for the component even more



(a) *Current state*



(b) hypothetical *PSS-modified state*

e engine component g gearbox component w wheel component combined flow

Figure 1: Three component material flows in Sweden for two states. Both states (a, b) deliver 360 million kilometers of truck function. Numbers for each arrow are stated in per mil (‰) of the total *current-state* material flow. Due to design and other changes, the *PSS-modified state* (b) demands 23% less total material input from the component manufacturer (top right of each diagram) than the *current state* (a).

precise. Adding material was not considered to be a likely choice – fuel costs and efficiency standards are a constant driving force that demands truck weight reduction. When it comes to an increase of measurement precision, C-Co already offers a few different levels of precision for its products and additional precision (and use life) could be offered at the right price. For this study, a use life increase of 50% is estimated. This estimate is well within the differentiation that exists between components of differing levels of precision.

Comparing the two states, it is seen that the modified state requires 23% less total material inputs (649+351 versus 598+173) to deliver the function of the three components. Looked at individually, 34% less material would be required to deliver function for the wheel component (*w*), 8% for the gearbox component (*g*), and 8% for the engine component (e).

Material efficiency gains for the studied engine and gearbox components may be considered modest, but they were calculated with conservative estimates. In addition, since most of the studied engine and gearbox components are replaced during remanufacturing, even sizable increases in remanufacturing do not reduce the material use related to these components tremendously. In order to increase material efficiency to a higher degree, components would have to be replaced to a lesser extent. For the wheel components, however, larger gains in material efficiency appear to be possible based on component design.

Finally, it should be noted that since components that are commonly considered to be consumables were assessed instead of the truck itself, some material efficiency potential is hidden. For example, if material efficiency of the engine or gearbox were assessed instead, much larger gains would be seen.

6. Conclusions

This study aimed to (1) assess the capabilities of two companies in a product chain to adopt a truck PSS and to (2) assess what material efficiency gains could be made. According to a capabilities assessment, T-Co has already partially developed many of the capabilities necessary to implement a PSS business model. It has certain key elements in place, such as infrastructure and design for remanufacturing, well-developed service channels, and utility and uptime-focused customers. As a supplier to T-Co, C-Co appears to be capable, in turn, to provide products and services to the PSS.

Looking at material efficiency, the material flow assessment of three chosen components showed that the material needed for function delivered by the wheel component would decrease by over 30%. Material needed for the other two components (used in in the gearbox, and the engine) would decrease by just less than 10%. Considered together, the material needed for the three components would be reduced by over 20%. This is promising, as relatively conservative "within reach" estimates were used. Combined, the results indicate that the firms may be "PSS-capable" and may be able to capitalize on related material efficiency gains.

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