Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 11 (2017) 1626 – 1633

Procedia MANUFACTURING

27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, 27-30 June 2017, Modena, Italy

Engineering Change Management Data analysis from the perspective of Information Quality

Lauri Jokinen[a]*, Ville Vainio[a], Antti Pulkkinen[a]

[a]*Department of Mechanical Engineering and Industrial Systems, Tampere University of Technology, P.O. Box 589, Tampere, FIN-33101, Finland*

Abstract

An efficient change management process is vital to companies in order to continuously improve their products. The processing times for Engineering Change Requests (ECR) vary from hours to years. The long processing times lead to unnecessary delays to requested fixes and improvements. This paper is based on analysis of Engineering Change Objects and semi-structured interviews in a case company, where the number of ECRs has been increasing significantly. The goal of the research was to find out reasons for varying ECR processing times. However, analyzing the data afterwards is difficult because part of the modification history disappears during the process.

Keywords: Product Lifecycle Management; Information Quality; Collaboration; Engineering Change Management; Product Development

1. Introduction

In a world of Mass Customization, the role of change management cannot be denied. In the early days of manufacturing, each product often was an individual with individual blueprint. Consequently, a faulty design only had effect on few units. Nowadays, each problematic design (for example an electronic component) may cause

* Corresponding author. Tel.: +358445436498
E-mail address: lauri.jokinen@kapsi.fi

doi:10.1016/j.promfg.2017.07.312

problems to several different products, and the number of affected units may vary from tens to millions. The problems must therefore be processed efficiently to prevent waste - and Engineering Change Management (ECM) is one of the most important tools for that.

Manufacturing companies handle a large number of engineering change requests every year. The number of ECRs produced varies as it depends, among other factors, on company size, product complexity and the extent of ECM use. The studies [1] [2] have shown that with complex products, the number of ECRs processed yearly may rise to thousands.

A large number of ECRs leads to considerable amount of work: For each request, a separate document must be created, the document needs to be linked to related information, and then the document needs to be processed. If the evaluators decide that the request should advance further, the problem described in the ECR needs to be fixed. The actual re-design work will cause changes to documents that need to be delivered to all stakeholders (purchasing, manufacturing, spare parts, sub-contractors, etc.) The changes also sometimes start a "snowball effect" [3] of changes to surrounding parts/modules - and sometimes even to other products, hence increasing the work load even more.

ECRs also create other costs than those related to work hours: new designs may require, for example, new prototypes, new tools, new physical manuals, or lead to indirect costs in forms of lost opportunities, fines, or damage to company's reputation [4].

As the ECRs cause considerable amount of work, there is a pressure from management to decrease the number of ECRs [2]. Some managers may even question the rationality of spending large amount of time and resources on ECR processing.

2. Research

2.1. Research background

When the engineering department of a company needs to process more than a thousand change requests a year, it may seem smart to try to reduce the number. However, it could also be argued that a large number of ECRs is a positive matter.

It is clear that a certain amount of ECRs is a consequence of poor design or poor requirements management – and that amount could be reduced. However, a large number of ECRs are based on the needs of lifecycle stakeholders (end-users, spare part sales, maintenance, sub-contractors, purchasing, sales, assembly, manufacturing, etc.) Improvements to safety, cost, manufacturability, usability, reparability etc. are often based on ECRs. And while the needs of internal and external customers will keep changing, new technologies will arrive, and as there are no perfect design engineers, there will always be a need for ECRs.

However, among these unavoidable ECRs, there are unnecessary , duplicate , and unclear requests. Time spent on handling unnecessary ECRs or improving the poor quality of a request is waste that should be minimized. All the time spent on waste delays other changes – and often the arrival of new designs – as the projects often compete for same resources [2]. If the resources are tied to processing change requests, it is a risk for New Product Development (NPD), as fewer resources may lead to rushed decisions. Moreover, rushed decisions in NPD likely cause more ECRs in the future. Or the other way around, if each change could be processed faster, the whole process would be more "frontloaded" and therefore the changes to products would arrive earlier – and cost less [5].

The relationship between information quality and ECM is not a widely studied subject: although there are several studies on improving the quality of ECM process, the main focus is often on information systems or change process itself. However, Tavčar & Duhovnik [6] have noted the link between communication quality and early parts of change process.

The potential for ECR quality improvements is also the motivation for this research. This paper aims to answer the following questions:

- Which quality aspects contribute to long EC processing times?
- Is it possible to shorten the EC processing time by improving the quality of the requests?

2.2. Research material and method

This paper is based on the analysis of real engineering change data consisting of more than two thousand change objects. The change objects were extracted from the case company's Engineering Change Management (ECM) database as raw and unfiltered as possible so that it would be presentative of real qualitative properties, and act as a frozen image of a certain date. The data was then sorted by using available classifications (date, state, type) by using different approaches. The sorted data was then analyzed in more detail and classified even further as common denominators were found.

The case company is a manufacturer of large, complex, mobile machines. The customer base spans the whole world, and often the customers have specific needs that differ from one customer to another. Hence, the products are often either partially or fully customized. Even the most popular "mass" products sell in hundreds rather than thousands of units. It is important to notice the difference to other companies that may seem similar, such as the ones that focus on mass production (cars) or engineered-to-order products (ships).

In the case company, the main processes for Engineering Change Management are embedded in one of its PDM systems. The process requires that each request has individual ID code and status. Each new ECR automatically receives a "Created" status, which should be then changed into "To Be Checked" before releasing the ECR for other stakeholders.

When a request is under a review, it will get "In Process" status. After the initial review, the handler (usually a change specialist / change manager / responsible designer) should decide whether the request should be put into practice. After the revision the document status changes to "ECO" (Engineering Change Order) if the change will be carried out, or "Returned" if more information is needed. Otherwise the status will be changed to "Rejected". When the change is complete, a release notification takes place and the status of the request gets changed to "ECN".

As it is assumed that there is a connection between information quality and ECR processing speed, a framework for information quality is needed. The one used in this paper is created by Martin J. Eppler [7]. In Eppler's framework the problems related to information quality are divided to into four levels: Community, Product, Process and Infrastructure. All levels consist of four criteria. Community level consists of Comprehensiveness, Accuracy, Clarity, and Applicability. Product level covers Conciseness, Consistency, Correctness, and Currency, while the process level comprises of Convenience, Timeliness, Traceability, and Interactivity. Accessibility, Security, Maintainability, and Speed are all members of infrastructure level.

Eppler's framework highlights the fact that for example delays may happen on different levels. If the problem is related to a slow system, training the user will not hasten the process.

3. Results

After a thorough analysis and double checking of the sample of ECRs we are able to answer the sub-questions; what kind of ECRs get rejected or get never a status change? We present our own classification of the classification characterization of ECRs in the results. The characteristics are briefly explained and related to Eppler's criteria.

3.1. What is rejected?

To find out what is considered as bad quality, attention was paid to rejected ECRs. All the rejected ECRs from the system were categorized, based on the reason for rejection. The categories and their explanations are described in Table 1. The table also shows the relation to Eppler's Information Quality Criteria as defined in [7]. The results are further analyzed in the discussion part.

Table 1. The reasons for ECR rejections.

Category	Explanation	Relation to Eppler's information quality criteria (IQC)	Percentage
New Design has already fixed	New version has already been designed before the ECR has been written but has not been released yet.	Speed, Timeliness, Currency	23
Normal reject	The request has been rejected because there is a better way. For example, the request would decrease quality or safety. Sometimes a request that is based on false assumption.	Applicability, Correctness	13
Not really an ECR; production related	ECR does not have any relation to engineering. It is purely a problem of production (planning) or using wrong tools.	Applicability, Accessibility	11
Duplicate ECR	ECR has been rejected as there were several similar requests.	Currency, Applicability	11
Not really an ECR; supplier quality	The design is good but supplier has accidentally manufactured the part / assembly/item incorrectly.	Applicability, Accessibility	9
Rejected without comments	Not possible to know what the problem was.	(Cannot be defined)	9
Solved outside ECM	A problem has been solved by using some other means. Probably a critical document correction.	Speed, Accessibility	7
ECR makes no sense	ECR conflicts with itself or just does not make any sense at all. Often a result of accident.	Clarity, Comprehensiveness, Consistency, Correctness	5
Withdrawn	ECR has been withdrawn. Possibly a duplicate. Sometimes the request was based on misunderstanding.	(Could be related to any criteria)	5
ECR not understood	The ECR is rational, but for some reason the handler has not been able to comprehend it.	Clarity, Comprehensiveness, Traceability,	3
Not ECR; in wrong system	The request is in wrong system. For example, safety problems that are not engineering-related.	Applicability, Accessibility	2
Not ECR; system problem	The problem is system-based. For example problems based on the enterprise resource planning (ERP).	Applicability, Accessibility	1
Combination ECR	The ECR consists of two or more separate problems. The ECR has been rejected as it was not possible to handle all the problems. Often the ECR has been split to smaller problems before the rejection	Applicability, Conciseness, Accuracy	1

3.2. The ECRs that never get even a first status change

It is a common practice that the documents with “Created” status do not receive many views. Usually the documents with this status do not yet contain all the necessary information. They may act as a note for someone who is currently gathering information on the subject. Documents should not stay in “Created” state for more than few days.

All the documents older than one month and still in “Created” state were classified according to their content. The findings are listed in Table 2. The majority of the ECRs are classified as “garbage”. The garbage primarily consists of change objects, where someone has opened a new id code but has since forgotten to complete the document. The reason could be a system crash or automatic system log out which has then lead to creation of another document.

Table 2. Classification of ECRs older than one month in “Created” state.

Category	Explanation	Relation to Eppler’s IQC.	Percentage
Garbage	A mistake, withdrawn request/worklist, forgotten reservation for a change number…. The status will most likely never change.	Timeliness, Maintainability, Applicability	49
Good Request, wrong status	The request seems to be complete but the state has never been changed.	Timeliness, Maintainability	22
Late ECR	The ECR is late. There is a reason to believe that it will get a status change.	Timeliness	19
Worklist	The ECR is being used as a long term worklist. It will be used as a base for a change notification.	(Cannot be defined)	10

3.3. Long handling times after the first status change

According to the interviews, each ECR should be processed to “ECO” state in two weeks. However, for this analysis, only ECRs older than one month and still with “To Be Checked” status were used.

Table 3. Classification of ECRs older than one month with “To Be Checked” status.

Category	Explanation	Percentage
“Normal” request	Normal request: normal quality, normal difficulty.	83
“Low Priority” request	The request itself is clear but it is not of high priority; usually a request that does not add value to end customer or lead to savings in production.	12
Will end up rejected	A request that is clearly of poor quality, consists of several separate requests, or is in wrong system.	4
Complicated Subject	A request that relates to very large number of products, is very difficult to execute, or otherwise requires high level decisions and several hours of thinking.	<1

The document linking for these ECRs was also checked. 52% of these ECRs had no supporting document (photo, pdf, Powerpoint, etc.) linked to them.

4. Discussion / Analysis

4.1. Rejections

The total number of ECRs rejected in the case company was small: less than 10% of the requests get rejected. The most common reason (30%) for rejection of ECR was the fact that a new design which should correct the error was already on its way – either in a form of "new design" (23%) or "fast lane correction" without ECR (7%). This is natural, as often it is not possible for a requestor to know what is under development at the time of request. On the other hand, a change to neighboring module may remove the problem near/in the interface. Similar phenomenon has been recognized by Giffin et al. [8].

Rejection may also be a sign of late request or a situation where the changes are being made without a formal request (for example, the request has been made by a customer by a phone call). It could be argued that the number of changes without a formal request should be low except in the case of New Product Development. If the change policy is very strict, all changes to current products should have a clear reason – and the reason should be explained in the request [2].

Using ECR system for non-ECM purposes is also quite common. There are several reasons for this: sometimes the requestor is not able to identify the source of a problem, and therefore thinks that the problem roots to product design, although the real problem lies in sub-contractor quality or production planning. On the other hand, sometimes the users may have no access to correct systems, or they may not even understand that there are several different systems for different reporting purposes – so they use the one they have access to. The combined percentage for rejections based on filing the report to wrong system is about 23. It is unclear whether these documents were ever transferred to correct systems.

4.2. Sometimes the status Never changes

Majority of the documents that are still in their initial state do not cause serious problems. Almost half of these documents contain no useful information and could just as well be deleted from the system. The relatively large number of "garbage" objects could be a sign of ECM software usability issues or inadequate training.

However, almost 41% of the documents in this category are causing serious delays for the ECM process. If the time span from the initial problem finding to the first ECR version is more than one month, it is very difficult to supplement the document if important information is missing. Even if a person is able to remember the problem case for several weeks, performing any measurements is usually not possible for long after the initial problem finding. If the problem is reported in assembly, the individual machine on which the request is based on may not be in the plant anymore. This dilemma is especially related to configurable structures and mass-customization because the reappearance of the specific problematic situation is unlikely to happen in the near future.

There is a reason to believe 22% of the ECRs in this category will never get a status change even though there seems to be nothing missing from them. This is problematic, as the design engineers do not touch to ECRs with "created" status – and therefore these ECRs will not get processed.

One thing worth noting is, that the information quality problems of ECRs in "Created" state seem to relate to Eppler's "system-level", whereas the ones that end up being rejected span the whole spectrum of quality criteria.

4.3. When the handler does not react…

The number of ECRs waiting for reaction from engineering was found to be quite high (close to 13% of the total requests). On the other hand, the number of old requests was smaller than new ones. The ECRs that had not been reacted to were mainly from assembly line whereas the ones based on customer need or safety were handled quicker. This proves that although the status had not been changed, attention was paid to all of the ECRs and the most important ones were processed.

The analysis on the ECRs on this "waiting list" showed that the majority of them were of normal quality, although there were some especially bad requests (4%) that will most likely cause extra work or get rejected. Although only a 12% of the requests were clearly low priority requests, there is a reason to believe that a large proportion of the normal requests were seen what Giffin et al. [8] call “nice to have” requests. “Nice to have” requests do not get processed because it is difficult to decide whether it is rational to implement the proposed change or not [8].

At the same time, there clearly was room for improvement among these ECRs as the majority of them were missing attachment file, which is according to interviews “the most important part of the request”. The results of the interviews are more explicitly analyzed in [9].

4.4. In the end everything is perfect

The interviews reveal that some of the design engineers struggle to understand the requests and use large amounts of time to find out the missing information. When a request handler is having a problem understanding the request he/she usually calls or e-mails to a person who wrote the request or tries to search the information by him/herself. The search for information often consists of browsing the part catalogs, PDM and ERP as well as visiting factory and talking to people responsible for assembly work. Usually, the missing information is then added to the request in order to avoid repeating the process of information recovery in the future.

However, although the ECR system stores a timestamp and status changes for each edit, it does not store specific information on how the request was changed. Therefore it is not possible to see how the request was altered after each edit – or know how many of the ECRs have been modified to be of better quality. On the other hand, none of the engineers or workers in the case company keeps a separate log on the time they spend on improving the quality of ECRs. As a result, the extra work done to increase the quality of ECR information does not show anywhere.

4.5. “I don’t care about quality, because it’s good enough for me!”

There is a clear and a bit unsettling trend visible in the database, where some engineers use ECR as “yellow stickers” for themselves. This seems to lead to information quality issues as people are often good at understanding notes they wrote for themselves. These ECRs often have very fast processing times, but understanding the core information is very complicated for other lifecycle stakeholders, especially after a long period of time. Of course, if the whole process is quick, it is possible to compare the changed document with the original, but this will only reveal what changed - the information about the actual problem and the root cause for it may not be available.

4.6. Better quality helps… but how much?

As the poor quality of a request may lead to several days of unnecessary work, it is clear that a good quality request saves work. However, how many hours can be saved depends on the complexity of problem, engineering skills of the handler, his/her knowledge on the subject and the target product, availability of information elsewhere, etc. As there are so many variables, using the case company data to form a reliable calculation is not possible.

In case company, the interviews and the database analysis both prove that time spent on adding information to optional fields and always attaching a file, such as photograph or screenshot of 3D model, or an e-mail, often reduces unnecessary work significantly. The additional information could be for example a name of a person who originally found a problem, estimated work hour or cost savings or a proposed solution. Of course, the time spent on creating attachments may sometimes be unnecessary waste, but the risk of inserting excess information is worth taking because the extra time spent early in the process could save a large amount of (more expensive) resources later.

5. Conclusion

The quality of an ECR is the end result of a process that covers several steps. The quality may be good from the very beginning or it may improve in the very last step. Exactly when the quality improves is difficult to know afterwards. If certain level of quality is never reached, the ECR will be rejected. Rejections, however, are relatively rare whereas spending large amounts of time to improve the quality is common. This indicates that the requests in the case company are usually relevant and get implemented.

Once the quality is good, the processing time of an ECR still depends on other factors, such as the criticality of the ECR, importance of the related product, engineering resources available. Nevertheless, it is clear that good quality requests enable fast changes while poor quality requests may cause more than a day of extra delay per request.

It is clear that the case company would benefit from better ECM training as the number of garbage in the system could be reduced significantly while the amount of hours spent on refining the ECRs could be reduced The number of rejections would also decrease slightly. However, the data used for this research do not clearly show how often and how much time is spent on improving the ECRs after the initial request phase.

References

[1] C. H. Loch and C. Terwiesch, "Accelerating the Process of Engineering Change Orders: Capacity and Congestion Effects," Journal of Product Innovation Management, vol. 16, no. 2, pp. 145-159, 1999.

[2] F. B. Watts, Engineering Documentation Control Handbook - Configuration Management and Product Lifecycle Management, 4th ed., Elsevier, 2012.

[3] C. Terwiesch and C. H. Loch, "Managing the Process of Engineering Change Orders: The Case of Climate Control System in Automobile Development," The Journal of Product Innovation Management, vol. 16, no. 2, pp. 160-172, 1999.

[4] B. Hamraz, Engineering Change Modelling Using a Function-Behaviour-Structure Scheme, PhD dissertation, University of Cambridge, 2013.

[5] E. Fricke and A. P. Schulz, "Design for Changeability (DfC): Principles To Enable Changes in Systems Throughout Their Entire Lifecycle," Systems Engineering, vol. 8, no. 4, pp. 342-359, 2005.

[6] J. Tavčar and J. Duhovnik, "Engineering change management in individual and mass production," Robotics and Computer-Integrated Manufacturing, no. 21, pp. 205-215, 2005.

[7] M. J. Eppler, Managing Information Quality, 2nd ed., Springer, 2006.

[8] M. Giffin, O. de Weck, G. Bounova, R. Keller, C. Eckert and P. J. Clarkson, "Change Propagation Analysis in Complex Technical Systems," Journal of Mechanical Design, no. 131, pp. 1-14, 2009.

[9] V. Vainio, L. Jokinen and A. Pulkkinen, "Quality Elements of Engineering Change Requests and Their Effect on Request Processing and Content Comprehension," in Proceedings of the 26th international conference on Flexible Automation and Intelligent Manufacturing, Seoul, 2016.