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Production System change strategy in lightweight manufacturing

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Abstract

Two change management strategies: a minimum change, exploitation strategy (kaizen) and a maximum output, exploration strategy (kaikaku) have been applied in a manufacturing case study. Value stream mapping and discrete event simulation were used to analyse the production system changes, with regards to robustness and total lead-time, to increase knowledge of how to choose change management strategy. The results point out that available time is crucial. It is important to consider not only product specification and return of investment, but also the change and risk management. Future research should develop engineering change management further.

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1. Introduction

When companies need to do process and product changes, two mental approaches comes in an engineer's mind: the first is "change as little as possible, improve in many small steps" the other approach is "take a large step, and include as many improvements as possible". The wanted output for the first exploitation-based approach is continuous improvements (kaizen) i.e. predictable controlled changes that may be reversed if they don't have the desired outcome. The second approach, however, is more explorative and aims at radical and innovative improvements (kaikaku).

In kaizen, or continuous improvements (CI), is control kept at team level and management focus on coaching improvements in a so called "Kata" process [1]. In order to create alignment, improvement challenges toward a vision target state are given, and actions are made as stepwise experiments toward that vision target state. Target states should not have a single numerical goal [1,2], rather several targets or performance measures are monitored in order to know if the target state is satisfied [1]. Teams should document 'next target state', expected result, the actual result

and the learning's for each experiment to define the 'next target state' towards the vision [3].

The radical improvement process, or kaikaku, however, is characterised by creativity and innovation to reach the target state, thus being concordant to exploration strategy [4, 5]. Exploration implies experimentation, a high novelty of the ideas generated, variation, deliberate risk-taking, free association, diversification and ample choice. Consequently, kaikaku significantly differs from kaizen/CI from a methodological standpoint, as kaizen instead corresponds to exploitation strategy, implying control, stability, reliability, refinement, minimal deviation, convergence and repetition.

In manufacturing there are several occasions when there are internal improvement needs, such as shorten lead-time or increase productivity, by doing process changes (e.g. reduce setup times) or product changes (e.g. change joining). But there may also be external, customer induced changes (e.g. shortening of lead-time or change of product properties). One example of a complex manufacturing process with internal and external requirements is injection moulding. Injection moulding (IM) with subsequent lamination is used for manufacturing of several types of automotive components. Due to high pressure, the IM-machines are heavy and hard to

handle manually, with the consequence that e.g. setup-times often becomes long. Set-ups include lifting, changing and cleaning tools/moulding dies, adjusting and trial runs. The changeover may typically take several hours [6]. The operation involve four stages to form the product out of plastic pellets; plasticization, injection, packing and cooling [7], with hydraulic and screw systems used in combination to press the plastic in the mould. The process stability and overall equipment efficiency are affected by the operator's experience, the design of parts and moulds and the plastic raw material characteristics. Increased knowledge regarding process parameter settings and adjustments is an important improvement factor. Since lamination and injection moulding equipment are large and expensive there is an important question of how to handle risk and management control in both the management strategies.

Although the extensive literature on kaizen/CI through the lean tradition, as well as more emerging literature on radical improvement, there is a lack of empirical studies of the link between chosen improvement strategy (radical or incremental) and the required strategy analysis (especially considering risk and verification analysis).

In order to address this identified research gap, a single case study was conducted involving a manufacturing process of a plastic component for vehicles where there is a customer demand to change to a lighter material and an internal factory demand to shorten lead-time and increase capacity and productivity. The specific research question for the case study was formulated as: *What are the management consequences of the choice of improvement strategy (radical or incremental improvement strategy)?* The case analysed two improvement scenarios, one radical improvement and one incremental improvement, and related those to the needs of analysis tools and strategies.

The situation described in this case study is common in automotive industry, where there are many similar situations in manufacturing industries when internal and external demands induce product and/or process changes and there is a managerial need to choose improvement change strategy. This case study is used to present the management dilemma and reasons to go in either strategic direction.

The paper presents the concepts of incremental improvement strategies like continuous improvements-kaizen and of radical improvement strategies kaikaku. These two have been compared in an early concept case study where engineering change management (ECM) has been used as structure for the case study investigation. Literature best practice data has been used as input, and then value stream mapping and discrete event simulation has been used as analysis tools in the comparison.

2. Theoretical background

There is an extensive body of literature and practice established for incremental improvements (kaizen/CI) in manufacturing. Using lean tools like SMED (single minute exchange of dye) often give improvements in reduced setup times. Although some early cases report more than 95% improvements [8], reductions in changeover time of between

50% and 75% is regularly reported [9,10]. Similarly if teams focus on unplanned machine stops, condition based maintenance and operator driven maintenance (autonomous maintenance) may reduce unplanned machine stops by 50-75% [11]. In injection moulding, SMED empowered with Taguchi parameter setting, may give improvements of at least 50% [7]. In addition simultaneously setup time reductions may improve maintenance and thus downtime due to maintenance [10]. In the case study, the easy improvement opportunities have already become exhausted, so the lower end of improvements are expected in the incremental improvement scenario. However if SMED knowledge is incorporated in machine design (as in the exploration scenario) a very high rate of improvement can be expected [12].

Radical improvement such as kaikaku is characterized by episodic occurrence and fundamental change. It is a process that intends dramatic redesign of existing processes. The expected end results are often expressed in terms of 30 – 50 % performance increase of important parameters [4, 13]. However, as the specific improvement is based on current status, process maturity, and the choice of parameter(s), thus being highly contextual, these measures should be used as input for target setting rather than decisive success criteria of the improvement conducted [13]. Contrary to operator driven continuous improvements, kaikaku is often a top-down driven design process and the tools used involve change of product or process design or change of concept.

Drawing on the broad definition of engineering change management, ECM, by Hamraz, Caldwell, and Clarkson (2013); "ECs are changes and/or modifications to released structure, behaviour, function, or the relations between functions and behaviour, or behaviour and structure of a technical artefact." [14], the component design change in this case certainly lends itself to ECM processes. However, also subsequent change to the manufacturing system in this case can be described as an implicit change as opposed to explicit [15] and may be included in the definition. It is important to make a distinction between emergent changes and initiated change [16]. In our case change of component material is planned for, initiated. However, the processes to resolve the change is the same for both emergent and initiated (as in [16]), which would imply that the ECM process would be similar for implicit vs. explicit [15].

In the six steps engineering change process developed by Jarratt, Clarkson, and Eckert [17] that is applicable to changes be they implicit, explicit, emergent or initiated follow the structure:

1. Engineering change request raised
2. Possible solutions identification
3. Risk assessment
4. Selection of solution
5. Implementation of solution
6. Review of solution

ECM as a research discipline does not give any guidance over when to use incremental or radical changes. That being said, if a radical change is chosen, the six steps [17] above

would be treated differently than if incremental changes needed to be managed since the risk is higher. This is partly a self-correcting problem that was observed by Pikosz and Malmqvist [18] as they studied three engineering cases and their ECM processes. They did see that smaller changes are often handled outside any formalised process, while larger changes often involve more departments as both the ECM process and review grew in scope [18]. The same organisational behaviour has been observed during radical improvements with a large degree of cross-functional and business focused processes [13].

3. Method and materials

A case studying manufacturing of plastic components to the vehicle industry has been used to demonstrate effects of implementing different change strategies in two scenarios. Value stream mapping (VSM), environmental value stream mapping (E-VSM) and discrete event simulation (DES) were used together with process technology literature and experience to analyse the implications of a change process in the automotive industry. VSM is a comprehensive static process analysis tool used to map processes with lead-times, capacity and buffers [19], in addition EVSM can include material efficiency [20]. DES can be used to analyse the dynamics of the process. The results were compared to hypothesise on different change management strategies on when to do incremental exploitation change vs. when to do large exploration step changes. The different considered solutions from material perspective are analysed and compared with regards to production flow and logistics considerations.

The process of analysing the two scenarios roughly follows the engineering change management (ECM) process suggested by Jarrat et al (2005) [17]:

0. Current state is analysed by Value stream mapping and Line walk.
1. Engineering change request raised – challenges on weight and productivity improvement.
2. Possible solutions identification – Scenario A (CI, using SMED and autonomous maintenance) and Scenario B. (Redesign of component and process) were drawn and the results calculated.
3. Risk assessment – Analysis of the solutions by VSM and potential gains and risks were assessed.
4. Selection of solution – Made from match-making of step 1 and 3.
5. Implementation of solution – a simulation of the current line and of each of the scenarios were built as to simulate and review solutions
6. Reviews of solution – Results of simulations were evaluated.

4. Empirical results

The case study includes one explicit initiated change, to make the material lighter, and one implicit emergent change, to improve the overall flow efficiency and capacity of a

mould injection and laminating line for automotive component manufacturing.

The current state is analysed in a Value stream map (VSM) drawn at two line-walks in the autumn of 2014. The process involves an injection moulding (IM), glue box, and a lamination after which a manual cleaning and assembly operation occurs before parts are grouped into sets and sent to the customer (figure 1). It is clear that the overall lead-time is a major challenge in the process. The VSM analysis shows that the value adding time (sum of cycle times in value adding operations) is 4.2 minutes while the overall lead-time of the line is around 13.2 hours. The line tact is just over 2,5 minutes for a set of four parts two right and two left. The lead-time is due to large batches in the IM machine. These are in turn forced by long setup times (40 minutes) and low availability and capacity of the IM machine. Except for the IM with 80.5% availability, the line has 90% equipment availability. The IM makes two left parts or two right parts per shot and each shot takes 60 seconds with 80.5% availability this gives 74.5 seconds per two parts. The tact-time at the time of the study was 157 seconds for two right and two left parts, leaving only 2 seconds per part for setups. With a 40 minute setup-time this gives a necessary batch size of 600 shots per batch which is the reason for the minimum lead-time of 11 hours for the process.



Figure 1 Schematic process overview

4.1. Scenario A. kaizen/CI strategy calculation of results

To produce plastic parts from mixtures of fibres and plastics is a plausible way to increase strength and thus be able to use less material in total than for a 100% plastic part. It is important to find the right material mix that increase strength without gaining too much material weight. Trials with bio-fibre (density 1400kg/m³) mixed with polypropylene (PP) (density 900kg/m³) show that at a too high fibre content (>50%) the strength of the material is reduced and thus give no weight reduction [21]. The optimal mix in granulate for IM is between 20% [22] and 40% fibre [23], while up to 30% is feasible without changing IM machine [24]. Optimal mix give around double the strength compared to pure PP and thus the weight reduction may be up to 44% reduction of weight. In this scenario a raw material, PP granulates with an incremental increase of fibre, is introduced. At least 20% fibre in PP can be reached, which give a 45% increase of strength or consequently a 30% reduction of volume [22] or 25% reduction of weight. This change requires minimum additional investment in the IM although it requires a more expensive raw material.

Scenario A is based upon a continuous improvement/kaizen strategy. With focused improvements on setup-times and stop-times in the IM process, as explained in theoretical background (ch. 2) improvements of 50% in setup-times and reducing downtimes by 50% by working with TPM, operator maintenance and condition based maintenance can be expected. This requires substantial investments in operator time for improvement work and investment in upgrading and

renovating the machine. The process changes mean that availability could increase to 90% (as the rest of the equipment on the line) and reducing the setup-time down to 20 minutes. The result of this is that the cycle time including availability is 66.7 seconds per two parts, leaving 11,8 seconds per part for setup and the batch size can theoretically be reduced to less than 51 shots per batch. The selected batch size was set to 90 shots per batch thus leading to a theoretical lead-time of two hours.

Most of the time gain is invested in lowering lead-time in this scenario. If there is increased demand from the customer batch sizes may need to increase again. The risks of doing scenario A is expected to be low since every step is reversible. The main implementation risk is that the calendar time to reach the improvements may be long and during the implementation time, to do setup and operator maintenance training, the process will need regular training stops.

4.2. Scenario B kaikaku strategy calculation of results

Scenario B is based upon a radical design change strategy. The visionary kaikaku goals of the line are a reduction of lead-time to 1-4 hours and reduction of weight by 50%. A new line is proposed (figure 2) where a preformed fibre mat is inserted in the mould and PP is injection moulded with low pressure on top of it. The fibre content then could be 40% with twice the strength of PP and thus a weight reduction to 61% of the original weight. The component is lifted over by a robot directly from the IM to the lamination. The cycle time of the pre-form mould and lift-out is expected to be 50-60 seconds in total, i.e. not much cycle time reduction. However by designing in low setup-time into the equipment [12], the setup-time is expected to be reduced to 5 minutes (almost 90% improvement) and an availability of 98% for each process step (pre-form inlay, IM, robot, lamination) is expected with overall availability of 0.98^4 > 90%.

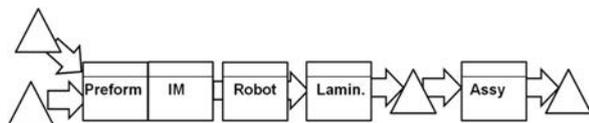


Figure 2 schematic overview of the new proposed process.

However the material need in preformed fibre demands five times the logistics compared to pellets. Since the setup preparations and follow through can be expected to use as much workers time as the original set-up the batch time should not be set lower than 40 minutes, thus a batch size of 50 were selected. The lead-time is calculated to 1.2 hours given the process goals are met.

The risk evaluation has to consider if setup time or availability goals might not be met. The setup-time reduction is in this scenario so large so that the setup-time is not critical. The batch size is chosen so that even with a doubled setup-time the production rate will be sufficient. Likewise the scenario may handle a 20% increase of demand without increasing batch size and lead-time. However the risks of disturbance and process variation is crucial since there is no

buffer in the new integrated process. For example, if availability for each step remains at 90% the overall availability can be calculated to $0.9^4=0.65$ which would not be sufficient to reach production demand. Even with 5 minute setup-time and the original batch time, the availability need to be larger than 93.7 % on each process giving 77% for the whole new process, to meet the capacity need.

Table 1 Results from VSM and bottleneck calculation

Scenario results		Baseline	Kaizen/CI	Kaikaku/redesign
Need	sets/h	23	23	>23
Tact time - parts	min	0,65	0,65	<0,65
IM* Capacity	#/min	2	2	2
IM* Cycle time	min	1	1	0,8-1
IM* availability	%	80,5	90	90-98
IM* setup time	min	40	20	5
IM* batch size	#	600	90	40-60
VA time	min	4,2	4,2	3,2
Minimum lead-time	hours	13,1	2,03	1,16
Max capacity	sets/h	22,92	24,7	27,9
Material weight	%	100%	75%	61%

4.3. Management strategy and simulation results

In the studied case the scenario B strategy were chosen as preferred. One of the main reasons was that there were no remaining available time to actually allocate the equipment and the team to do improvement work. In strategy B the new process can be installed and started in parallel to the old line. Strategy B also is expected to give a good baseline for future continuous improvements.

Discrete event simulation (DES) was used to review the solutions. A DES model, with no stochastic variation of operation times and down times, confirms the results from the VSM calculations in the current state. When introducing stochastic variation in the current state only small changes in lead time and capacity of the system were detected which confirm current process stability (although capacity is slightly to low) Then scenario A and scenario B were simulated, showing that dynamic capacity is slightly lower than calculated in Table 1 but still sufficient. In both scenarios the bottleneck moves towards the three assembly stations. These are however highly flexible and may be rebalanced with extra personnel within hours, making it not critical. In scenario A this means that the resulting capacity in the IM is still the significant issue. However, most goals are met at low investment cost. In case B the remaining issue is the stability of the process due to availability of each operation, considering the difficulty to predict availability when introducing new technology.

5. Discussion

Both management strategies eventually reach large improvements; these should be monitored by the performance measurement system specified to see how well the target states are met [26].

The need for engineering control over the change process may be larger in the explorative approach than in the exploiting approach, since the risk is higher. Product changes may often need more assurance than process changes since customer demands usually need more control. In this case the ECM process worked appropriately. Especially radical changes should be thoroughly assessed and weighed against other options, steps 3 and 2 respectively [16]. Step 2 is often omitted resulting in that the first conceivable solution is used and implemented. This may lead to more changes in an uncontrolled propagation pattern. In this research project both steps 2 and step 6 have been worked through thoroughly. First, turning an implicit change to the manufacturing system into an opportunity by evaluating how a change, incremental or radical, could improve the existing process, e.g. implementing radical changes as a result of product changes that would have propagated into the production system in any case. This might be defining the difference in a radical as opposed to an incremental change scenario from an ECM perspective. Secondly, investing the time to evaluate the implemented situation is something that is often omitted in industry [16]. In order to avoid optimism bias the review of any radical change is more important than for incremental changes as those seldom elicit the same drive in the people implementing them. This can be avoided by a rigorous review using e.g. discrete event simulation and risk analysis.

In this case it became obvious that the need for investing operator and equipment time in continuous improvement work (typically one or more hours each week need to be invested) in scenario A would be impossible if customer demand would be kept. The kaizen/CI approach, if chosen, needs to be applied in situations when there is sufficient time available to develop the personnel together with the equipment. If there is time however it seems like a reasonable approach, it meets most demands at low investment cost and low risk, it also involves the team which may give additional improvements in occupational health and safety, reducing risks and improving quality and material efficiency.

When it comes to scenario B it is clearly less predictable and thus includes a higher initial risk as well as more opportunities. To reduce risks the systematic investigation of the concept before start of implementation is more crucial. Also proper risk evaluation using e.g. FMEA (Failure Mode Effect Analysis) for the system of machines, which is standard in the automotive industry, is regarded as necessary. However it seemed as the structure of ECM emphasising on risk assessment and review is appropriate; however there may be other as appropriate methodologies within e.g. system specification for manufacturing applications [26]. This may be subject for future research.

Finally both strategies may reach important improvements. Incremental improvements by kaizen or continuous improvements seem to introduce lower risk, but take longer time to implement. The radical improvement strategy, involving more redesign element can be performed faster with support from external resources but require more risk management and project management structure. This is in line with earlier research on kaizen and kaikaku [4]

6. Conclusion

The relation between the change management strategy (incremental or radical) and analysis strategy (considering risk analysis and verification) have been analysed through a single case study for manufacturing of plastic components to the automotive industry. The general approach on how to study strategy selection for combined material and process changes is proposed to follow the engineering change management (ECM) process [17]. It was concluded that if a continuous improvement strategy is used, the risk analysis and verification process is less critical, while if a radical improvement (kaikaku) strategy is used, the risk analysis and verification is critical and tools such as FMEA and discrete event simulation is even more important in order to find limits of process capacity and process stability. The available time for change was crucial for the studied case to choose a radical change strategy.

A single case study does not give universal answers for combined product-process change management. However it gives insights in the specific case and can be used for building hypotheses for wider studies. Although a single case study cannot give a general response to the research question, the results demonstrate how management strategy has been selected in a real industrial case. It is important to consider not only return of investment and product specification, but also how large the process change need is, scheduling time of the improvement work and the risks associated with the changes involved.

Further case studies on improvement strategies are needed to learn more of the limits of each strategy. Inclusion of improvement strategy in engineering change management may also be of interest in future research

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