AN EXAMINATION OF THE APPLICATION OF PLAN-DO-CHECK-ACT CYCLE IN PRODUCT DEVELOPMENT

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ABSTRACT

Plan-Do-Check-Act (PDCA) cycle is a high level method for achieving continuous improvement that has been a basic element of the total quality management movement. It is a practical tool and is widely adopted in the automotive sector as an improvement tool to managing improvement projects especially within manufacturing. The aim of this paper is to evaluate how the continuous improvement processes are conducted compared to the PDCA cycle and to better understand the improvement processes in a PD environment. The results from the case study shows that the PDCA cycle is not always followed precisely according to the formally described quality assurance system in the companies. Nevertheless, the case companies emphasizes that they naturally, as engineers, do improvements every day. The companies have according to our evaluations never given the PDCA method a proper chance to prove its usefulness in PD. Consequently, the companies claim that the method will be most suitable when the problem to be analyzed is sufficiently complex, when there are no time constraints and enough resources to spend on the problem.

Keywords: PDCA cycle, continuous improvement, product development, automotive supplier industry

1 INTRODUCTION

The Norwegian first tiers suppliers to the automotive original equipment manufacturers, included in this study, face contractual requirements of yearly price reductions over the life cycle of a model or a platform. The speed at which firms develop and roll out new products has become an increasingly critical competitive issue. The long term business sustainability therefore depends on the ability to acquire knowledge throughout the organization to develop better products and processes.
Many companies have focused their time and effort on improving the manufacturing processes. JIT, TPM, Six Sigma are well known tools that to a large extent are successfully implemented to improve or redesign the value stream of physical products. There are still potentials for improvements by making manufacturing processes more adaptable and flexible, however, it is equally important to focus on the PD process to become competitive in the future[1]. Considering that at least 80% of the life cycle costs of a product are determined in the early phase of PD, the rate of success is heavily dependent on how this initial phase is performed[2]. Continuous improvement is found important as a never ending process of performance improvements to gain efficient processes in PD environment [3].
The aim of this paper is to investigate how PDCA are conducted in PD in two automotive supplier companies. This is again compared to the PDCA method described in their formal quality assurance system. Do the case companies follow the PDCA method as described in their formal quality assurance system? If not, which strengthens and weakness can be identified through the in-house approach compared to the PDCA method?
In the following sections, we first outline the theoretical background of total quality management (TQM), continuous improvement processes, and the specific approach used in this research study, PDCA. Next, two case studies are presented to illustrate the continuous method used in the case companies. The experiences from the case study will be presented and compared to the theoretical background for the PDCA method. Finally, the main concluding remarks about strengthens and weakness to show the usefulness of the PDCA method will be summarized.

2 TOTAL QUALITY MANAGEMENT

The TQM philosophy highlights systematic, integrated, consistent, organization-wide perspective that involves everyone and everything. It focuses primarily on total satisfaction for both the internal and external customers, and it seeks continuous improvement of all systems and processes in companies [4], [5],. Thus, TQM could be said to mostly focus on the process when using the definition; "*a collection of activities that takes one or more kinds of input and creates an output that is of value for the customer*" [6].This is in line with one definition of a PD process; "*a sequence of steps or activities which an enterprise employs to conceive, design and commercialize a product*"[7].

The beginning of TQM can be traced back to Shewhart who introduced the use of statistical quality control in the 1920s [8]. His work was later broadened by other statisticians, and in 1949 the Union of Japanese Scientists and Engineers, influenced by Deming and Juran, formed a committee devoted to improve the Japanese productivity [9]. In Japan, TQM produced managerial innovations as quality circles, supplier partnership, cellular manufacturing and just-in-time production among others.

Continuous improvement, a core principle in total quality management (TQM), is commonly recognized and used in industrial companies all over the world [10]. There are many definitions of continuous improvement, and two of them are: "a *continuous stream of high-involvement, incremental changes in products and processes for enhanced business performance*"[10] and "*a conscious effort to manage and accelerate the learning curve by involving a maximum number of people in improvement*" [11].Both of these definitions emphasize involvement from the entire organization, consequently also people working with research and PD. In complex and turbulent environments the need for continuous improvement of products and in processes is widely recognized [12]. This statement is very adoptable to the automotive industry and its suppliers to be able to develop better products and processes to succeed in a demanding market.

3 CONTINUOUS IMPROVEMENT IN PRODUCT DEVELOPMENT

Even though TQM and continuous improvement have been well known techniques for decades it is still reported that little has been written about the application of TQM and continuous improvement to PD [13], [14], [15]. The mechanisms whereby continuous improvement can be achieved are often less clearly identified. Although many "*kaizen*" or continuous improvement projects based on employee involvement are started, the failure rate is high [12]. Companies often achieve significant improvements in the short run, but continuous improvement ultimately falls apart or does not materialize. A study by Lillrank et al[16] shows that two out of every three continuous improvement initiative fail to deliver desired performance. Powell [9] also reported a considerable variability in TQM performance, ranging from success, abandonment of TQM to bankruptcy. The experience of disappointment and failure with continuous improvement initiatives reported by many organizations derives mainly from a lack of understanding of the behavioral dimension[12]. Too much focus on continuous improvement tools and techniques, neglecting human factors and how continuous improvement behavior patterns emerge in the workplace, is also reported as a pitfall in a study by Ljungström and Klefsjö[10]. Lack of focus on human resources is also reported as a weakness in the ISO 9001 quality system [8].

The applications of TQM to PD are reported as everything from beneficial to fundamentally unsound [13]. This lack of extensiveness to PD is somehow contradictory to the intension in the pioneering work by Deming and Juran, who stated that the quality concept cannot be tested into a manufactured product but must be designed into the product: "quality at the source" [17]. Sandström and Toivanen[18] argued that management should realize that the key to strategic success lies not in making manufacturing more efficient, but rather in making PD more effective and conscious about quality. Ekvall[19] found a tendency that managers seek to control and manage the research and development processes more than before. This may be performed by using the management philosophies such as concurrent engineering and ISO 9001[20]. In addition one has to find a balance between formal processes and freedom to succeed with continuous improvement and TQM work among engineers. In the terms of Mintzberg [21] this can be classified within the professional bureaucracy, where professionals expect freedom and decentralization to apply their special competence in their work and thereby show resistance to rules and procedures. Professionals claim to have different standards than the rest of the organization because of learned methodologies during education and earlier work experiences[22]. It is therefore important to pay attention to this resistance

to rigid systems and procedures, and thereby try to agree upon a level of standardization which both satisfies the quality standard and the professionals.

4 THE PLAN – DO – CHECK- ACT METHOD

The concept of the PDCA cycle was originally conceived by Walter Shewhart and W. Edwards Deming was the one who first coined the term PDCA and he encouraged the Japanese in the 1950s to adopt the PDCA method. The PDCA cycle, also called the Deming wheel [23], or by Deming himself the Shewhart cycle [24], is a main tool in continuous improvement. The PDCA cycle describes a systematic and continuous problem solving approach, which has been used since 1950 by the Japanese to improve the quality in the entire organization. This tool is widely outspread in the industry today, and the PDCA approach is also highly recommended by the quality assurance standard ISO/TS 16949 used by the Norwegian first tier suppliers in the automotive industry [25].
Coordinating continuous improvement plans with a PDCA cycle involves four steps: Plan, Do, Check and Act, carried out in the cycle illustrated in figure 1. The PDCA cycle is designed to be used as a dynamic model, and completion of one turn of the cycle flows into the beginning of a new cycle again. Normally, it needs to go through multiple iterations of phases (PDC-PDC-PDCA) within the same cycle, before the desired results can be accomplished.

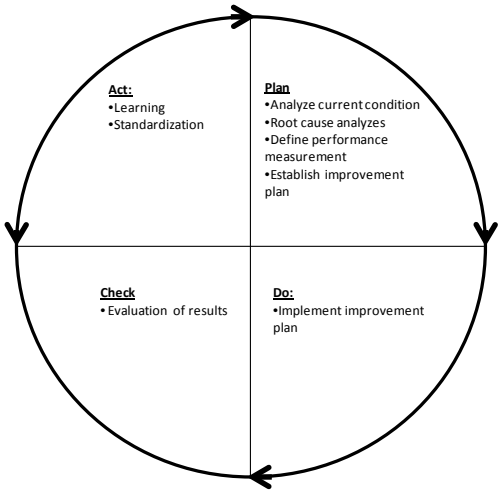

Figure 1: The four phases of the PDCA cycle

The PDCA cycle is a valuable process that has a wide applicability[1]. Although it is frequently used as a process improvement tool by teams, individuals will also find it useful. Toyota has for instance found the PDCA method to be generic and applicable to the PD, additional to manufacturing. Using the PDCA method lies in their culture and is daily used as a problem solving method to ensure fact based solution and to avoid solutions which only remove symptoms [26]. Short-termism and sub-optimization through partial fulfillment of the PDCA cycle can be seen as a contrast to the strength of the Toyota product development system. Most of the organizations are not consistently effective in addressing the day to day problems they face, but instead they have developed sophisticated in "fire fighting skills [3]. In the West many companies are adept to just "do" and neglect the P-C-A phases [27].
Coordinating continuous improvement with a PDCA cycle involves four phases Plan, Do, Check and Act, which can be explicitly stated as follows:

4.1 "Plan" Phase

This phase is not just about planning what to do, but also to identify and analyze the problem and establish performance targets and methods to reach the targets. Normally a continuous improvement team is established to solve a specific problem were the team involve the type of resources which have the necessary competence and mandate to achieve desire improvement. The team is established, recourses identified, responsibility assigned, before executing the improvement plan. Initially, one

must understand the process or system that gave rise to the problem, in the context where the problem occurred, to clarify the problem further and find out why the problem is a problem. Typically, continuous improvement teams spend the vast majority of their time and effort in this phase[24]. When the current condition is analyzed then performance measurements must be defined to know what the targets for the improvement are. Performance targets to use in evaluating the results of the problem-solving effort, is important to secure that an improvement is achieved. It is often difficult to identify the specific metrics to achieve desired improvement[28].
Beneath every problem lies causes and it is easy to underestimate the effort it sometimes takes to find the root causes of a problem. Causes can be classified as one of the following as described by Andersen [29]:

- *Symptoms: These are not regarded as actual causes, but rather as signs of existing problems.*
- *First-level causes: Causes that directly lead to a problem.*
- *High-level causes: Causes that lead to the first-level causes form links in the chain of cause-and-effect relationships that ultimately create the problem*

This demonstrates that a problem can be the results of multiple causes of different levels and some causes affect other causes. One way of identifying causes is to perform Root Cause Analysis. It can be described as [29]: *Root cause analysis is a structured investigation that aims to identify the true cause of a problem and the actions necessary to eliminate it.* The challenges is to correctly identify the root causes, as there may be multiple root causes, moreover the identification of one of a root cause is not sufficient to bring about the desired results, action have to be implemented.
Hence in order to prevent recurrence of problem, causes have to be eliminated. Otherwise the problem will occur again. Developing and evaluating a number of possible improvement alternatives and creating an effective improvement plan are important in this context. Improvement plan describes who will do what by when.

4.2 "Do" phase

The improvement plan is now formulated and it is time to execute it according to the schedule. It is expected that the "do" phase is where all defined issues are implemented according to the improvement plan defined in the "plan" phase. There may be several potential or competing causes to the actual problem. Consequently the improvement plan contain items that attempted, but that in the end, wind up not affecting the observed problem[3]. In the "do" phase it is just as important to understand what did not work as it is to know what did work. In this phase the continuous improvement teams will maximize its learning from the experience.

4.3 "Check" phase

This is a crucial step in the PDCA cycle, where the data gathered during the "do" phase" is studied in order to evaluate the effect of the implementations [24]. Performance targets are summarized and evaluated and a review is made of actual and expected results. This phase emphasizes the success of the planned actions in addressing the core problem and whether the root causes have been eliminated. If the problem is completely solved you can move on to the next phase, if the action items was only partially successful it is necessary to revisit previous phases.

4.4 "Act" phase

The effectiveness of the improvement issues implemented is confirmed in the previous phase and further work is to use the valuable work in a proper way both, inside the continuous team, and other relevant persons. The potential for standardization of improved processes and learning relies mainly on the "act" phase to ensuring that the improved level of performance is maintained and to capture the learning during the work performed in all of the phases in the PDCA cycle.

5 CASE STUDY METHOD

The following section outlines the method used to conduct the multiple case studies in the Norwegian automotive supplier industry. Automotive supplier industry was chosen as a case as they already has a formal requirement to define a continuous improvement method and to use it as a method to secure continuous improvement for all processes at the companies. Both companies have decades of

experience with the continuous improvement methodologies primary in the manufacturing department therefore it will be exciting to investigate the experience in PD.
Two specific cases were chosen to allow analyzing the continuous improvement method, compared to PDCA, in Norwegian automotive first tier supplier industry. Multiple cases are chosen to ensure higher external validity than use of a single case[30].
A research protocol including the main questions for the interviews was developed prior to conducting the research. Semi-structured interviews were performed in both case companies. The interviews were answered by the professions design and engineering, project managers and quality assurance, and were directed at understanding the use of PDCA cycle in PD. Since both the companies participating in this study are committed to PDCA cycle, the studies were concerned with implementation and performance, issues related to the use of this method. To allow deeper examination and ensure the reliability of the data from the interviews, one of the cases was analyzed more thoroughly through direct observations, informal conversations, attendance at meetings and events, and review of archival sources.
Central to effective case research is coding of the observations and data collecting in the field. It is important to try to code data into categories[31]. Data from this study was first coded into categories according to the different PDCA phases in question (see figure no. 1). Thereafter the data was analyzed with respect to patterns, and finally cross cases analysis.
In the following section, we will present the results from the case studies and discuss them relative to existing literature.

6 CASE STUDY RESULTS AND DISCUSSION

Both industrial cases have described formally the use of PDCA cycle for the continuous improvement in PD in their formal quality assurance system, to improve their business performance and customer satisfaction. This section aims to present the qualitative data gathered trough the case study from each of the four phases according to the PDCA cycle, which is also presented as a summary in table 1.

6.1 "Plan" phase

There is no clear answer to how the case companies perform the Plan phase. The daily observations concerning what to choose for improvement and how problem solving is conducted are highly dependent on the type of problem. Customers have much influence on what is chosen to improve based on customer requirement and expectations. The focus on improving customer satisfaction is highly influential for the case companies in identifying the main performance target for the improvement tasks.
The normal procedure at the case companies is to gather a improvement team with the relevant knowledge and experience, and start an informal process of brainstorming and discussions. Based on the problem different procedure is used. In this, the involved people are informed about the problem, so that they can begin to generate solutions individually before they meet and discuss. This process seems to ensure that everybody is prepared before the formal PDCA process begins.
A problem with the way companies perform the "plan" phase, is that they very quickly go into the root-cause discussion, and consequently quickly come up with solutions. Although speed is positive, it often means that they do not analyze the problem properly and the solutions therefore may be superficial "quick fixes" rather than more permanent good solutions. It has been observed that this has lead to a new round of PDCA after the quick fix fails in the market. Too often, only one alternative is really examined, and a real evaluation of alternatives does therefore not take place.
Although the employees are aware of the formal procedure of PDCA, they often lack the discipline to go through all phases, do all necessary analysis and evaluation, and therefore end up not following it. The procedure is seen as a formality, and the attitude is that "they have done all those things, if not in the same sequence and same way". Quite understandably, this reflects on the results of the process as well as the continuous improvement learning taking part during it.

6.2 "Do" phase

In product development, a key issue is to implement improvements to enhance efficient processes with the aim to meet the customers' expectations. The case study companies demonstrate that decisions are normally followed up by a "to do list", project meetings, time schedules and so on, by the project manager or by individuals. If the proposed change did not result in the desired improvements, then

they will start the planning phase again according to the PDCA cycle [3]. The main focus then is to find better solution according to existing findings. Still the quick fixer's approaches dominates in spite of that they didn't succeed with the last used approach when deciding the solution.

6.3 "Check" phase

The way the improvement team verify their current decisions depend on the characteristics of the problem and feedback from the customer. To decide when a performance goal is reached the case companies normally discuss with the customer. Some things, which are quantifiable, are easy to communicate, whereas other things have to be agreed upon with the customer. Customers prefer fast response times, so they have to be fast to conclude on solution and they don't always manage to have proper time to check the solution sufficiently. If the solution fails, they try a new solution- just an elongation- or a new iteration, of the PD process. This is according to the iterative cycle, starting with the first phase again [24]. Continuous improvement is done to satisfy a set of customer requirements so when the customer is satisfied with their answers they stop investigation. According to the interviewees they do not have time for more research or investigation into problems. This method has evolved into an in-house method common to both case companies; based on a trial and error approach, which underestimate the plan phase and mainly focusing on the do phase.

Table 1. Summary of the case studies

Phase	Step	Action according to PDCA	Action not according to PDCA	Reasons/Why
Plan	Analyze current condition	Gather people with relevant knowledge and experience	Fast to next step Missing fact based solution	Time pressure Quick fixers
	Root cause analyzes		Fast to conclude without analyzing the root causes	Time pressure Quick fixers
	Define performance measurement	Use mainly customer specifications	Insufficient measurement when not a customer requirement	Customer-oriented
	Establish improvement plan	To do list	Not always a formal plan	Satisfy customer Not found of documentation
Do	Implement improvement plan	Implement action according to the plan		Doers
Check	Evaluation of results	Using to do list Formal meeting Informal meeting Start on Plan phase again when necessary	Stop further investigation when satisfied customer	Time pressure Tight contact with customer
Act	Learning/ standardizing	Informal communication Some documentation especially when customer is involved	Insufficient documentation Not systematically standardize	Time pressure Don't see the value of documentation
	Next improvement issue		Not systematically according to findings	Customer oriented which influence on next improvement issues

6.4 "Act" phase

The case studies show that documentation of knowledge is individual, both in transferring knowledge between and inside projects. Hence, knowledge that occurred during the previous phase, is not always

written down, but shared in a small group via small talk, speaker's corners, and lunch and so on. In such, the case study project teams know what work challenges others are striving with. The problem is that people solve their problems by informal talk, and then important pieces might be lost due to poor documentation. The informal information exchange is very important in spreading knowledge and coming up with new ideas according to the described PDCA cycle [3]. The interviewees explain that their geographical closeness, (the resources are gathered together), gives a unique possibility, compared to others, regarding learning. "*If we had not been so close to each other, we would have had to work in a much more formal way*". They also emphasize that they are too informal, and want more formality regarding documentation. With very few resources available, they experience process bottlenecks and fear that formal ways of working might take longer than informal ones. This may be one explanation for the tendency to do quick fixers rather than complete PDCA cycle.

6.5 Application of the in-house method compared to the PDCA method

The results from the case study shows that the PDCA cycle is not always followed precisely according to the formally described quality assurance system in the companies, which is the PDCA method. They have made their own in-house method which they emphasize is less time consuming and is satisfactory enough to achieve the desired improvements. This is the main reason why they do not use the PDCA method today. The companies have less experience with us of the PDCA method and have not given the PDCA method a real chance.

The most visible difference between the formal PDCA method and the case companies' in-house approach is in the "plan" phase. Quick fixers are prioritized in a demanding customer driven business, where fast response time for the customer is highly appreciated. In the case companies they are heavily focused on the customer satisfaction. Whenever the customer requests an engineering change order, resources are allocated immediately to solve it. This is regarded as the main competitive edge for Norwegian automotive suppliers and focusing on continuous improvement has to fit into this picture [32]. High skilled professional often offer good solutions which further excite their customers, in spite of that they not always analyze both the current situation and the root causes sufficiently according to the PDCA method. The professionals appreciate the culture of pleasing the customer with fast response on problem solving issues. If they have chosen to use the PDCA method, they may have been forced to investigate for the root causes at first time to find solutions to eliminate the problem. When they do not have the correct root causes it can cause insufficient learning effect in the project team because of lack of analysis of the real problem. When they jump directly to conclusions about what to do and they succeeded with the solution they emphasize that it will contribute to time reduction compare to the rigorous PDCA method. It may be possible that use of the PDCA method would have given them better quality on defined solutions for the customer in total and that they have experienced that the investigation of the root causes are not so time consuming as they believe today.

In the third phase, "check" phase, where the countermeasure designed to achieve the performance measurement defined in the "plan" phase, will be followed up with a process of studying and adjusting for actual results, mainly the case companies use the customer to decide when the performance target is met. They stop further investigation if the customer is satisfied. If not they start on a new solution using the same approach with quick fixers who is fast to conclude next solution. This could be an advantages approach because of a demanding customer who highly appreciates fast responding time, which can force you to find a quick solution. The PDCA method is using the defined performance measurement, defined in the "plan" phase, to study if the desired improvement is met. This approach will enhance that you implement the issues to remove the root causes by study the results according to the performance targets defined in the plan phase. When not achieving the performance targets then you have to consider the root causes again to improve the correct causes. This will lead you to assure solving the root causes and further improve the defined problem.

Finally, as the "act" phase, some formal documentation at the case companies are done to share and store results and enables learning based on the implemented improvement actions. Mainly the informal information exchange is done as small talk, speaker's corners with well experience professionals and the learning is based on the experimental iterative process and the modification of the product to satisfy the customer through this approach. The PDCA method emphasizes to document and standardize achieved improvement and secure learning to other teams or individuals. This will enhance the learning process for the companies.

7 CONLUDING REMARKS

Continuous improvements are an opportunity which can contribute and strengthen the product development phase. Utilization of the PDCA cycle, as a systematically continuous improvement method, can be one possible valuable tool to achieve the desired improvements for companies [1, 3, 26].

This paper analyzes the systematic way of using of the PDCA cycle as a continuous improvement tool according to two case companies in the Norwegian automotive supplier industry. The case companies emphasize that the PDCA cycle is an impressively systematic approach for improvement, but is also incredibly time consuming and that it is not always an approach that works well in their rapidly changing environment. Consequently, the companies claim that the method will be most suitable when the problem to be analyzed is sufficiently complex, when there are no time constraints and enough resources to spend on the problem. Improvement issue needs both time and size of the problem before this systematic and rigorous approach can be evaluated for cost versus benefit. The results shows that both case companies have developed an in-house continuous improvement approach despite of they have desired to use the PDCA method in their formal quality system. The companies have according to our evaluations never given the PDCA method a proper chance to prove its usefulness in PD. It will however, require that the company is interested to give the PDCA method a real chance and starting to systematically implement defined improvement issue by using the PDCA cycle. Without systematically integration of the PDCA method the usefulness of the improvement method is expected to be limited.

Further interesting extension for this research might be to take a closer look at continuous improvement projects using the described PDCA method and compared it with the existing in-house method to evaluate when the methods are valuable. This might allow identifying which success factors must be in place in the PD organization to succeed of using the PDCA cycle to increase efficiency as necessary for a company's long term survival in a demanding market. When knowing the success factors before implementing such systematic method you can implement those factors in combination of the PDCA method to enhance successful implementation.

ACKNOWLEDGEMENT

The research was funded by the so-called Center for Research-based Innovation on the Norwegian Manufacturing Future, financed by the Norwegian Research Council and the participating enterprises.

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