Linking lean production and design for sustainability on the issue of waste reduction

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Abstract: The present paper aims to establish a connection between lean production and design for sustainability on the issue of waste reduction. Initially it presents the meaning of waste within the "lean production" and "design for sustainability" fields and the correspondent heuristic approaches used in both fields to reduce waste. Finally, it presents a case study carried out within an Audi/VW Plant in Brazil that illustrates the implications of putting together lean and sustainable design principles. The overall conclusion is that dealing with waste using solely the lean production theory is not enough and, likewise, better results are likely to be achieved on production systems by integrating sustainable design practices.

Keywords: design for sustainability, lean production, sustainable manufacturing.

1. Introduction

Reduction of waste is one of the main focuses of lean production. This is also a key issue in sustainable design where, like on the field of lean production, there is already considerable amount of knowledge developed both in terms of high abstract concepts and principles as well as on heuristics and practical tools. Sustainable design looks at all dimensions of the life cycle of a given product, including the production stage. However its usual focus is on the interface between the user and the product itself and considerably less literature can be found regarding a more systematic view of design towards its environmental/ social impact on production systems. Indeed, only in the 90s the link between production management and sustainable design began to be more clarified with a better understanding of environmental requirements for industrial products and through the concept of life cycle design (LCD).

Despite the clear link between both fields of research on the issue of waste there is little amount of work attempting to connect their theoretical concepts and principles. In practice this lack of integration is also witnessed within companies where it is possible to find people applying sustainable design and lean production as a separate managerial and technological battleground. Next sections present insights on the implications of bringing these two different fields of research to work together.

2. Waste reduction in the lean production theory

The lean paradigm sees production system as a flow constituted of processing, waiting, inspecting and transporting activities. Within this model, processing activities are the only ones that can add value to the customer and, therefore, waiting, inspecting and transporting are considered non-value-adding activities and should be eliminated from the main process flow (SANTOS, 1999).

Based on this model, a production system could be further described as a network of process flows and operations flows, lying along intersecting axes. A process flow is the designation for the flow of materials (or information) and represents the pathway in which raw material is transformed into semi-processed components and then into a finished product. An operations flow is the designation for the flow of humans or machines that carry on the work over each stage of the process flow. Operations are very diverse and dynamic in terms of content and position in time and space. The process flow should receive priority when searching for improvements in production systems. For example, and conventionally, most people simply think that improving transport efficiency refers to the adoption of forklifts or installing conveyors, etc. However, within the process/operation model, improving transport can also mean reducing or even eliminating the transport altogether. It is only after this broader analysis has been carried out in the entire 'process' that improvements should be devoted to the actual operation of "transport" (SHINGO, 1989).

The aim of the flow model is to obtain "lean production systems", with little or no waste of resources. Therefore, identifying and eliminating sources of waste is a constant issue on the minds of production personnel using this paradigm in their every day activities. According to Imai (1997) and Shingo (1989), sources of waste (muda) in production are classified according to seven main categories:

- overproduction: this type of waste results from "getting ahead" with respect to production schedules. Here the required number of products is disregarded in favour of efficient utilisation of the production capacity;
- inventory: final products, semi-finished products, or parts kept in storage do not add any value. Even worse, they normally add cost to the production system by occupying space and financial resources and, also, by requiring additional equipment, facilities and manpower;
- repair/rejects: rejects interrupt production and, in general, require expensive rework. Moreover, they may end up discarded or damaging other equipment or generating extra paperwork when dealing with customer complaints;
- motion: any motion not related to adding value is unproductive;
- transport: although sometimes this activity seems to be an essential part of production, moving materials or products adds no value at all;
- processing: this waste happens when the use of inadequate technology or poor design results in inefficient processing activities. Sometimes this waste may appear as a consequence of a failure to synchronise processes, where workers achieve performance levels beyond or below the requirements of downstream processes; and
- waiting: this waste occurs when the hands of a worker are idle such as when there are imbalances in schedule, lack of parts, machine downtime or when the worker is simply monitoring a machine performing a value-adding job.

This classification could extend further with the inclusion of vandalism, theft and other sources of waste. Koskela (1999) proposes the inclusion of a type of waste that occurs frequently when production operates under 'sub-optimal conditions'. Congestion of a workstation in small places, work out-of-sequence and excessive stops in the flow are examples of these conditions that lead to production having sub-optimal performance (KOSKELA, 1999). Formoso et al. (1999) adds that it is possible to find waste due to 'substitution'. This waste happens when, for instance, there is a monetary loss caused by the substitution of a material by a more expensive one or when the execution of a simple task uses over qualified workers.

There are many techniques available to analyse and improve production systems using the flow model as the conceptual base. They allow the analyst to understand actual behaviour, sequence, proportion and variability of inspecting, waiting, processing and transporting activities. Many of them were invented in the early days of Scientific Management School, such as time-lapse video recording, work sampling and flow charts. Obviously a given production process is often the direct result of the decisions taken at the design stage. Next section reviews the overall strategies of design that affect directly the reduction of waste not only at the production stage but the entire life cycle of a given product.

3. Principles for waste reduction in design for sustainability

Most authors on the field of design for sustainability (BREZET; VAN HEMEL, 1997; CHARTER; TISCHNER, 2001; MONT, 2002; MANZINI: VEZZOLI, 2002) agree that its leading principles include:

- the extension of the design horizon: from product design to the (systemic) design of the product life cycle stages; and
- a new design reference: from product design to product function design.

Within this framework products have to be designed considering all phases of the life cycle. All activities related to the product, from the production of materials to its distribution, to its use and finally its disposal, are considered as a single unit. This leads to a shift from the design of the product to the design of the product-system, the whole of processes characterizing its life cycle. Waste is then analysed looking at the entire flow of a material/product, far beyond the limits of production (VEZZOLI, 1999).

The second criterion is to design referring at the function delivered by the product, more than from the physical product itself (MONT, 2002; VEZZOLI, 2003). In fact it is in relation to this function (functional unit) that it is possible to assess whether the environmental impact has been reduced and how. Function, a fundamental and historic theme in the culture and practice of design, acquires in this context a new meaning and a new vitality. Waste could then be considered as any resource that does not add value to the functional unit.

The reduction of waste within the life cycle design perspective involves some criteria and guidelines that can direct product development towards smaller environmental impact (VEZZOLI, 2007):

- material consumption reduction;
- energy consumption reduction;

- toxicity and harmfulness reduction;
- bio-compatibility and resources conservation;
- product life optimisation (extension and use intensification);
- material life extension; and
- design for disassembly.

All these criteria have direct implications on waste reduction, not only at the production stage but throughout the entire life cycle of a given product. A product with a longer lifespan than another (having the same function), for instance, generally determines smaller environmental impact. If a product lasts less, usually it not only generates waste prematurely, but also determines further indirect impact due to the need to replace it. Production and distribution of a new product to replace its function involves the consumption of new resources and the further generation of emissions.

On the other hand, the extension of its lifespan does not necessarily determine a reduction in environmental impact; it may even happen that continuing to use an old product causes an increase in impact. If, for the same service provided, technological development offers the opportunity to have new products with better environmental effectiveness (lower consumption of energy or materials or reductions in emissions), the time will come when the need to manufacture, distribute and dispose of a new product will be compensated for, in terms of balancing environmental impact, by improved performance in use.

However, the duration of products can be planned by increasing their reliability and facilitating updating, adaptability, maintenance, repairs, re-use and re-manufacturing. Actually we can optimise the lifespan of products from the environmental point of view by intensifying their use: a number of people using the same product (or component) at different times. A product used more intensely than others leads to a reduction in the quantity of product present at a given time or in a given place in order to meet a given demand for a function; i.e. it determines a reduction in environmental impact.

In the case of "extending the lifespan of materials" it means in practice a design that valorises material from scrapped products, which rather than ending up in landfills, can be reprocessed to obtain new secondary raw materials, or incinerated (burned) to recover their energy content. The term "recycling" is used when secondary raw materials are used to manufacture new industrial products. On the other hand, a secondary raw materials can also be directed towards composting. In all these cases the environmental advantage is double. In the first place we avoid the environmental impact of disposing of materials in landfills. In the second place resources (not virgin) are made available for the production of materials or energy which avoid the impact from the removal and production of a corresponding quantity of materials and energy from virgin natural resources. The impact of these avoided processes can be considered an indirect environmental advantage.

Design for the extension of the lifespan of materials does not mean simply choosing materials with efficient recycling or combustion technologies. We must facilitate all the stages of recycling (or composting or incineration), and design to facilitate collection and transport after use, identify materials, minimize the number of incompatible materials, facilitate separation of incompatible materials and facilitate their cleaning.

The approach of "facilitating disassembly" also affects directly the amount of waste in production. It means design that aids the separation of parts (for maintenance, repairs, updating or re-use) or incompatible materials (to be recycled or from which to recover energy content). This strategy is therefore helpful for both product life extension and use intensification and material life extension.

4. Research method

Case study is the main research strategy adopted in this study. The data collection used direct observation, image recording, flow mapping and measurement of key indicators. The analysis used a process called pattern matching where the researcher looked for direct replications of the theoretical propositions as described by Santos et al. (2001). In this process, the empirical evidence was considered to be a "literal replication" when observed results matched the theoretical predictions. In contrast, when the case study produced contrasting results but for predictable reasons, it was called a "theoretical replication" (Yin, 1984).

5. Results and analysis

5.1. General characteristics of the case study

The analysis of the linkage between sustainable design and lean production was carried out within one of the production processes observed within an Audi/VW Plant in Brazil. This process contains most activities related to the production of the body sub-system that involves the back wheels of a car, as illustrated on Figure 1.

The assembling process follows a sequential mode, producing isolated parts of the sub-systems within a cell manufacturing layout arrangement. Due to economical barriers and to the complexity of the sub-system it is divided in a total of 10 parts. Inside of the factory the production activity involves basically welding the interface between parts.

As Figure 2 shows the entire production process of this sub-system involves a total of 16 processing, 03 inspecting, 10 waiting and 03 storage activities throughout. In order to perform all these activities there is a total of 144 meters of

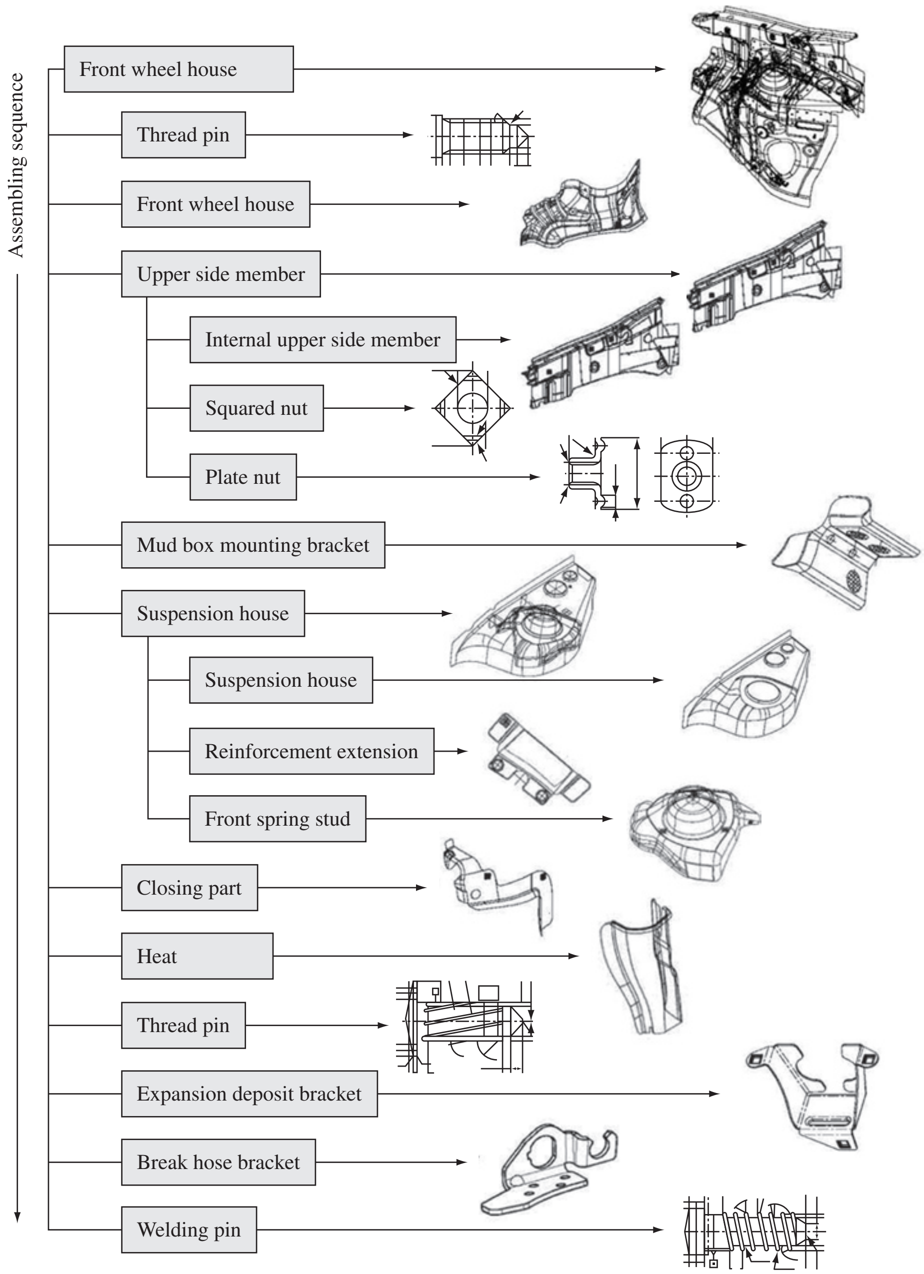

Figure 1. Process/product analysed within the case study.

transportation and movement activities, which includes both machines and humans.

5.2. Results and analysis of waste from a lean perspective

This company, as it is usual in companies on the automotive sector, already applies most lean production principles on the issue of waste:

- overproduction: the production system adopted the kanban technique and adopted boxes instead of cards to communicate orders to upstream operations. Further development on the system was required for third tie suppliers and for supporting processes;
- inventory: direct observation of the process revealed a large amount of semi-finished parts acting as a buffer in the process, ranging from 260 units (8 hours) for part 6Q0 809 222A to 6.000 units (92 hours) for part N 906 526 01. The company used Kanban associated with TPM/ERP systems to monitor and reduce continuously this inventory;
- repair/rejects: the company has a daily track of its rejects showing a great differences between the various components, ranging from 0.063 units/thousand vehicles on part 5Z6 805 116 to 147.34 units/thousand vehicles on part N 906 526 01. TQM activities were already part of the daily routine of this company

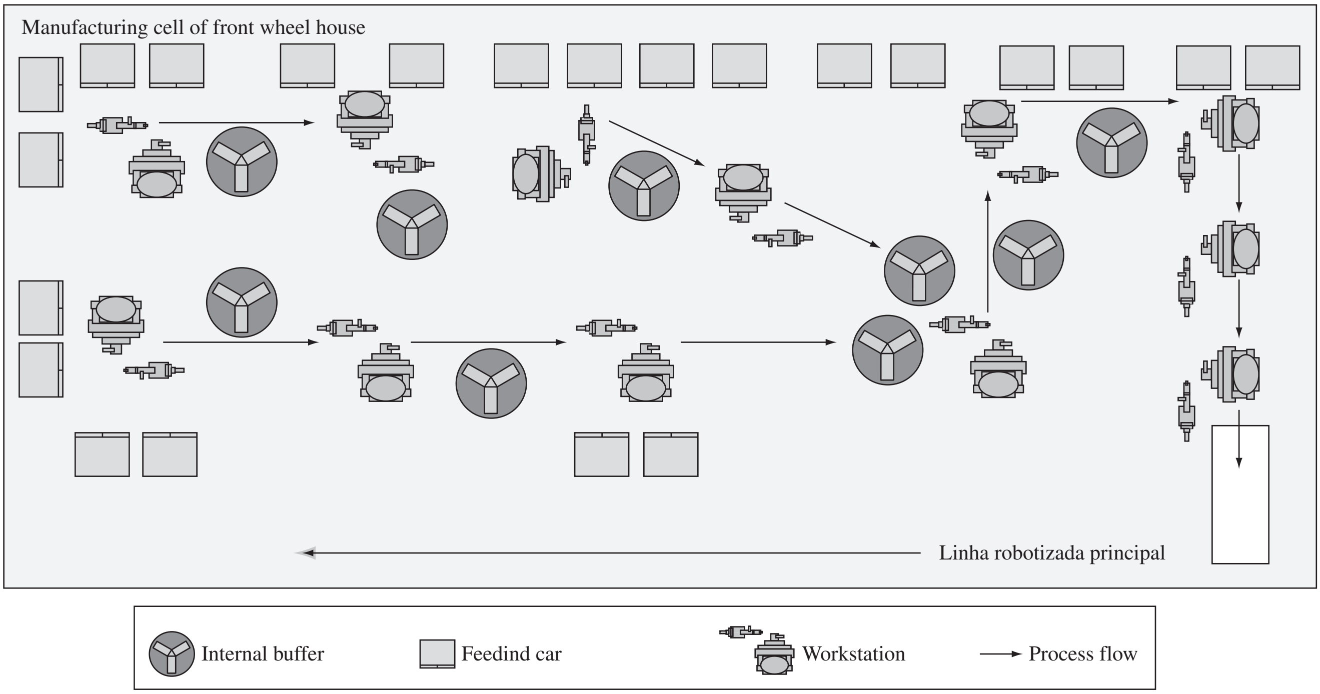

Figure 2. General view of the production process.

and reducing rejects is one of the main themes of their continuous improvement activities which involves all stakeholders on their meetings

- motion: the data collection revealed that typically a total of 24.5 meters of idle movement of workers and machines occurred every day. In order to tackle the problem this company perform regular ergonomic and time study analysis, involving all workers at the workstation on the process through continuous improvement activities;
- transport: process mapping showed a total of 120 of transportation activities using machines. The fixity of the building infrastructure and the heavy equipment on the factory played a key role on limiting the opportunities for transport reduction. Communication/control systems such as Andon, Kanban, TPM/ERP contribute to reduce the amount of transport within the factory, particularly when it was automatic. Here also the complexity and amount of parts increased the total time spent on transportation;
- processing: the quality of the processing activities was severely affected by human error due mainly to ergonomic deficiencies of the workstations and, also, to the pressure for keeping up with the production orders. Establishing stretch targets was the one of the main approaches for instigate improvements in this area;
- waiting: a significant impact on the lead time of this process was the amount of setups (10 setups throughout the entire process). Eliminating or reducing the amount of time spent on setup required a fundamental change on the design solution of the sub-system;

5.3. Analysis of waste from a sustainable design perspective

Critical analysis of the sub-system using the sustainable design criteria reveals various opportunities for waste reduction at the production stage with a focus on the product. Some of them are described below:

- material consumption reduction: there was an excessive amount of parts. Reducing the number of parts could lead to a reduction in the amount of material and energy used to weld the sub-system;
- energy consumption reduction: each part is welded in different workstations which demand an excessive amount of transportation/movement activities. The use of multi-functional workstations could reduce such waste and that demands improvements on the design of the sub-system in order to make it more agile the setup activities;
- toxicity and harmfulness reduction: the use of steel on the design solution demands a welding process that produces toxic emissions. Reviewing the design choices (ex: reducing the number of parts) could reduce or eliminate this welding process;
- bio-compatibility and resources conservation: the product could adopt less energy consuming material such as polymers obtained from renewable sources which could also eliminate the need for all painting activities. The painting process adopted on the

product turns the recycling process more complex and expensive;

- product life optimisation (extension and use intensification): there was no clear attempt to enable future upgradability of the sub-system to new design requirements neither there were solutions for reduce the amount of resources required for maintenance;
- material life extension: there was no ID on the materials that could help future stakeholders to identify the type of material used on the sub-system. Also, the researchers have not identified the use of a "cascade approach" for material recycling; and
- design for disassembly: the current design solution and the associated production process increase and make it difficult the movements and operations for disassembly. Furthermore, the sub-system adopts an asymmetric shape that does not provide a support base and/or grasping feature.

5.4. Main links identified between sustainable design and lean production

The observation of this case study has enabled to identify various linkages among lean production practices (or absence) and the implications of sustainable design concepts/principles. Table 1 below shows such linkages focusing on the environmental dimension of sustainability.

Some of the direct and evident implications of these linkages are:

Table 1. Main linkages between sustainable design (environmental dimension) and lean production on the issue of waste reduction.

		Lean production						
		Reduce overproduction	Reduce inventory	Reduce repairs/rejects	Reduce motion	Reduce transport	Improve efficiency in processing	Reduce waiting
Sustainable design	Material consumption reduction	■	■	■	▒	▒	▒	▒
	Energy consumption reduction	▒	▒	■	■	■	■	▒
	Toxicity and harmufulness reduction		▒	■				
	Bio-compatibility and resources conservation		▒	■			▒	
	Product life optimization			▒				
	Material life extension		▒	■				
	Design for dissassembly	■	▒	■	▒	▒	▒	

- a reduction on the amount of material used on a given product through sustainable design turns the transport lighter and faster (reducing CO_2 emissions during production) and, also, can speed up the processing activities;
- implementing solutions for more optimized transport and processing activities reduces the energy consumption necessary to produce a given product;
- reducing the toxicity and harmfulness of materials used on a given product affect the complexity and costs involved on repair, transport and processing activities, thus affecting the economic dimension of sustainable design;
- improving the bio-compatibility of materials, using as much as possible resources from renewable sources, can enable during production and on the usage phase the possibility of implementing cheaper repair activities as well as processing activities;
- product life optimization may demand more transportation, particularly when it involves assembling activities outside of the production system. Product-service system, for instance, may demand a continuous flow of assembling/disassembling activities throughout the product life cycle;
- material life cycle extension helps the feasibility of repairs on the long term and, at the same time, the quality of the inventory activities the achievement of a longer life span; and
- designing a product oriented to make it easier the disassembling process brings benefits to the reduction of waste with over-production, particularly on those cases where there is an opportunity of re-using components and parts that do have firm orders from clients.

Santos (1999) suggests that lean production can only achieve full results if applied entirely. Isolated practices offer solely sub-optimal results which may even have negative results. This case study suggests a similar hypothesis since the application of an isolated sustainable design heuristics may not result on its expected benefits if applied in isolation. Expanding such hypothesis to the integration of lean production and sustainable design practices has profound implications in practice. Furthermost, that will demand production and design personnel with a minimum domain on the concepts/principles of both lean production/design for sustainability in order to allow communication and joint action of both professionals.

6. Conclusions

Sustainable design has clearly a broader perspective on waste reduction than lean production. Indeed, it leads to a more fundamental question: "do we really need to produce a new product?" and such question is not part of the lean production scope. Lean production is all about reducing waste and increasing value but when it defines value it always assumes that at a given point it will be materialized into a product/system. On sustainable design the provision of value (function) not necessarily implies the an actual production as it was described earlier in this paper

However, the theory of sustainable design is not sufficient to achieve a waste reduction at the production level since by focusing on the product it overlooks the waste on flow, both on operations (flow of people/machines) and processes (flow of material/information). Therefore, both areas have to work together in order to accomplish a comprehensive reduction/elimination of waste.

Whilst lean production would look solely into wastes such as overproduction, inventory, repair/rejects, motion, transport, processing and waiting, sustainable design will look at other sources of waste throughout the entire life cycle of a given construction component.

There are a limited number of design and production management professionals with knowledge and competencies to operate across both fields of knowledge and such gap presents an opportunity for research since there is a need for a more comprehensive approach for waste reduction.

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