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FUTURE-ADAPTABILITY FOR ENERGY AND RESOURCE EFFICIENT VEHICLES

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Abstract

In contrast to linear business models, circular business models (CBMs) assign the product value and its lifecycle responsibility to a manufacturer or service provider where customers get access to functionality and performance during multiple use cycles. A CBM requires (due to the increased business risk for product obsolescence) suitable products designed for long service life, changes in service content, repair, upgrades and remanufacturing. This paper illustrates drivers that can make three categories of vehicles obsolete in a circular business model. We propose a conceptual framework where drivers for obsolescence are used as enablers for future adaptable design, exemplified with industry cases. Future adaptable vehicles have the potential to be both profitable and energy and resource efficient during use and in end of life in a CBM. However, it will challenge today´s business models with a design logic that rewards longer and more flexible product life. Current barriers are legislation, standards and certification, and consumer acceptance. Besides organizations barriers and a general reluctance to changes.

Keywords: Adaptable design, Business models and considerations, Product-Service Systems (PSS), Conceptual design

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1 INTRODUCTION

Humanity has always faced challenges to adapt in order to find food, shelter, and make tools to solve various problems (Darwin, 1859 in Hekkert et al., 2008) with limited resources. During industrial development, thriftiness was both necessary and considered as financially sound (Lovins, et al., 2007) but also to stay competitive with continuous and increased product sales, that today has created a path dependency towards faster replacement cycles to retain sales volumes as markets become saturated. In a business logic where continuous new products and a short lifespan is rewarded and integrated into manufacturing companies' business models, design and marketing play a central role as both the engine of continuous product innovation, new value propositions, as well as a tool for a" planned obsolescence" (Slade, 2006). As the current business model affect the existing design and decision logic quite effectively, it has to be addressed first in manufacturing companies that want to make significant eco-sustainability improvements (Nyström and Williander, 2013). In a circular economy "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized" (European Union, 2015) there will be increased incentives to design products with controllable and longer lifespans that systematically can be reused, upgraded, remanufactured, and as a last resort be recycled. Especially for companies aiming at develop and implement a CBM, and considering to keep ownership over their products, and sell functions or performances in a product service system (PSS), where service content may have to be changed occasionally. The current rapid rate of technology changes for example in autonomous drive, collision protection systems, electrification etc. will probably increase the pace at which on board vehicle systems will become obsolete in the years to come. However, vehicles produced and sold today rarely perform better than initially rated for and when introduced on the market, but why cannot a vehicle perform better the older it gets? This research aims to combine the business and design perspectives to answer the question; how can adaptable design help OEMs in the transition towards a circular economy? Narrowed down to the questions of: (1) What factors drive obsolescence of different types of vehicles today? (2) What are prerequisites for design of future-adaptable vehicles that could perform better over time? (3) What are examples of adaptable design that can lower business risks in a circular business model?

2 THEORY

2.1 What is a circular business model?

A circular business model assigns the responsibility over the product value and its lifecycle to a manufacturer or service provider and is here defined as *"a business model in which the conceptual logic for value creation is based on utilizing economic value retained in products after use in the production of new offerings"* (Linder and Williander, 2015). Circular business models rely on a set of circular economy principles where products systematically should be designed to fit biological and technical material cycles (Braungart et al., 2007). Where waste becomes "food" in a preferred sequence of reuse, remanufacturing and material recycling (Stahel, 2013). The literature on CBMs, also called closed-loop business models, is large but fragmented. It covers areas like product service systems (Tukker, 2004), industrial symbiosis (Chertow, 2007), and remanufacturing, reverse and closed-loop supply chains (Guide and Van Wassenhove, 2001).

2.2 What is adaptable design?

Adaptable products could, according to Gu and Hashemian (2004) be divided into specific and general adaptable products, indicating different degrees of complexity. The specific adaptable product allows potential applications that are foreseen at the time when the product is initially designed, for example the possibility to upgrade a product with a certain amount/type of memory. This is somewhat less complex compared to the general adaptable product, which can be described as a product designed to adapt to future unknown needs and requirements that are unforeseen at the point of design, for example prepare the product for different types of future memory upgradability. Adaptable products and adaptable design build on existing design methods, including modular design, platform design, and mass customization (Li et al., 2008). Other aspects that are discussed are durability and upgradeability (Li et al., 2008), reliability and robustness (Uckun et al., 2014; Willems et al., 2003); product attachment (Hekkert, 2008), and the possibility to extend functions, either obtained within the existing parts or due to replacement of components (Li et al., 2008). A further aspect is strategies to control product wear and history for preventive maintenance (Cullinen, 2013). Gu et al. (2004) and Zhang et al. (2015) differentiate between design adaptability and product adaptability. Design adaptability means that the design process can be adapted to generate variations of a product. Zhang et al. (2015) defined this as "an approach to design adaptable products" that can be changed/adapted, such as reconfigured and upgraded, during a product operation stage to satisfy different requirements of customers".

2.3 Drivers for product obsolescence?

According to Chapman (2005) and Cooper (2004), product durability, (technical lifetime), is often not the main reason for discarding the product as the actual product lifetime largely depends on the user, his or her behaviour, and socio-cultural influences. Rai and Terpenny (2008) define obsolescence, from a product design perspective, as "a measure of a product's loss in value resulting from a reduction in the utility of the product relative to consumer expectations". Cooper (2010) identified four modes of obsolescence (aesthetic, social, technological, and economic). A fifth dimension (functional) is defined by Caccavelli and Gugerli (2002) as "the lack of ability to provide sufficient level of services to the users with regard to their needs and expectations". Aesthetic obsolescence occurs according to Cooper (2010) when a customer discards a product no longer considered fashionable, or perceived to be worn out. Technical obsolescence occurs when new technology due to innovation replaces a product (Rai and Terpenny, 2008). Changes in social norms and behavior, laws, voluntary standards etc. can reduce or eliminate the need for certain products, making them social obsolete, driven both from societal changes in preferred aesthetics (Teo and Lin, 2010; 2012), as well as in technical changes. Or forced by physical obsolescence (Guiltinan, 2009) for example by" death dating", where a product will be worn out, or completely stop working after a specific time of usage (Slade, 2006). Economic obsolescence can according to Cooper (2004) occur due to depreciation, high cost of repair or maintenance relative to replacement, or due to low performance / cost ratio of the product.

2.4 The time factor

Time influences all artefacts that humans create and all that we do (Thompson et al., 2011). Sooner or later all human artefacts will start to degrade and decrease in human value due to a specific or combination of the above obsolescence drivers. Since the fifties, the dominated trend has been an increased speed in most humans' activities, such as personal traveling, communications and timesaving in product development and production is seen as crucial. For example, the fashion brand Zara requires only approximately 15 days, to get from design-concept to a product in store[1], while the average time to market is 6 months. Also the pace of new technology introduced vary significantly between different product categories, while data processing and storage capacity in information and communication technology (ICT) has a fast development rate, for example in on-board vehicle-systems as infotainment and navigation systems, mechanical components or accessories could take much longer time before becoming obsolete. The effects of increased pace in product renewal and shorter product lifetimes, is increased resource consumption (Krausmann et al., 2009), and waste from obsolete products, which seriously affects planetary boundaries (Rockström et al., 2009).

3 METHOD

The research follows an inductive approach to develop the basis for further research. The knowledge has been built upon a literature review, personal in depth interviews and focus groups with OEMs and examplary cases from industry. We employed an abductive approach based on systematic combining (Dubois and Gadde, 2002). Initially we reviewed previous literature and compiled a list of tentative challenges in current business and design logic that formed a questionnaire used.

[1] https://www.tradegecko.com/blog/zara-supply-chain-its-secret-to-retail-success.

3.1 Data collection

Four companies within the automotive sector participated in the research study. Three of them are manufacturing passenger vehicles and vehicles' components, construction equipment, and service vehicle interiors. The fourth company is a large fleet owner of heavy vehicles and machinery. In-depth interviews with several participants at each company were held to understand their current business and design logic. Participants of the interviews included at least one person responsible for design, one for business strategy, and one for marketing or customer relationships. The same set of questions were asked to all persons, regardless of their background, to understand the relationship between design and business. After the one-on-one interviews, (company internal) workshops were conducted where a scenario for a CBM and a conceptual framework with a set of enablers for future adaptability were presented (Table 1). A following discussion highlighted opportunities and barriers towards such a scenario based on historical and existing company activities, as well as implications between current product design and business development. Based on the proposed set of enablers a search and collection of industrial examples was made to exemplify how these enablers can be visible in industry today. The examples chosen were based on a combination of personal interviews, study visits and public company information.

3.2 Data analysis

Based on company-interviews, workshops and the literature study, four levels of adaptability were identified and categorized as follows; 1: Adaptable infrastructure: A supportive infrastructure that can provide different types of fuels and energy and that can be adapted to changing needs of volumes and sizes. 2: Adaptable fleet: A flexible fleet of vehicles that can fulfil the changing requirements of mobility. 3: Adaptable vehicles: Customer products that are adaptable to the changing requirements of the users. 4: Adaptable components: Sub systems or components that are used by the end-consumer as part of a larger product. For example, an electronic controller in a vehicle that can be upgraded with more processing capacity or software. Due to a further research focus on product level, we will only discuss enabling factors and industrial examples on product level (adaptable products).

4 RESULTS

During the interviews with participating and inspirational example companies, the main drivers for traditional automotive OEMs in B2C were described as primarily designing vehicles for cost-efficient production, with continuous investments in facelifts, new design and technology that can attract new customers, while keeping brand loyalty to existing customers. There is no explicit intention to keep products as long as possible on the market, by making them more adaptable, even though aftermarket services were described as a very profitable business activity today (compared to the profit on vehicle sales). For products with high material and component values as for construction equipment, aviation and space industry products, very long usage times, remanufacturing and rebuilding operations have become business as usual, but limited to remanufactured components like alternators, generators etc. in the B2C segment. However, remanufacturing and rebuilding of heavy vehicles also has limitations from a technical, economic and social (legislative) perspective. For example, can the life time of special retrofitted accessories (common on refuse vehicles), be much longer than the lifetime of the carrying vehicle, and reusing old accessories on new vehicles can be very difficult and costly. Social reasons as improved emission legislation, or a higher focus on ergonomics, can also lead to certain vehicles being banned or being less attractive, influenced by political pressure as procurement criteria. Or due to personal motivations from customers. Both in B2B and B2C markets, todays rapid ICT development rate is described as drivers for obsolescence, as vehicles may not be able to be upgraded to autonomous drive, automatic brake functionality, electric drivetrains, etc. without changing the overall product architecture. A practical example is the "in-car delivery"[2] service that is dependent on the fact that the cars' hardware can provide delivery companies one-time access to the car boot. Aesthetical aspects are described as a stronger driver for obsolescence in the B2C market than in B2B, although regular aesthetical upgrades are made in B2B vehicles to build a visual identity for heavy vehicles. B2B customers also expect different looks from previous models or expecting a lower price if

[2] https://incardelivery.volvocars.com/#/

no updates are made since. Among B2C customers and large fleet owners there is a rising trend to lease instead of owning a personal car, or to buy mobility, a specific functionality or a performance, for example a certain amount of material per hour.

4.1 Designing for adaptability

Design for future adaptable products will most certainly challenge designers, engineers and business developers, not only to identify todays users' needs, but also to broader imagination about future needs that can make the product obsolete and thus increase business risks for the product owner in a circular business model. Designing for adaptability will need a different approach regarding those factors that today drive products to be obsolete as previously been discussed, and the same driver that makes a product obsolete can theoretically be used to prevent obsolescence, if taken into account in the business development and design process for adaptability. Below we propose a conceptual framework with enablers that can be prerequisites for designing future adaptable products. These enablers could be used alone or in combination to optimize the design. Under each main enabler we propose tentative sub-enablers that can help in the detailed design work.

Table 1. A conceptual framework with main and sub "enablers" for design of future adaptable vehicles[3]

Aesthetical enablers	**Functional enablers**	**Technical enablers**	**Social enablers**	**Economical enablers**
Emotional attachments (keeping product contemporary over time) **Product history** (provenance)	**Modularity** **Platform-design** **Open architecture** **Upgradeability** **Standardisation**	**Durability** **Serviceability** **Controllable wear** **Upgradeability** **Remanufacturing** **Recyclability**	**Access and transparency** (open design) **Co & user-driven innovation**	**Value recovery** **Traceability** (position, behaviour, history) Off book solutions (enabler for PSS) **Responsibility** (e.g. retained ownership from an OEM or service provider)

4.2 Examples of enablers for adaptable design in industry today

The examples in Tables 2,3,4,5 and 6 illustrate how different enablers for product adaptability can be used in practice as steps towards product adaptability. The examples are based on a combination of personal interviews, study visits and company information. The examples are mainly from the automotive sector, with two exceptions from the telecom industry illustrating better the current trend towards modularity and reparability, and the increasingly used ICT in vehicles, for example by autonomous drive. Besides, actors outside the automotive industry developing their own autonomous vehicles[4].

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[3] Tentative sub-enablers are proposed for each main enabler. These enablers were identified from literature and from company interviews, and given equal weight.

[4] For example Googles self-driving car; https://waymo.com/journey/

Table 2. ***Aesthetical enablers:*** *Keeping products contemporary over time*

Example: *The Mini* *www.mini.com*	***Enablers for adaptability:***	
The Mini, launched in 1959 has become an iconic product sign for small cars. The current design still bears traces of the original mini character from the 50-ies, even with significant updates in the exterior design.	-A human inspired exterior design with a personal character - A balance between novelty and typicality, where the original product sign still can be recognised in current models	 *Image: Thomas Nyström*

Table 3. ***Functional enablers****: Modularity & Platform design*

Example: *Modular smartphones* *https://atap.google.com/ara/*	***Enablers for adaptability:***	
Several actors in the telecom industry as LG, Motorola and Goole has developed modular smartphones with upgradeable modules. Even if add-on modularity has been available for a long time for accessories, this trend is more advanced. And, in some cases (Fairphone, Google ARA) also based on different business models.	-A modular design made for exchangeable modules -Open hardware and software protocols -An intention to build a community of developers -A possibility to customise modules by personal shape, colours and patterns by 3D printing	 *A prototype of the Google project ARAs "endoskeleton" with exchangeablehardware modules. Image: Maurizio Pesce*

Table 4. ***Technical enablers****: service and reparability*

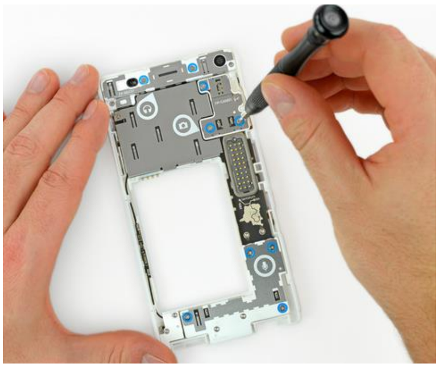
Example: *Fairphone* *www.fairphone.com*	***Enablers for adaptability:***	
Fairphone tries to change the way smartphones are made throughout the whole value-chain via design for long usage time, recyclable materials and fair working conditions. Fairphone 2 is designed with a modular setup where components are easy to disassemble and repair with standard tools by the users themselves.	-Design for longevity and repair -Low margins on spare parts -Supply of spare parts after last day of sales. -Open software -Robust cover to prevent screen damage -Expandable memory and two sim cards, reduces the need for an extra phone. -Expansion port for future applications	 *The mainframe in Fairphone 2, designed for easy repair. Visual indications show functions of the modules (white rings), and fastening point for screws (blue rings). Image: Ifixit.org*

Table 5. **Social enablers:** Co creation and micro production

Example: *Local Motors* *https://localmotors.com/*	***Enablers for adaptability:***	
Local Motors is a start-up company with the aim to disrupt current ways of designing and producing vehicles, with co-creation, standard components, 3D printing and ”micro” production plants. By this Local Motors claim to have shorten development time, reduced cost in product development, and produced several vehicles for both private use and for mobility as a service (MAAS).	-Open hardware and software protocols. -A large co-creation community -A community that can be engaged both as users and paying customers -Intellectual property investors that want to realize products. -Flexible production of vehicles and spare parts.	 *Local Motor’s autonomous shuttle “Olli” Image: Azra Habibovic*

Table 6. **Economical enablers:** value recovery

Example: Remanufacturing and rebuild of construction equipment www.remanufacturing.eu	***Enablers for adaptability:***	
Remanufacturing (REMAN) of components and rebuild of entire construction machines is well established at most construction equipment manufacturers. Machines that have been in heavy use can usually be rebuilt several times, before material recycled. By reusing old engines, up to 66% of the energy consumed in the production stage can be saved.	-Customers want to use their machines as cost effective as possible. -A possibility to rebuild machines to original specifications for at least two life cycles. - Some vehicle components can be upgraded, if changes occur in production -The used parts (cores) have a value which reduces the price of REMAN components	 *Image: www.pixabay.com*

5 DISCUSSION AND CONCLUSIONS

Today, islands of knowledge and excellence applicable for developing adaptable products exist, in the automotive industry as well as in research fields such as product modularity, mass customization, design for X, predictive maintenance, and product attachments etc. Multiple lifecycle strategies have also been extensively researched, including reuse, refurbishment, remanufacturing, and recycling. However, in most examples and research areas, the main focus has been on a more efficient production, and not on making products more adaptable during its use phase. And where available methods and tools for adaptable design have a theoretical and technical focus, not aligned with business and design logics, making them difficult to use for practitioners within business and design. We therefore see a need to bridge and combine existing knowledge of adaptable design with business model innovation, to be able to handle the complexity in the transformation from a linear to a circular business model.
All the previously described enablers for product adaptability can be used by business developers and designers. Used one by one, they can be tools for ideation of incremental steps towards circularity. Used

as a whole palette, it can be useful for developing circular business models with a combination of products and services that can lower business risks and increase energy and resource efficiency. By using parts of the vehicle longer and thereby reducing the negative environmental impacts from mining and production, while simultaneously upgrading energy consuming parts with new technology that leads to improved energy efficiency and lower emissions during the use phase, we anticipate massive environmental improvements in the vehicle fleet. In the next phase of our research, we will test this hypothesis. In addition, other barriers and enablers for adaptable design will be further assessed and design methods for adaptability will be established. For example, adaptable design might meet organizational barriers, since it most likely increases development cost in business development and early design phases, which require taking a calculated risk. Other aspects that need further investigation are e.g. deeper understanding of product users and products attachments over longer periods of usage time than today, legislation and certification issues that might limit the reuse potential of products, for example when upgrading a diesel engine to better emission standards than original. Or if material ingredients, allowed at first market introduction, has been restricted at the point of resell or remanufacture years later.

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