ENGINEERING CHANGE MANAGEMENT: STATE OF THE ART, A CASE STUDY AND PROPOSITION OF A DETAILED MODEL FOR EFFECTIVE MANAGEMENT IN AUTOMOBILE INDUSTRIES

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ABSTRACT

Doing things the right way in first attempt" is what today's demand is. However, talking realistically, the ultra-competitive market condition has led the automotive sector to such a phase where continuous improvement or 'change' is inevitable. With these changes comes the serious need of an efficient as well as effective (Engineering) Change Management (ECM) system.And the organisation which will have a better ECM system will only survive in this market.Various researchers and organisations have come up with their own Change Management System models. However, none of these models discusses the complete management steps incorporating both the process as well as the information flow necessary for an ideal management system amongst the various stakeholders of any Engineering Change (EC).This paper aims at studying thesemodels along with the ECM system of TATA Motors, CVBU-Pune and attempts to suggest a generic ECM model free from the limitations of such models as well as the problems identified in the various ECs studied at TATA Motors. The modeldeveloped can be applied in any automobile industry and with little or no modification to any other complex manufacturing organisations as well.

Keywords: Engineering Change Management, P.L.M., Process-Data Diagrams, System Engineering.

I. INTRODUCTION

Like aeronautical and IT industries, the automobile industry too is undergoing through tremendous increase in complexity levels. And with these complexities comes the continuous engineering changes required in order to survive this ultra-competitive market.

Over the past few years a lot of research has been done to develop a pathway towards efficient Engineering Change Management (ECM) system. Various models have been given by the researchers as well as organisations dealing with ECM systems. However, these models give only the superficial steps for managing the ECs. Also, giving a more holistic view, these models need some restructuring and detailing before they can be applied to automobile industry.

This paper aims at restructuring the entire ECM model giving more detailed steps along with attending to the limitations of the previously given models. Also, it highlights the common factors that result into delaying the implementation of the ECs. In order to better understand the ECM system, a thorough study of various ECs at the Gear Factory of Tata Motors, CVBU-Pune has been done. The various ‘bugs’ or factors that delayed the ECs has also been discussed in this paper along with removing them in the proposed model.

II. WHAT IS AN ENGINEERING CHANGE (EC)?

The *US Military Standard 480B* (1988) [1] defines EC as "*an alteration in the approved configuration of a product related item*." An item can be a document or a physical component (virtual or real) of the product structure. The approved configurations of these items move along the product life cycle depending on formal or informal configurations reviews. Wright [2]defines an EC as "*a modification to a component of a product, after that product has entered production*."

In more elaborated way, an EC can be defined as “*an alteration in the existing product in terms of design, configuration or process either at the component level or at an assembly level with the objective to improve quality, reduce cost, lead time or complexity, or to fulfil customer’s requirement or solve a problem identified in the existing product*.”

Quoting Smith et al. [3], “ECs are part of almost every development process. They result from the fact that engineering is an iterative rather than a purely linear process and are traditionally targeted toward correcting mistakes, integrating components, or the fine tuning of a product.” These ECs have a role in improving the product, and efforts to eliminate them entirely are both undesirable and unrealistic [4].

III. WHY ECM?

The change management process in *systems engineering* is “the process of requesting, determining attainability, planning, implementing, and evaluating changes to a system”. Its main goal is to support the processing and traceability of changes to an interconnected set of factors.

It is estimated that in North America alone 300,000 ECs take place within the automotive and related industries. Further each EC can cost up to US $50,000 to process (excluding materials and tools) (source: *Automotive Industry Action Group*). Ford, GM and DaimlerChrysler conducted in 2005 an internal count of ECs within their supply chain and came up with around 350,000 ECs per year for the three combined. Feedback from each organization about the costs suggest over US $50,000 per EC. This includes not just hard dollar losses, but also soft/hidden losses such as lost man hours and delays [5].

Also, the OEM members of the German VDA (The German Association of the Automotive Industry) (2006) have more than 1,000 change orders per month, with about 7,000 internal and external users involved in commenting. The average process cost per change is 20,000–50,000 Euros (Daimler-Chrysler AG, Mercedes Car Group). Another estimate for the number of orders comes from the Chief Engineer of Magna Steyr (which engineers, develops and assembles automobiles for other companies on a contractual basis) stating that they can have up to 12,000 ECs in one month for one car project [5]. At TATA Motors, CVBU-Pune alone approximately 4000 major ECs have been either released or are in process of release for the financial year 2014-15.

These figures well explain why there is a need of an effective as well as an efficient EC Management System. The number of ‘open’ changes, the resources allotted to these changes and the objectives of those changes together make the change management difficult as well as challenging. The negative impact of these ECs have been discussed in a number of studies. ECs can consume 1/3rd to ½ of engineering capacity [6] and represents 20-50% of tool costs [7], which can easily account for over US $100Min large development projects.

Soderberg [6] in his study, reports that about 45% of engineering time was spent on changing components that had been 'thought to be ready'. As a result, the average component was developed at least twice. These research work confirm that 'change' in complex organisations such as automobile itself, is inevitable. Therefore, efforts should be made not in avoiding them but in developing a management system that would ensure a seamless and a bug-free management of these changes.

IV. TRADITIONAL ECM MODELS

Most of the ECM models given by researchers as well as organisations are limited to the five steps: Identify the Need/Potential Change, Investigate/Analyse Change, Evaluate Change, Plan Change and Implement Change. A few researchers (like Marijn Plomp^, etc.) as well as organisations such as PTC and CISCO have included the sixth and very important step as 'Post Implementation Review and Close Change'.

Fig. 1 shows a generic ECP model with complete process divided over three stages namely EC Proposal, EC Investigation and EC Embodiment. Though the model well explains the sequential processes carried out in any EC, it fails to explain the various decision making processes in these stages and the possible outcomes of those decision making processes. Also, the model is linear whereas almost every EC process has an iterative approach which this model fails to explain.

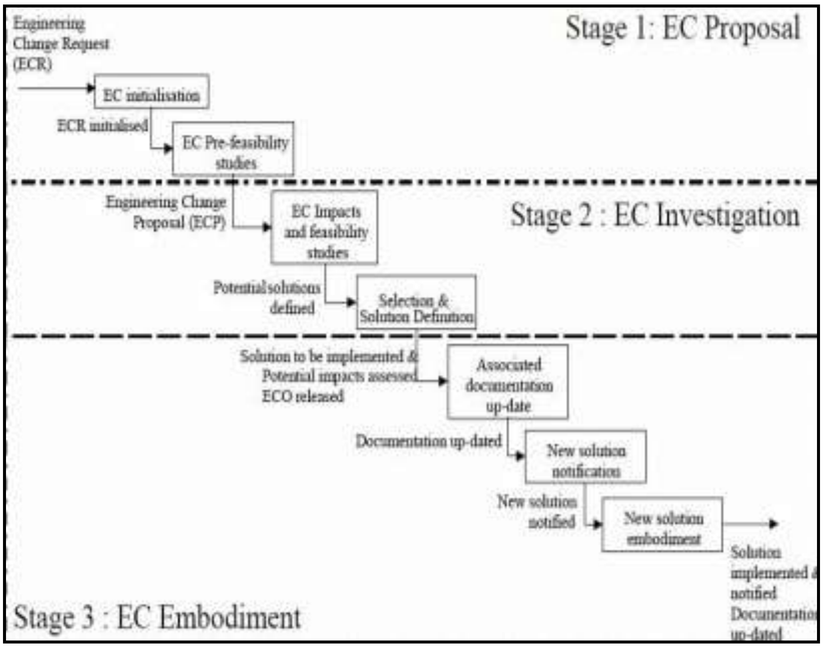

Figure 1- A generic Engineering Change Process (ECP) Model [8]

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Fig. 2 shows a bit more detailed breakdown of ECM process. However, even this model represents ECM process as a linear process and not an iterative process. Also, both the models does not include the "Post-Implementation Review" step before closing any EC. This step has a very huge significance especially in automobile industries where any EC directly or indirectly affects the entire vehicle assembly and any possibility of mistake means compromising with the safety and lives of passengers. And hence, most of the ECs are reviewed even after implementation. The details of this will be discussed in further sections.

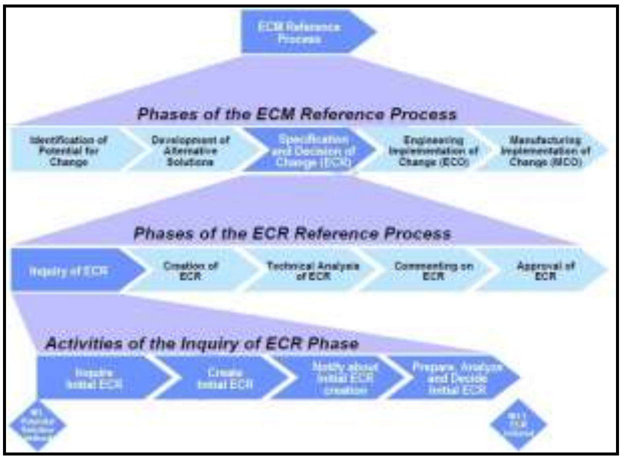

Figure 2- ECM Process Breakdown Model [5]

Fig. 3 shows the change and configuration process flow model of PTC. Unlike previous models, this model has a post-implementation review step. Also, this model explains the various decision making steps that are considered in any EC. However, all the above three models are in absence of any IT support. The absence of IT support such as OMG-PLM (Object Management Group- Product Lifecycle Management) Services, Siemen's PLM Services, etc. make ECM not only difficult but also inefficient and ineffective. Instead of continuously exchanging information, engineers of different functions then meet only at specified milestones or review points to discuss the current status of the project/EC along with the various 'issues' that delays it. In the most extreme cases, the whole product engineering information is packed in one batch and then 'thrown over the wall' to process engineering. Descriptions of such behaviour can be found in Blackburn [9] or Clark and Fujimoto [4].

Quoting McKinsey & Company, "it's typical to see 33% of development cycle time wasted either on unnecessary work, waiting for decisions or waiting for information regarding a change". Besides these wastes, the improper communication may also lead to design and decision conflicts, insufficient change tracking, long response time, etc. A long response time causes late implementation of the final ECR (Engineering Change Request), which is not desirable because of the increasing change costs for tools and interfacing components.

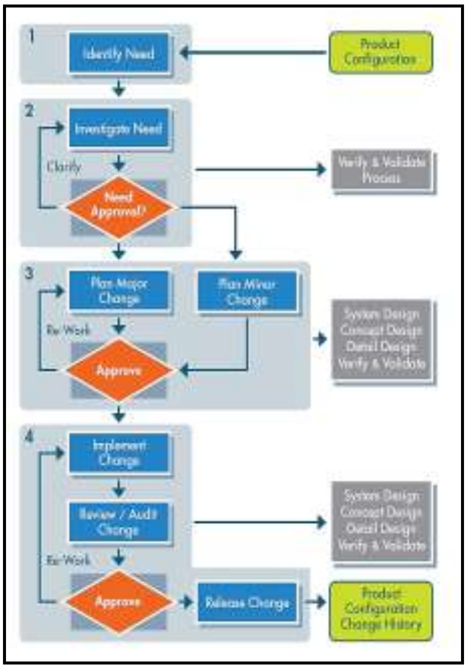

Figure 3- Change and Configuration Process Flow Model by PTC

Fig. 4 shows the normal change process flow model by CISCO. This model covers more iterative processes than previously discussed models. Also, it suggests the use of a central configuration database to maintain a record of all the ECs processed by the organisation. Such a database can help in efficient management of similar ECs in future. Also, the learnings from executed ECs can help in avoiding any previously faced problems.

However, this model does not suggest any active change tracking method that can be used to establish an effective communication channel between the various members of the cross-functional team (CFT) handling the EC along with various CFTs associated with the interfacing components and/or process. Such a communication channel can not only avoid any decision and/or design conflicts but also reduce the decision response time.

The ECM model given by Marijn Plomp, as shown in Fig. 5, is so far the most detailed model that not only incorporates the various iterative phases that are often faced in real-time EC management but also includes the various "change reports" that should be generated and maintained throughout the ECM cycle. These change reports are process and/or stage wise documents that should be developed and maintained by the ECM supporting software package such as PLM. These change reports will help in case of iterating processes and can also be used to trigger the next step in the ECM without causing any delay. Further, as in most ECs, the Central Coordinating Agency can easily keep track and manage the EC along with the propagated changes needed in the interfacing products and/or processes.

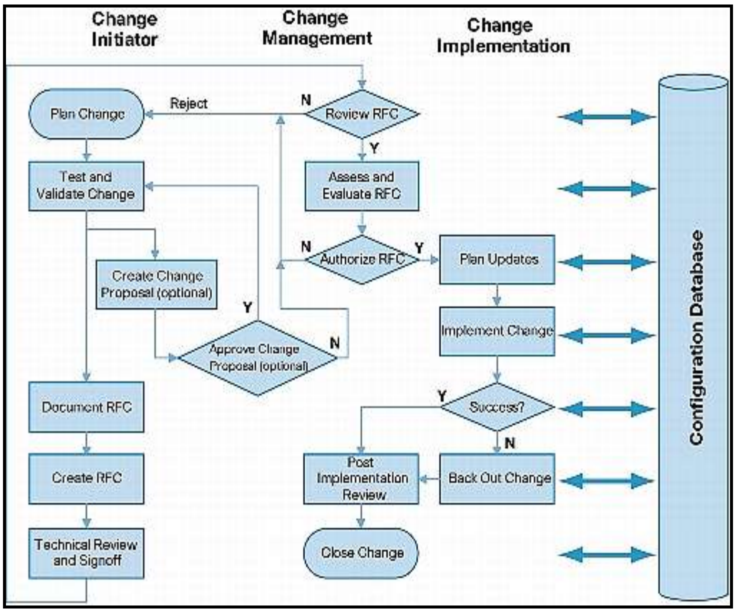

Figure 4- Normal Change Process Flow Model by CISCO

However, even this model along with all the previously discussed models fail to suggest the detailed implementation phase. An effective ECM model should well explain the implementation strategy to be followed for quick and seamless change from the existing product/process to the newly tested product/process without significantly affecting the production and other related activities. An ineffective implementation strategy can further delay the EC implementation by as much as 20-30% along with the significant cost escalation in the EC being carried out.

Also, unlike shown in the model, not all ECs on failing at post-implementation review need to be handled from the execution phase again as it totally depends on the level of modification required in the failed EC. This will be more evident after looking the proposed ECM model discussed in later section.

Thus, the various limitations of the above discussed models can be summarised as follows:

- No or limited in-depth explanation of various phases or steps involved in ECM.

- No or insufficient change tracking.
- No implementation strategy suggested for smooth 'switchover'.
- No or insufficient information sharing.
- Generic but superficial steps of ECM only.

V. DEVELOPED ECM MODEL

Fig. 6 shows the developed ECM model. As evident, this model not only shows the main steps or phases of an ECM but also the detailed sub-steps or processes being carried out in every individual step. Also, it takes into account the various stakeholders of any EC. These stakeholders are the participating departments that form the CFTs for every EC.

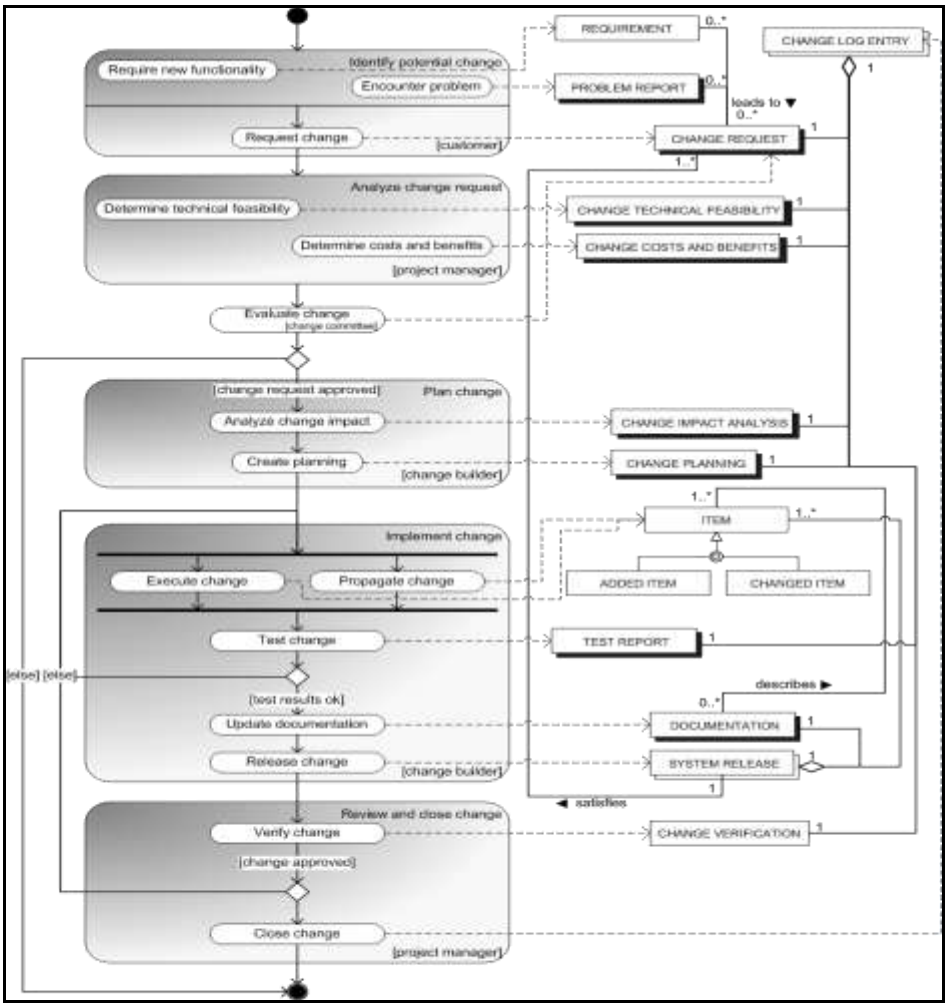

Figure 5- Engineering Change Management model by Marijn Plomp

5.1 Identify Potential Change

Customers being one of the most important stakeholder, they are represented by the Marketing and Quality Assurance (QA) departments. Marketing where brings the 'New Functionality Requirement', QA handles the problems encountered by the customers. Together, the two departments are responsible for initiating any 'change' coming through customers in form of Project Initiation Process (PIP).

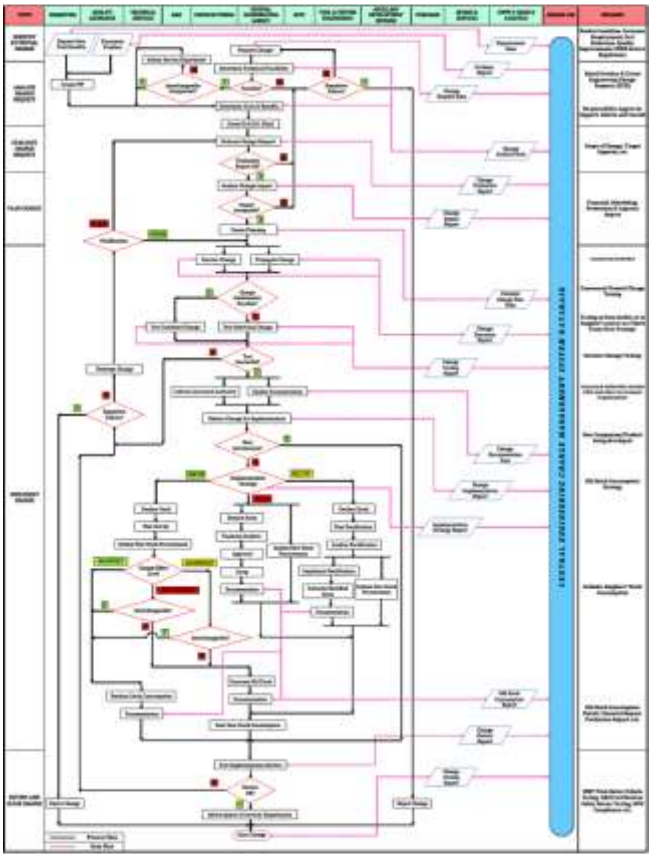

Figure 6- Developed ECM Model

ECs can also be initiated internally by a Central Coordinating Agency, Research & Development or even Manufacturing and similar departments with the objective of cost reduction, quality improvement, complexity reduction, etc. The various causes for initiating an EC has been discussed in detail by Wasmer et al [5] and Pikosz et al [10]. Depending upon the source of change initiation, a report is generated and stored on ECM System database such as PLM, etc.

5.2 Analyse Change Request

Once the ‘change’ is initiated, the feasibility tests are done and for the feasible ‘change’ Engineering Change Request (ECR) is created. The details of the feasibility tests conducted are stored in the database which can be used in case the ECR fails at any later stage. After the successful feasible tests, it is essential to communicate the EC related information to Spares & Service department. By doing so, necessary action can be taken to control the spare stock of component(s) affect by the ECR created. In cases where this communication was not established, the implementation phase was delayed in order to consume the old stock.

After the ECR is created and gone through an initial scrutiny, a RASIC (Responsibility, Approval, Support, Inform and Consult) chart is created. This chart summarises the innermost CFT allotted for any ECR created and is very helpful in ensuring little or no time wastage in decision making processes for the same.

5.3 Evaluate Change Request

In evaluation phase, the scope of ECR is determined along with the segment targeted. Based upon the “change analysis report” and benefits of ECR, the RASIC team takes the GO/NO-GO decision. In cases where the scope of the EC is changed at this stage, another iteration of feasibility for the ‘revised change’ is carried out. The final evaluation report along with any change in terms of scope, target segment, etc. is generated at the end of this step.

5.4 Plan Change

In this stage, the ECR is viewed with a more holistic approach. The role of Couplings for the EC process, as discussed by Terwiesch and Loch [11], comes into picture and hence an even more detailed analysis of ECR is done as explained below.

5.4.1 Analyse Change Impact

In this sub-step, the change impact analysis in terms of financial, production planning and scheduling, logistics, etc. is done. Also, the impact of ECR on interfacing or coupled product(s) and processes is also studied. Another feasibility study, based on the impact analysis report generated taking into consideration the interfacing components and processes, is carried out before making a GO/NO-GO decision.

5.4.2 Create Planning

In this sub-step the detail planning of ECR for implementation is done. The procurement of necessary tooling and material is also planned. The "batching" of changes at this stage is also very common. Batching of Engineering Change Orders (ECOs) is not an inefficient practice in the presence of conditions described by Loch and Terwiesch [12]. However, the larger the ECO batch size, the longer is the average time between problem detection and final implementation. And in order to avoid this, the strategies suggested by Terwiesch and Loch [11] should be followed.

The detailed planning report generated during this step should be shared with the various stakeholders and CFTs of interfacing components and processes through the ECM database. This will assure least decision making and waiting time in subsequent processes.

5.5 Implement Change

5.5.1 Change Execution

The implementation step beings with the execution of planning done in the previous step. An important aspect that is missing in most of the traditional models discussed in the earlier section as well as in industrial practise is to 'propagate' the ECR execution to the interfacing systems or couplings. That is, the necessary changes in the 'couplings' required to absorb the change impact analysed in previous steps should also begin at this stage. In case this is not done, the change implementation can get delayed by weeks or even months in certain ECs. The detailed execution report generated is shared with the CFTs handling the interfacing systems.

5.5.2 Test Change

The testing step begins with a study on whether this EC can be combined with any other open EC being executed during the same time. As obvious, by doing so the total lead time of two or more ECs combined will get reduced. Besides this, the testing is also planned. The planning includes the various tests to be carried out, whether testing will be done at own facility or at supplier's end or whether a third party testing will be conducted. In some cases the testing can be done even at user's end. It is essential to plan the testing at this stage so as to avoid any further delay in ECR implementation.

The test results are stored in test report and acts as a trigger to initiate documentation. Simultaneously, the successful ECR test reports should be brought to the notice of concerned authorities such as ARAI for automobile industries, etc. By doing so, any glitches in the testing or any necessary modification needed to adhere to the government regulations can be attended.

5.5.3 Release Change for Implementation

The documentation report of ECR generated after a successful test initiates the process of release for implementation. This process is carried out by the Central Coordinating Agency. Once the ECR is released for implementation, the detailed strategy is planned. The strategy here basically aims at effective consumption of stock (self as well as supplier's) of existing component and smooth changeover to modified component. In case where the EC is a new introduction, the post implementation review process is initiated directly.

However, if the EC is not a new introduction but a modification or development project, the strategy for implementation can be of three types: Use Up, Rectify and Scrap. The "Use Up" strategy says that consume the existing stock depending upon interchangeability of components and change effect level as shown in the model and then move towards full usage of new component. The "Rectify" strategy says that modify the existing component into new component and then consume it before moving on to new component consumption. And the "Scrap" strategy says that in cases where the old or existing component cannot be used any further because of design issues, defects, uneconomical reason or obsoleteness, scrap the complete old stock and procure new components. However, the procurement of new components in last two strategies should be done as a parallel activity as shown in the model in order to reduce any delay in implementation.

5.6 Review and Close Change

5.6.1 Post Implementation Review

Although in most of the cases the post implementation review is more of a formality wherein the complete ECR is presented before the higher management before closing any EC, there were certain cases where an ECR failed to pass the review and was required to redesign and implemented again. In this step, they final jury trial (as is often called in automobile industries) before higher management and/or government authorities is conducted. In case the ECR passes the review trial, change review report is generated and closing of ECR is initiated. Also, requisite information is passed on to Sales & Service department.

5.6.2 Close Change

In this step, the reviewed and accepted ECRs along with the rejected ECRs are closed with a complete final closing report being generated and stored in ECM database. This final report is often used as a reference in similar ECs or in initiating another change.

VI. CONCLUSION

The developed ECM model not only fulfils the limitations of the traditional models but also gives the detailed structure of an effective and efficient ECM system. This model has also taken into account the learnings from various ECs in Gear Factory as well as other divisions of TATA Motors, CVBU-Pune. The problems faced in these ECs have also been answered in this model.

This model takes into consideration the various stakeholders of any EC and also shows the information flow necessary for effective ECM. The departments such as Tooling and Fixture design, Purchase and Logistics, Ancillary Development Division (Vendor's Development) and Spares& Service departments are often left out. However, these departments play a very significant role in ECM and hence should be included in the CFT formed for any EC.

The detailed implementation phase shown in the model makes an EC easy to implement with least possible wastage in terms of time, cost and labour. Also, the possible iterations at various steps have also been taken into consideration. Though this model has been developed for complex organisations such as automobile industry, with little modification it be applied to any industry.

Also, though this model gives a detailed implementation strategy, the problems such as batching, congestion and organisational issues as discussed by Terwiesch and Loch [11, 12] continue to delay the time between EC initiation and final implementation. This delay can amount up to 90% of waiting time [11]. A research work can be carried out here to study the applicability of strategies suggested by them in automobile industries. Also, the validity of 13 Lean Principles of Product Development (given by Morgan & Liker and applied by Strom [13] for ECM in his thesis) on the developed model can also be studied.

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