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The Contribution of Modularity to Green Operations Practices

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Abstract
This paper discusses the possible contributions from modularity and industrial condominiums towards enhancing environmental performance in the automotive industry. The research described in this study is underpinned by a review of journal articles and books on the topics of: modularity of production systems; green operations practices, and the automotive industry and sustainability. The methodology is based on theoretical analysis of the contribution of the modular production system characteristics used in the automotive industry for Green Operations Practices (GOP). The following GOPs were considered: green buildings, eco-design, green supply chains, greener manufacturing, and reverse logistics. The results are theoretical in nature; however, due to the small number of studies that investigate the relationship between modularity and sustainability, this work is relevant to increase knowledge in academic circles and among practitioners in order to understand the possible environmental benefits from modular production systems. For instance, based upon our analysis, we could deduce that the existing modular production systems in the automotive industry may contribute in different ways to the implementation of GOPs. In all types of modularity, product simplification through the use of modules can enhance environmental performance and facilitate further activities such as maintenance and repair contributing to a longer life of cars on the road. Moreover, modules will make automobiles easier to disassembly, so increasing the chances of reuse of valuable components and a better final disposal of scrap. Regarding the potential benefits of each type of modularity, it is expected that modular consortia will have a better integration of environmental practices with suppliers and seize on high efficiency during manufacturing and logistics compared with conventional production systems.

Keywords: green operations practices, modularity, automotive industry

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Introduction

The automotive industry is criticised frequently in the media because of its perceived environmental burden, and also is often cited in the management literature because of conservative and reactive behaviour producing few radical innovations. In fact, many economic and environmental problems are challenging the automotive industry, which is the largest manufacturing sector in the world. The main challenges that have emerged in the 21st Century include: pressure to increase profit margins and reduce break-even points, the call to minimise (or even eliminate) greenhouse gases emission from vehicles, the need to pursue rational use of natural resources and having to deal with impacts like congestion and accident fatalities (Orsato and Wells, 2007; Wells, 2007).

From the production system perspective, the use of modularity is regarded as one of the latest changes in the automotive industry. Arnheiter and Harren (2005) refer to four types of modularity: manufacturing, product use, limited life and data access modularity. The authors explain that complex products like automobiles make use of all four types of modularity. Indeed, modularity is a significant change in the production system of the automotive industry and several authors present it as a trend to be extended beyond existing assembly plants.

Since Volkswagen adopted the term "modular consortium" for its plant in Brazil, other car manufacturers are following this philosophy of locating tier suppliers under the same roof and producing cars through the combination of independent modules. However, assembling modules to produce vehicles is not a recent idea. In the early 1970s, as part of a university research project in Manchester (UK), the vehicle "Trantor" was designed for farmers to have a single vehicle that replaces a tractor (for conventional agricultural tasks) and a truck, hauling heavy loads, but also carrying several people in comfort (Bennett, 1986). Besides the product innovation, there was a new process design with group technology manufacturing. What is more, the same philosophy, of breaking the product or the process into independent modules, is found in two Swedish companies, Saab Cars and Volvo, in the 1970s through the use of autonomous working groups (Bennett, 1986; Bennett and Karlsson, 1992). These modules or cells of production were the solution to respond to the conflict between the nature of the work and Swedish worker's education, and its consequent high levels of employee turnover and absenteeism (Bennett and Karlsson, 1992).

Nevertheless, today's modular production system in the automotive industry is seen as an evolution of Toyota Production System – Just in Time (JIT). Indeed, the modular system used by Volkswagen, General Motors and Ford is, besides simplifying the final product and transferring the competence and responsibility of manufacturing components to suppliers, aimed at low inventory levels (or even no stock), zero-waste philosophy and high integration of suppliers (keiretsu), i.e., all of them are considered a heritage from JIT (Parente, 2003).

In this paper, the examples of modularity in the automobile industry are highlighted and their potential contributions to the implementation of Green Operations Practices (GOP) are discussed. The methodology is described in Figure 1. It was based on theoretical analysis of the contribution of the modular production system characteristics used in the automotive industry for Green Operations Practices (GOP). Two major body of knowledge included in the literature review were: Environmental Management (Green Operations) and Modularity (Modular Production Systems). Due to its extension, substantial environmental impacts and significant use of modular production systems, the automotive industry was selected as the object of our study; therefore, academic studies and institutional reports on automotive industry and sustainability were also included in our literature review. From the literature, we could compile the main facts, and from them, using hypothetico-deduction as our main scientific method we could infer our propositions. We first looked at the literature on *green operations*, which permitted us to identify the major environmental practices. Secondly, we gathered relevant academic papers on modularity at production systems level. Then, we narrow our search to the use of environmental practices and modular production systems by the automotive industry. As a result, we found a gap in the literature referring to *the potential contribution of modularity in greening operations in the automotive industry*.

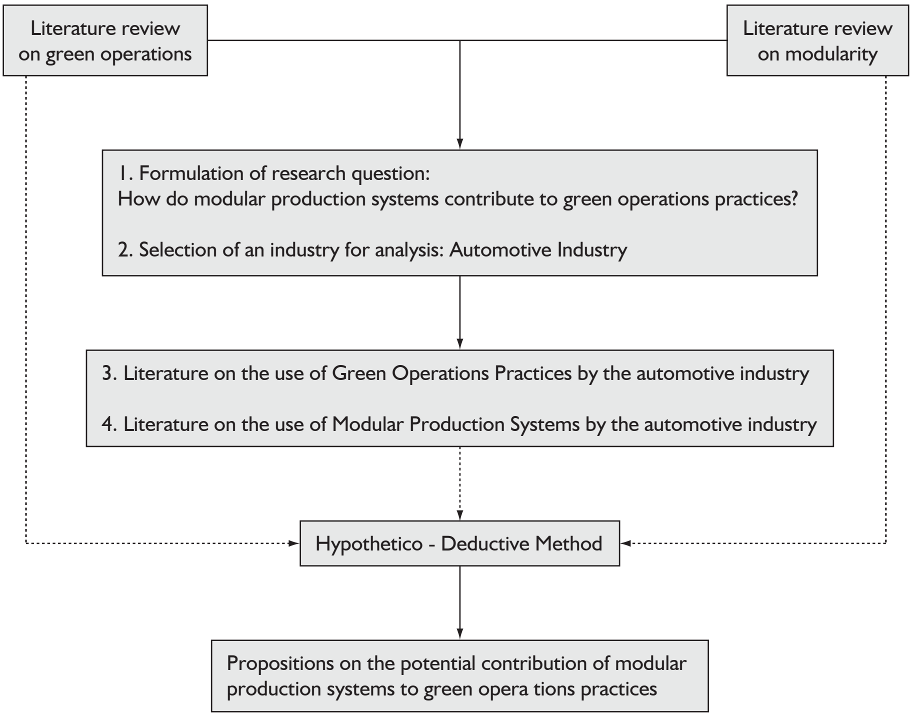

Figure 1 - Methodology for the study.

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Literature review was mostly composed of academic and scientific papers. They were found through the use of academic data bases such as: Science Direct, Emerald, Proquest, and EBSCO. Due to the overlap between modularity, green operations and automotive industry; we have also accessed books and articles on sustainable mobility written by experts in the filed appointed by our literature review.

Green Operations means the integration of environmental considerations into day-to-day operations, as it was conceptualised by the Canadian Department of Foreign Affairs and International Trade (DAIFT, 2006). Five GOPs are considered in this study: green buildings, eco-design, green supply chains, greener manufacturing and reverse logistics. These five GOPs were selected in order to cover six strategic activities of operations function: production capacity planning, product and process development, supplier relationship, manufacturing (production), in-bound and out-bound logistics, and after sales.

In summary, as operations function plays the most important role amongst other functions (e.g., marketing and finance) to achieve corporative sustainability, we believe that this study can hopefully contribute to the discussion of environmental benefits related to modular production system in the automobile industry.

Modularity in the Automobile Industry

One of the most significant developments in the automobile industry in recent years has been the changing relationship between the major vehicle producers and their component suppliers (Dicken, 2003). This significant change has been intensified by the use of modular production systems associated with industrial consortiums or condominiums. To understand the meaning of module, modularity and also, modular consortia is an essential task before analysing their characteristics, benefits, risks and drawbacks.

Defining what is a module as opposed to a system is far from an exact science, as the words are often used interchangeably (Collins et al., 1997), who provide the following definitions that have been adapted from Mckinsey: a *module* is a physical subassembly – e.g. seats, dashboard/cockpit and front-end assemblies, while a *system* is a functional aggregate of components not necessarily delivered as one physical unit – e.g. braking system. Another concept is provided by Baldwin and Clark (2000) who define module “as a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units”. A modular system is composed of units (or modules) that are designed independently but still function as an integrated whole (Baldwin and Clark, 1997).

Baldwin and Clark (1997) also contributed with insights on the concept of modularity. For them, modularity is a strategy for organising complex products and processes efficiently. Parent (2003) says that product modularity can be seen as the process of assembling final products from a number of predetermined and interchangeable modules, i.e., it involves the assembly of products from combining independent modules.

Moreover, Arnheiter and Harren (2005) highlight that modularity can be used to design products as well as production systems. The authors define and explain four types of modularity: (1) manufacturing modularity, (2) product use modularity, (3) limited life modularity and, (4) data access modularity.

In essence, manufacturing modularity is a philosophy for producing fully finished products by using only a handful of pre-manufactured subassemblies (Arnheiter and Harren, 2005). In the automotive industry, Brazil has been identified as an environment offering appropriate conditions for the application of alternative and innovative methods of production (Parente, 2003). For Parente (2003), a combination of government incentives and fast-growing market demand has made Brazil the testing ground for automakers to implement their modularisation strategies mostly in green field investments as well as in old traditional plants. Modular production/supply systems tested in Brazil have been at the centre of the discussions about "transplanting" new models of production systems to traditional industrialised countries, such as in the GM case and its so called "Yellowstone project", in Ford's plans for modular assembly of the Focus and in Fiat's Amazon project for renewal of the Punto, etc. (Salerno and Dias, 2002). Although there are structural differences between the existing practical examples of modular consortium, industrial condominium and supplier park such as contract, investments from supplier, etc; the philosophy is basically the same: locate main supplier closer to the governance (inside plant campus or under same roof), build deeper relationship through long-term contract, reduce time and costs of components transportation, enhance interaction between buyer-supplier, and reduce complexity of global operations.

Arnheiter and Harren (2005) explain "product use modularity" as the use of modules to facilitate product customisation by the user. Probably, the most radical example of "product use modularity" in the automotive industry is given by Dower (2006), who holds a patent for a modular vehicle, the Ridek, composed of a motorised deck (the Modek) with a passenger compartment (the Ridon) riding upon it. The "product use modularity" is provided when, for urban use, the readily exchanged Modek would run on its electric battery, making the Ridek a zero-polluting electric vehicle; while, for inter-urban use, the Modek could be quickly exchanged (at a Modek exchange station) for a fuel-burning ICE Modek (Dower, 2006). Indeed, product modularity is not only important during use; but it may allow the firm to achieve higher level of product mix flexibility (Mikkola, 2006).

The third type of modularity defined by Arnheiter and Harren (2005) is "limited life modularity". This refers to those parts of a product that will have to be replaced during the product life time (e.g. car battery). Finally, the fourth type is "data access modularity", which is widely used and includes modules such as CDs, DVDs, storage cards, USB memory sticks. Their main purpose is to provide data storage, separately from the system in which they are used (Arnheiter and Harren, 2005).

Arnheiter and Harren (2005) cites the automobile as a classical example that makes use of all four types of modularity, e.g., the previous examples from manufacturing modules (seats, engines, panels, etc); the brake pads as limited life modules; a luggage box as an example of product-use modules; and the chip controlling the fuel injection is in most cases a data access module.

Arnheiter and Harren's taxonomy is important to visualise modules in production systems. Nevertheless, as the authors warn, one firm (or even a product) may encompass more than one type of modularity. Sanchez (2004) describes how modular platforms can actually transform businesses. For Sanchez, firms successfully pursuing platform-driven strategies have learned that platforms are a powerful design approach that requires clarity, definition, and discipline—as well as creativity—in conceiving strategically focused and carefully coordinated modular product and process architectures. In fact, modular architectures are far beyond than only product development, and its application in other processes may result in increased flexibility for the company (Sanchez and Mahoney, 1996). Latest research in the topic have suggested that mass customization in terms of product variety is easier achieved through modular architectures (Mikkola, 2007).

To enable the analysis, we can identify basically three distinct radical interventions of modularity in the automobile system. First, is the concept of modular consortia in Brazil locating module suppliers inside the plant campus (or even under the roof). Second, the Ridek concept, extending the use of modularity from manufacturing to product-use and changing the business model through the adoption of product-service systems. Williams (2006) explains the advantages of using micro-factory retailing (MFR) and product-service system (PSS) combined in the automotive industry. Wells and Orsato (2005) and Williams (2006) list economic, social and environmental benefits such as reduction of break-even point, better work environment and the use of alternative material (e.g. carbon fiber) and fuel system (e.g electricity, fuel cells).

The third is the use of small plants (MFR) rather than large plants; however, without the transfer of ownership and use of PSS as it is proposed by Dower (2006) in the Ridek concept. The examples provided in the literature of other MFR in the automotive industry show 4 experiences: Th!nk, Oscar, MDI Air Car, and GM AUTOnomy (Wells and Orsato, 2005; Wells and Nieuwenhuis, 2006). The MFR would also take responsibility for commercialisation and maintenance in order to increase profit margins.

Indeed, modularity is a vital condition to the use of MFR. Wells and Nieuwenhuis (2006) suggest the moving of economies of scale up the supply chain and well away from assembly in order to make MFR a viable idea.

> "Economies of scale can be achieved in key modules, components or other elements that are of less interest to the customer, such as basic powertrain and chassis items, rather than in that most visible element – the car body" (Wells and Nieuwenhuis, 2006).

According to Orsato and Wells (2007), the automotive industry is currently facing economic and environmental challenges. The sector is usually targeted as the main contributor of deteriorations of air quality in urban areas and associated with global issues such as global warming, treatment of scrapped vehicles and intensive use of raw material. On the economic side, the industry is notably over-capacity; saturated and fragmenting markets; capital intensity; and persistent problems with achieving adequate profitability (Orsato and Wells, 2007).

Considering that modularity will advance as a trend within car automakers in order to surpass those economic and environmental challenges, it is important to analyse the contribution to sustainability from these three concepts of modularity: (1) Modular consortia, (2) Ridek and (3) MFR. The next section presents the concept and practices of Green Operations, from whose perspective we will analyse the contribution of modularity to sustainability in the automobile industry.

Green Operations: Concept and Practices

As a recent concept amongst academics and practitioners, the term "Green Operations" may be found in the literature also as "environmental operations", "sustainable operations" or even "greener operations".

For instance, Gupta and Sharma (1996) define Environmental Operations Management (EOM) as the integration of Environmental Management principles with the decision-making process for converting resources into usable products. They believe that EOM is a strategic level of operations management since it primarily concerns product and process design. In fact, defining the strategic operations objectives is strongly connected to environmental issues.

Sarkis (2001) has designed the concept of greener manufacturing and operations through the use of environmental tools such as: design for environment, green supply chains, total quality environmental management and reverse logistics.

Moreover, Kleindorfer et al. (2005) say that the question for companies has become not whether to commit to a strong environmental, health, and safety record, but how to do so in the most cost-effective manner. They have identified the evolution towards sustainable Operations Management is clear in three areas that integrate the three Ps (People, Profit and the Planet) of sustainable operations management: (1) Green product and process development, (2) Lean and green OM and (3) Remanufacturing and closed-loop supply chains.

DAIFT (2006), whose Green Operations concept was cited early, highlight the importance of operations being conducted in a manner consistent with good environmental stewardship principles and practices while taking into account competing demands on financial and human resources.

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In summary, the concept of Green Operations is presented in two ways: first, as an approach of the introduction of environmental concerns to operations functions activities and decisions; and second, as a set of environmental practices and technologies.

Here, we consider both approaches with the intent of keeping the way of thinking of environmental issues in a broad perspective for operations function; but at the same time giving the set of existing practices that cover all activities of operations function. Important to highlight that the second approach (the set of practices) should not limit companies in maintaining the status quo of their production system and, on contrary to that, organisation must foster innovation towards higher levels of sustainability considering economic, environmental and social aspects - see "General Framework for Green Operations" in Nunes and Bennett (2008).

Green operations practices - GOPs

Elliott (2001) points out operations management as a key player to achieve a sustainable future and examines the factors of the operations function (plant, place, process, programmes, people and product) and their natural involvement with social and environmental care.

If operations function is analysed by its broad processes, we would have basically six activities: (1) production capacity planning, (2) product and process development, (3) supplier relationship, (4) manufacturing (production), (5) in-bound and out-bound logistics, and (6) after sales. Thus, aiming at covering all these six processes, there are five environmental practices already defined in the literature: green buildings, eco-design, green supply chains, greener manufacturing, and reverse logistics. We acknowledge the fact that innovation can play an important role in greening operations, therefore, we also included it in Table 1. Table 1 presents the GOPs, their relationship with operations function, objectives and main benefits.

Contributions from Modularity to Green Operations Practices

This section provides a discussion and the authors' assumptions on the potential contribution from modularity to Green Operations Practices. Each of the three types of modularity considered from the practical examples described in the literature are analysed here. The analysis is composed of the characteristics of each type and their implications for implementing GOPs and seizing on environmental benefits.

Contributions for green buildings

Regarding this practice that refers to the reduction of environmental burdens on construction and operations phases of the manufacturing plants, the basic difference between the modularity types is that Modular consortia still keeps the current paradigm of few centralised and large manufacturing plants, whereas Ridek and MFR choose many and small plants.

Basically, the modular consortia reduce energy transportation consumption of tier supplier by locating them inside the production site. Another positive point is that it would be easy to transfer technology of green buildings for suppliers during plant design. However, there are the same sustainability constraints of the current industry regarding the large use of green fields, concentration of pollutants and so on.

On the other hand, both concepts of Ridek and MFR seize on a higher sustainability of sites due to the possibility of (re)use of brownfields and the proximity of markets and therefore, customers (Wells and Orsato, 2005). Health and safety systems tend to be easier to be managed because of the low level of complexity and green buildings practices might be replicated to other production units. However, context may play a very important role and the transfer of technology will be affected. What is more, it will require more from local infrastructure to provide knowledge and solution to the manufacturing process, even if it happens in small scale.

Contributions for eco-design

Considering the features of Eco-Design, all three types have different contributions. Compared with non-modular production systems, all of them tend to better incorporate environmental concerns to the product and process development. The heritage of zero waste from JIT and the higher level of flexibility allow modular consortia, Ridek and MFR to introduce innovation in a faster pace.

Modular consortia have definitely improved process design with an economic and environmental analysis. There is significant cost reductions listed in the literature (Correa and Miranda, 1998), and the waste minimisation and energy conservation are the main achievements from the environmental perspective. Once module providers are developing a core expertise on the production of components and the assembler are responsible for managing the supply chain, the opportunities for eco-design are now spread up to the supply chain. It is expected that the freedom and focus given to module suppliers will contribute to the use of less harmful materials, possibility of disassembly, and therefore, a greener product.

The Ridek concept is the only type of modularity that considers product use as a radical innovation due to its change in the business model. The flexibility to meet the needs of urban and motorway environment makes the Ridek product design very important in the minimisation of air pollution, which is one of the greatest benefits in this product use modularity. In addition, the Ridek concept would also take advantage of MFR's contribution for eco-design as it is produce locally and in small scale.

The MFR concept claims that small factories could be more flexible and better designed to local context (Wells and Orsato, 2005; Dower, 2006; Williams, 2006). In this case, MFR's contributions to eco-design could come from the use of renewable material in small scale and the reuse of components (once the MFR increases the possibility of collecting scrap; see *Contributions for reverse logistics*).

Table 1 – Green Operations Practices: their relationship with the operations function, objectives, and main benefits (developed by the authors based on an analysis of the literature).

Green operations practices	Activities of the operations function	Objectives	Main benefits
Green buildings	Production capacity planning	Enhance environmental performance during construction and operation of an industrial plant considering sustainability of the production site, water and energy efficiency, resource and materials use, indoor environmental quality, and innovation and design process	Higher worker productivity; Reduction in health and safety costs; Improvements in indoor environmental quality Reduction in maintenance costs; Energy and water savings Better waste management in construction and operations phase
Eco-design or Design for environment	Product and process development	Consider the product's life-cycle in order to design more environmentally-friendly products and use environmentally sound processes	Enhancement of reusability, recyclability and remanufacturing possibilities; Reduction on the use of hazardous substances First-mover advantages (royalties, access to green market niches, etc) Reduction of final disposal costs Higher eco-efficiency and eco-effectiveness
Green supply chains	Supplier relationship and in-bound and out-bound logistics	Incorporate environmental criteria and concerns into organisational purchasing decisions and long-term relationship with suppliers	Sharing risks and pressures along the supply chain Transfer of environmental technology and consequently waste and cost reduction in the suppliers' operations
Greener manufacturing	Manufacturing (Production)	Increase efficiency continuously and integrate 4Rs' in the production: Reduce, Reuse, Remanufacture and Recycle	Better economic, environmental, social and economic performance through reduction of waste and therefore, costs
Reverse logistics	Supplier relationship, logistics and after sales	Plan, implement and control backward flows during process and after use of finished goods, mainly to end-of-life products	Reduction of environmental burdens on the final disposal Reduction of landfill and environmental liability costs (Re)use of valuable components of an end-of-life product
Innovation	All activities and beyond operations including business model designs.	Improve goods and services and increase profitability	Eliminate unnecessary processes, sources of pollution, waste, etc

Contributions for green supply chains

The modular Consortium is probably the application of modularity to production systems that has the better opportunities. The proximity to a small number of key suppliers permits better transfer of technology. Moreover, car assemblers have gained know-how of managing supply chains in a global context taking advantage of information technology solutions.

In the Ridek and MFR concepts, automakers will require a different range of competences and skills to assemble cars and deal with their module suppliers. Indeed, if the economies of scale are pushed up to the supply chain, it means that module supplier will need to have large manufacturing plants; carrying on with them not only the economies of scale but also the environmental impacts probably. In this case, the car assemblers will receive pressures from public and government, and pass it to module suppliers, which will now need to develop by their own environmental practices (including green logistics) and then transfer them to their suppliers of raw material and other inputs. The major advantage of MFR is basically the proximity to markets (outbound logistics).

Contributions for greener manufacturing

Using the indicators of efficiency (input/car produced), large plants may have a better use of energy, water and material. Therefore, modular consortia tend to have this characteristic of its production system. Nevertheless, the incorporation of components for reuse, remanufacture and recycle might be low due to the capabilities of collecting scrap and flexibility of its manufacturing system. On the other hand, large plants also take advantage of economies of scale for the treatment of by-products, waste stream and other undesirable outputs.

The Ridek concept allows the manufacturer to track and control components of product (modek) during its life-cycle (Dower, 2006) better than modular consortia and MFR. So, there is a strong possibility of collecting valuable components and reusing then later. On the other hand, small scale systems will make Ridek and MFR have a lower efficiency and depending on the type of energy used greener manufacturing practice may not have a great potential. Final disposal and treatment of possible waste stream will probably face problems as well.

Contributions for reverse logistics

End-of-life regulations for manufacturing goods may change significantly the cost structure of many sectors, mainly because a landfill shortage is expected. The cost increase because of the backward flows will need to be added to the product price; therefore, a strong expertise in eco-design and reverse logistic will be required. Eco-design can reduce environmental burden through the use of greener material and also facilitate disassembly of product to further reuse, remanufacture or recycle. Nevertheless, planning and implementing the product recovery is already a challenge in itself.

Modular consortia may permit an easy replacement of some components during the car use life-cycle because of the product simplification through the modules. The retail unit might be used as a collecting and maintenance points. However, it depends on the company's customer relationship management. Loosing contact with customers after warranty time and the large-centralised manufacturing plants will probably make collecting of scrap more difficult.

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Ridek concept permits a continuous contact with clients, accumulating information every time the modek need to be exchanged. Similarly to MFR, various small factories producing may have a positive impact on collection of end-of-life cars.

Table 2 summarises the contribution of the three modular production systems to the five GOPs.

Table 2 - Contribution from modular production systems to GOPs (developed by the authors based on an analysis of the literature).

GOPs	Modular consortia	Ridek	MFR
Green buildings	Small or no distance between tier suppliers and the assembler Possibilities of standardisation of green building techniques	Proximity of markets and customers Higher sustainability of the site Better health and safety systems	Proximity of markets and customers Higher sustainability of the site Better health and safety systems
Eco-design	Improvements on process design Product simplification	Radical improvements on product and process design extended to product use.	Radical improvements on product and process design
Green supply chains	Supplier integration with better inbound logistics systems. Better transfer of environmental technology	Better outbound logistics Permanent contact with components (modek) after-sales	Better outbound logistics
Greener manufacturing	High efficiency (energy, water and raw materials consumed per car)	Flexibility to incorporate components (reusing, remanufacturing and recycling)	Flexibility to incorporate components (reusing, remanufacturing and recycling)
Reverse logistics	Product simplification, easier to disassembly	Easier to collect and disassembly end-of-life cars	Easier to collect and disassembly end-of-life cars

Conclusions

The Toyota production system (JIT) has provided an important contribution to environmental management through the philosophy of zero waste and transfer of technology to suppliers. Although *green production* has a broader perspective than *lean production*, it is notable that the benefits somewhat overlap (e.g. economic benefits of waste minimisation). With the automobile industry evolving from JIT to a modular production it is necessary to study the contribution from this new production system towards the enhancement of the sustainability of the sector, i.e., profit increase associated with environmental protection and social responsibility.

In this paper, we found that the existing modular production systems in the automotive industry may contribute in different ways to the implementation of GOPs. In all types of modularity, product simplification through the use of modules might enhance environmental performance and facilitate further activities such as maintenance and repair contributing to a long life of cars on the road. Moreover, modules will make automobiles easier to disassembly increasing the chances of reuse of valuable components and a better final disposal of scraps.

Regarding the potential benefits of each type of modularity, it is expected modular consortia to have a better integration of environmental practices to the suppliers and seize on high efficiency during the manufacturing and logistics comparing to non-modular production systems.

On the other hand, Ridek and MFR have opportunities of using brownfields and proximity of markets may increase sustainability of the production sites. Flexibility of small factories might favour the innovation in car design allowing the use of new materials and improving the process. For example, the "Th!nk" (a Norwegian MFR) eliminated the paint shop, which is the main source of environmental impacts in the manufacturing phase, and uses aluminium and plastic to build the car. MFR also have positive impact for collecting end-of-life vehicles. Moreover, their contribution from economic and social aspects involves the reduction of break even point and requirement of higher skilled workforce.

It is also clear the innovation in the business model and the potential environmental benefits from the Ridek concept mainly because of the ownership of the modek; nevertheless, this approach needs to persuade customers to buy the Ridek idea. This is considered a difficult barrier to overcome as we know the current automobile culture and the little role environmental issues play in buyers' decisions (Lane and Potter, 2007; Vergragt and Brown, 2007).

In conclusion, it is early to measure the exact benefits from modularity to environmental performance of companies in the automotive industry. In this paper, we aim at fostering the discussion of the possibilities of enhancing sustainability of the sector and adopting green operations philosophy, i.e., to introduce environmental concerns to all activities of the operations function and its strategic decisions. We believe that there are natural limitations to our results since they are theoretical. However, they are useful and relevant to visualise the potential benefits and establish directions of empirical research in order to investigate not only opportunities of improvement, but also barriers to green operations implementation within automotive companies.

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