Accepted Manuscript

An industry approach to shared, cross-organisational engineering change handling; The road towards standards for product data processing

Anna Wasmer, Günter Staub, Regine W. Vroom

PII: S0010-4485(10)00196-X
DOI: 10.1016/j.cad.2010.10.002
Reference: JCAD 1680

To appear in: Computer-Aided Design

Received date: 28 November 2006
Accepted date: 17 October 2010


This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.
An industry approach to shared, cross-organisational Engineering Change handling; The road towards standards for product data processing.

Anna Wasmer\textsuperscript{a}, Günter Staub\textsuperscript{a} and Regine W. Vroom\textsuperscript{b}

\textsuperscript{a}PDTec AG, Albert-Nestler-Straße 10, 76131 Karlsruhe, Germany
\textsuperscript{b}Delft University of Technology, Industrial Design Engineering, Delft, The Netherlands

Abstract

Standards for cross-enterprise communication between systems that actively manage product data and which control the associated workflows - including release and approval processes - are in industrial use for some time. Experiences gained during the last decade showed that purely data centric approaches, such as supported by IGES, ISO 10303 (STEP) and IFC are not sufficient. Cross-enterprise communication requires not only agreements about data format and semantics, but also about orderly procedures for efficient communication between the stakeholders in a workflow.

This paper presents the background and approach taken for the development of a standard for cross-company engineering change management (ECM), which is currently undertaken as a joint activity between VDA (German Association of the Automotive Industry) and ProSTEP iViP (international association for information integration in industry). Based on the result of this joint activity, which was recently published as SASIG ECM Recommendation V2.0 and as VDA 4965 V3.0, ECM Pilot implementations within member companies were conducted. They proved that a lead-time reduction of the engineering change process of 20 - 40\% is possible while the quality of the process increases. The approach itself should work not only in engineering change or product data environments, but also in document oriented environments as well as in other sectors than automotive.

The ECM standard provides specifications of reference business processes, including the definition of the participants' roles and the interaction and synchronization ("touch") points where data are communicated. It leverages and builds on other established product data standards wherever possible. Thus, the data model defined by STEP AP214, (Core Data for automotive mechanical design processes) is used to describe the "pay load" - i.e. the product data content to be exchanged - at defined synchronization points. OMG's PLM Services provide the framework for sending messages between the stakeholders of an Engineering Change, and business process modelling languages such as e.g. BPEL (Business Process Execution Language), standardized by OASIS, provide the capability to execute the ECM protocol specification. They ensure the ability to use the latest state of the art internet technologies such as XML and web-services.

Keywords:

Engineering Change Management, Engineering Change Process Automation, Product Data Technology, Collaborative Engineering, Continuous Improvement, Product Lifecycle Management, Product Lifecycle Knowledge
1 Introduction

Due to changing market demands and ongoing technological advances, complex products tend to evolve from their original product design. This happens even during product development itself. Changes to technical product specifications are unavoidable, especially for complex products [1], and reflect for a part the learning process of professionals during product development.

Empirical studies have provided some figures about Engineering Changes (EC’s) in the automotive industry. 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 $ 50,000 per engineering change. This includes not just hard dollar losses, but also soft/hidden losses such as lost man hours and delays [2]. In [3] and [4] it is stated that the OEM members of the German VDA (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 [5] in which the chief engineer of Magna Steyr states that they can have 12,000 engineering changes in one month for one car project.

These examples give considerable figures, justifying the significance of this subject. However, the differences between the reported figures are remarkable. They result partially from different conventions of automotive companies to package changes. Sometimes an EC refers to a change request necessary to address a single problem, but in other cases the term is used as a synonym for ECO (Engineering Change Order). The latter means that change requests are combined into packages or groups of changes. Some companies make only a few but large Change Packages (thus containing a lot of individual part changes) while other companies keep the number of part changes per Change Package small but have a larger number of them.

Furthermore, diverse interpretations of the concept of costs could cause differences in the reported numbers. As an example: the VDA talks only about “process cost”, while there are also other costs caused by a change such as the procurement of the modified parts and of tools. A third consideration is that changes counted during series development (before start of production – SOP) will be much higher than during series maintenance (after SOP). Once a car is in production the number of changes decreases significantly because of collecting numerous individual changes into fewer so called “model year change packages”. Magna Steyr is mainly concerned with series development. In short, the figures about the numbers and financial volume of ECs in companies stem from different sources that have used different interpretations of concepts.

But one thing is clear: ECs are costly. Moreover, the later they occur, the more significant the time and effort needed to implement them [6], [7]. The costs of an engineering change grow by a factor of five to ten as one moves from early design to manufacturing. Typical figures are: Prototype stage: < $ 20,000 and after start of production: > $100,000. [8].

Although ECs form a high cost factor, they are often unavoidable and even necessary to guarantee a high quality end-product. To a large degree they reflect the learning process of professionals during product development.

1 Magna Steyr engineers, develops and assembles automobiles for other companies on a contractual basis.
professionals in the organization. Focus should therefore not be on attempts to reduce their number or frequency, but on the reduction of costs per change. In particular, all activities that do not add value to the EC process itself should, if possible, be eliminated. Lower costs and time reductions will not only lead to lower overall product development costs and reduced time-to-market, but will also encourage developers to increase the EC frequency with, hopefully, a better and more reliable final product. Hence, the improvement of EC will most likely contribute to improved overall Product Lifecycle Knowledge (PLK).

Of course, not all ECs are a result of learning and improvement. Avoidable ECs are for example those due to poor communications, faulty interpretations, missing or late information, and terminology mismatches.

Practically every new insight that results in an Engineering Change invokes a process of redesign, documentation change and related administrative processes. This is an important area where time-consuming, non-value adding activities can be found. The huge number of changes, and the fact that even small changes often result in significant costs and delays in development and production, makes the ability to effectively manage these a key success factor of every product development process [2].

Managing engineering changes across different organizations and disciplines within a single company is a non-trivial task. But today’s global engineering environment, in which product development happens in distributed networks involving multiple OEM’s, engineering service providers and suppliers (tier 0.5 … n), faces even bigger challenges. OEMs and suppliers usually have their own engineering change process and related terminology in place, supported by a wide number of individual workflow and data management systems and specific infrastructures to manage and communicate engineering changes. Thus, every time when change related information crosses company borders, translation and interpretation of data is needed. There is a need for individual ECM processes to communicate across the supply chain using a “universal language” for ECM. This is not the case today.

Currently, the automotive industry deals with multiple ECM systems and supporting processes to communicate changes. These systems include multiple formats and multiple definitions, many of which include manual tasks. All these issues lead to increased confusion, cost and overall inefficiencies in the system. The figures given in this section show that hundreds of thousands of engineering changes take place within the automotive and related industries each year, with each engineering change costing up to EUR 50,000 to process (including direct and indirect costs, but excluding materials and tools). However, the costs of not changing will be quality pitfalls and may cause product/car recalls in the worst case.

Among the high pain points for automotive industry are [2]:

- multiple systems and formats
- multiple definitions and terminology
- multiple processes
- multiple skills sets needed to support multi process/system environment
- missing information
- conflicting changes
- insufficient change tracking
- deficient communication of change to all stakeholders
- manual re-keying of information
- wait time/responsiveness
- confusion
- unauthorized changes processed
- un-reimbursed changes
- translation/interpretation is needed at each point of exchange resulting in costly time and process delays

A more effective and efficient engineering change management (ECM) procedure may ensure that issues regarding an existing product design are clearly defined and carefully evaluated. It may ensure also that change requests and resulting changes are documented, and that their implementation is controlled throughout the product life cycle without interrupting production of existing products.

2 Overview Literature

Huang et al. [9] report about an investigation carried out in 1996 within 100 UK manufacturing companies concerning industrial practices in managing ECs. Numerous aspects have been considered including the systems, organisations, activities, influential factors, strategies, techniques and computer aids. Their major concern is the balance between the effectiveness and efficiency of the engineering change management system. The findings reveal that guidelines for good ECM practices are required for most companies involved in the study. The supplier relationships in the European Motor Industry have changed fundamentally in the last 10 to 15 years due to trends like the reduction of vertical integration, just in time delivery, global sourcing, simultaneous engineering and so on. Suppliers have become much more important for both production and development of more complex components of cars like modules or systems. Nevertheless, what has not changed is the role of the OEM in defining products and standards. [10]

Many of the Engineering Changes are formally initiated by the customer as new requirements or by the company as modified specifications or manufacturing changes. Changes can also occur during a product’s use due to design errors, alternatives for replacement parts, or modifications for improvement towards the end of the life of the product [11]. In short, engineering changes occur also after the product design is released [1], [12], [13], and [14]. Some work has been done on the categorization of engineering changes (ECs) by Hsu [15], Riviere et al. [16] and Lee et al. [14]. Riviere et al. used the list of Hsu, which was valid for military aircraft programs, and completed it with causes of changes
identified in the automotive and aeronautic industries. Lee et al. examined a Korean automobile company for an analysis of the automobile industry's unique requirements concerning engineering changes. They also composed a list with causes of engineering changes based on publications [6], [12], [17], [18], [19], and [20]. All together the following causes have been identified:

- Changes in needs and requirements, including: evolving customer needs triggered by the identification of new product attributes and operational modes; new offers introduced to the market by competitors; needs of privileged suppliers; the introduction of new technologies etc. Requirements can also be reconsidered due to problems or misunderstandings in capturing them right first time.

- Programme or project interactions: within an organization, programmes and projects can be tightly linked. An EC studied and implemented in a programme can lead to an upgrade of an earlier programme or can become the standard for a future programme. This is called a snowballing change - the change of a part depending on altered function or production requirements, or on organizational, technological and operational changes.

- Need to fix deficiencies.

- Technological changes or changes in the manufacturing process or situations.

- Legislative changes.

- Changes in project scheduling.

- Careless mistakes, such as corrections of errors on a document.

- Poor communication, such as faults in the interpretations

- Cost savings, such as by the change, replacement, withdrawal, and introduction of a part

- Ease of manufacturing, such as difficulties found in parts fabrication or assembly

- Product performance improvement

Earl et al [21] examined design change in terms of changing descriptions, and Juerging [22] analyzed the influence of engineering change orders on the performance during the manufacturing start-up in German car manufacturers.

An effective engineering change management ensures that technical requirements are clearly defined, documented and controlled throughout the product life cycle. In the SASIG White Paper [23] the ECM Process is defined as “the coordinated management and uniform tracking of Engineering Changes, starting with the identification of potential for change and ending with the manufacturing implementation of change”.
3 Existing standards

The representation and exchange of ECM related data has already been addressed by existing product data technology standards such as ISO 10303 (STEP). The data model of AP214, an application protocol of the ISO 10303 suite of standards addressing “Core Data for automotive mechanical design processes”, includes objects to convey and communicate ECM related data such as Engineering Change Requests (ECRs) and Engineering Change Orders (ECOs) including the necessary attributes and relationships to attach product definition data and related documents relevant for the engineering change. The history of STEP development can be found in [24]. A comprehensive overview of the current state of STEP is available in [25], [26]. So, how come - despite the broadly recognized potential of standards usage in the ECM area - that these existing standards have not yet been implemented widely to support communication of ECM related information between the stakeholders in a cross-company ECM process?

Neutral data formats supported by corresponding converters/translators for the single systems are important and basic tools for cross-company collaboration. They are well suited for exchange between “traditional” end user applications like CAD, analysis or simulation applications. But experiences during the last decade of product data standards implementation show that “data centric” standards, which mainly standardize data models and formats, are not sufficient to support complex process interactions between systems that actively manage product data in different versions and that facilitate and control the associated workflows including release and approval processes. Especially when it comes to support complex engineering collaboration processes, a new approach is needed that focuses on the collaboration process itself, including the interaction between the participating parties. Especially the lack of well defined cross-company processes and the missing information about the context of communication is seen as a major drawback of product data standards such as STEP. Therefore, the objective of a new approach must not only be to define and exchange product definition data based on a neutral data format with well defined semantics that each partner is supposed to understand, but also to provide a set of orderly procedures for efficient communication between the different stakeholders in the particular engineering workflow. In the ECM area, this means that process related issues, which are identified as high pain points by the automotive industry, such as the lack of understanding of process needs, lack of process compliance, and lack of workflow control (see above), have to be addressed on top of data translation, interpretation and data quality issues.

To address these issues a project consisting of leading industry experts in the ECM area was founded as a common workgroup of the ProSTEP iViP association and the VDA CAD/CAM Working Group. The objective of this project was to develop guidelines to support cross-company ECM processes based on standards and to validate these guidelines by individual pilot projects of participating companies [27]. By applying these guidelines, every stakeholder in a particular cross-company ECM process shall have a clear understanding of his role, milestones and necessary synchronization points, and about the kind of data to be delivered or to be expected at each synchronization point.

The prime focus of such a standard for cross-company engineering change management is to increase the efficiency of processing engineering changes by around 10-20% throughout the whole product development process. In addition, the automotive OEMs and their suppliers assume that such a standard improves the process reliability in a sustainable way
and therefore also indirectly increases the quality of the car. Along the way such a standard will automatically decrease the costs of engineering changes, reduce the time to market and reduce many other indirect costs caused by inefficient processes.

4 Approach

4.1 Assumptions

In the following, the approach taken by the workgroup to develop the ECM guideline is described. It will be illustrated using examples from the ECM area, but could be transferred and applied to develop communication protocols to support cross-company collaboration processes in other domains as well. The approach itself is of more general nature, i.e. it is assumed to work not only in engineering change or product data environments but also in document oriented environments as well as in other sectors than automotive.

As illustrated above, at the starting point of this development the focus has been on defining a company independent ECM reference process and the collaboration and communication requirements during the different stages of that process. Only in a second step, the data content to be exchanged at each milestone and synchronization point in the process is derived from the communication needs at this point and the data model describing this information content is defined in detail.

Also in the STEP application protocol (AP) development, a first step consists of describing an application activity model (AAM), using the IDEF-0 methodology. The AAM identifies processes and information flows between them. The content of these information flows are specified by the STEP AP data model. But how is that different from the process oriented approach taken for the development of the ECM guideline? The activity model of a STEP AP captures activities ('what is done') and describes the input and output information requirements of these activities in scope of the AP. The goal of the STEP activity model is to describe the scope of the shared data and to identify the information flows. Its goal is not to standardize a workflow, or to define the detailed processes ('how it is done') which may vary between organizations. It also does not define potential synchronization points between activities of the partners involved.

The goal of the ECM “reference process” is not to standardize the way ECM processes are carried out within the individual participating companies, but to enable synchronized and controlled processing of engineering changes by defining a guiding cross-company reference process for the ECM domain.

Before continuing with describing the single development steps performed during development of the guideline, it is important to note the following fundamental assumptions:

- The ECM reference process provides a common process context for collaboration and supports common understanding and transparency of the interaction and communication between partners at the various stages in that process, thus reducing the lead time for processing engineering changes. It defines synchronization points at which communication between the stakeholders of an engineering change is possible, or required, and thus serves as a reference for standardized interaction.
In every interaction scenario of the ECM reference process, there is one coordinating partner ("coordinator") responsible for coordinating that particular stage of the process, and potentially many additional "participants" who are involved in the process.

- All participating partners i.e. stakeholders in the ECM process use their own company specific ECM process and systems that typically vary between organizations.
- Each partner has to map his specific engineering change process onto the ECM reference process for the defined synchronisation points and milestones.

4.2 Development steps

The development of the ECM standard has been done in the following steps (see also Figure 1):

- In an initial step, company specific ECM processes of the participating companies (OEM and suppliers) and the associated data requirements and specific terminologies were analyzed and documented using a common notation (UML Use Case Diagrams). This analysis resulted in the definition of a consolidated set of ECM Use Cases common for all members of the standardization group.

- On this basis, the ECM reference process was defined including potential synchronization points at which the internal ECM processes of the involved partners have to be aligned (i.e. communication may or has to take place) in order to support cross-company ECM collaboration.

- In a next step, a detailed ECM data model was developed. This model represents the information requirements - i.e. data content - to be communicated between the stakeholders in the cross-company ECM process during the various synchronization points.

- Finally, the ECM Protocol has been specified as a set of interaction scenarios, each defining a set of messages, which enables the controlled communication of the ECM related data required at the synchronization points such as defined by the ECM reference process.

- To be compatible with existing standards, the ECM protocol specification, the ECM messages and the ECM data model may be mapped onto established standards like ISO STEP AP214, the OMG PLM Services (Object Management Group – Product Lifecycle Management) [28] and OASIS BPEL (Business Process Execution Language) [29]. This step is optional, i.e. only if one or more of the aforementioned standards is already in place, the usage of these standards including the required mapping from the ECM application level to these standards is recommended.
The main objective of defining the ECM Reference process is that the partners don’t have to change their company internal ECM Process, but simply have to map their own internal ECM Process onto the agreed ECM reference process (and its synchronization points respectively) in order to know when and what has to be communicated with their ECM partner (see Figure 2).

In the following sections the steps 2-4 outlined above are described in more detail. Examples are given for the ECR sub-process of the overall ECM reference process.

### 5 Results

#### 5.1 The ECM Reference Process

Starting with the consolidated set of common ECM Use Cases from the analysis phase, at first, a rough ECM phase model of the ECM reference process and its identified sub-
processes Identification of Potential for Change, Development of Alternative Solutions, Specification and Decision of Change (Engineering Change Request - ECR), Engineering Implementation of Change (Engineering Change Order - ECO) and Manufacturing Implementation of Change (Manufacturing Change Order - MCO) and the relevant milestones for each sub-process has been developed. These sub-processes are further broken down into a sequence of, potentially parallel, activities and synchronization points at which an ECM related communication between the stakeholders may take place (see Figure 3).

The ECM process and its sub-processes are described from the point of view of the primary process owner (coordinator). Interactions between the coordinator and the partners (participants) may take place at every synchronization point identified. Milestones at the different process phases also constitute synchronization points as the participants usually have to be notified about reaching (or missing) the particular milestone.

In addition, the roles of the various actors participating in that particular part of the cross-company ECM reference process were defined (e.g., coordinator, participant, EC manager, change team, and decision team). The result of this breakdown into activities, including the synchronization points, has been documented using UML 2.0 activity diagrams² (see Figure 3).

Figure 3: Illustration of the ECM reference process breakdown (synchronization points are not shown)

² UML 2.0 activity diagrams were chosen because of the experience available in the working group. The usage of other notations like e.g. PSL (Process Specification Language) or ARIS-EPK would have been also possible.
Each potential synchronization point is modelled as a message (e.g., Request_Initial_ECR) that is sent by one role and received by another role.

The following Figure 4 illustrates an example of an activity diagram for the breakdown of the Inquiry of ECR phase of the ECR reference process. This phase serves to receive proposals for changes. The proposals for changes typically originate from development, production, sales and other specialist departments or from partners (suppliers, development partners, etc.). Proposals for changes are aimed at reducing costs, improving quality, adapting to changes in the production process, responding to statutory constraints (environment, safety) or at implementing customer wishes with respect to new functionality, special equipment, etc.

This phase starts with the participant sending the message Request_initial_ECR to the coordinator. The coordinator receives the message Request_initial_ECR and creates the Initial ECR in his change management system in the Create Initial ECR activity for the purpose of subsequent analysis, evaluation and documentation. He then sends a response message Respond_initial_ECR to the participant, to confirm receipt of the Initial ECR and to notify the partner of the reference to the Initial ECR to allow the partner to address queries and monitor the Initial ECR.

The coordinator then prepares the Initial ECR in the Prepare Initial ECR activity by adding any necessary information and a description, such as classification criteria and description of

![Activity diagram for the “Inquiry of ECR” phase of the ECR reference process (UML 2.0 activity diagram)](image-url)
the cause. He then examines the proposal for a change in the Analyze Initial ECR activity, for example taking account of similar change requests from the past or current change requests with a similar scope. He can then decide whether the Initial ECR is to be pursued as an ECR or not in the subsequent activity Decide Initial ECR. If the proposal is not to be pursued (i.e. ECR_acceptance.decision = ‘rejected’) the coordinator then sends the participant the message Notify_initial_ECR_rejected, in order to inform him about the decision supported with arguments. Otherwise (i.e. ECR_acceptance.decision = ‘accepted’) the activity is finished. (In this case, a notification takes place in the following phase Creation of ECR).

The activity Inquiry of ECR ends in the status Initial ECR accepted if the Initial ECR is to be pursued (in this case a defined milestone is reached and the next phase of the ECR reference process is entered, see Figure 5) or in the status Initial ECR rejected, if the Initial ECR is not to be pursued.

![Figure 5: Entering the next sub-phase of the ECM reference process](image)

5.2 The ECM Data Model

Based on the initial end user specific ECM terminology, the ECM reference process and the ECM data requirements (i.e. the data flows between the activities and the required data at the synchronisation points) a detailed data model for each ECM sub-process was developed by mapping the identified end user concepts to classes of that data model with attributes describing the details of these concepts. Figure 6 depicts for example a simplified extract of the data model illustrating the data requirements of the ECR reference process.
This data model in end user terminology, modelled in detail using EXPRESS-G [30], serves as the common communication basis in discussions between the members of the ECM working group. Subsequently it defines the pieces of information to be sent at particular synchronization points of the ECM reference process. The ECM data model is not designed to be directly used as the communication format. It is comparable to the Application Requirements Model in STEP application protocols.

5.3 ECM Interaction Scenarios and ECM Messages

As the ECM reference process and its sub-processes are supposed to support and contain all theoretically possible collaboration scenarios, its usage in its entirety within a concrete collaboration e.g. in a car project is in general not feasible. The degrees of freedom contained in the ECM reference process are too large. Therefore, typical interaction scenarios that occur frequently in practice were identified based on specific partnership constellations (i.e. prime contractor, system supplier, module supplier, part supplier or engineering service provider as defined by VDA 4961). Each of those interaction scenarios supports a well-defined number of activities of the ECM reference process and is defined by the relevant subset of synchronization points necessary to support that particular interaction scenario.

ECM interaction scenarios are defined by certain sequences of ECM messages that may be sent between the stakeholders at each of these synchronization points. Every synchronization point is represented as exactly one ECM message. The valid sequence of ECM messages between the different stakeholders is therefore defined by the sequence of synchronization points within the ECM reference process. For the Engineering Change Request (ECR) sub-phase, the following four interaction scenarios were identified:

- **ECR interaction scenario 1: Participant proposal for a change**
  Within ECR interaction scenario 1, the participant is typically a part supplier of an OEM. He triggers the change but is not affected by the change itself. Therefore the participant does not need much information about the ECR and is only loosely coupled with the
ECR process at coordinator site. ECR updates from the coordinator, rollbacks in the ECR process, and revisions of an ECR in the approval phase, if any, are coordinator internal only and are not visible for the participant.

- **ECR interaction scenario 2: Participant comments**
  Within ECR interaction scenario 2, the participant is typically a part or module supplier of an OEM. The ECR process is driven by the coordinator. The participant may or may not trigger the change, but the participant in this interaction scenario is always affected by the change itself; especially the participant is involved in the commenting phase of the ECR process. Therefore the participant needs more information about the ECR and is more closely coupled with the ECR process at coordinator site. ECR updates from the coordinator, rollbacks in the ECR process, and revision of an ECR in the approval phase which are visible for the participant may occur.

- **ECR interaction scenario 3: Participant approval**
  Within ECR interaction scenario 3, the participant is typically a customer (e.g. an OEM) and the coordinator is typically a supplier (e.g. a general contractor). The ECR process is driven by the coordinator. The communication in this interaction scenario takes place in the approval phase of the ECR process only. Rollbacks in the ECR process and revisions of an ECR in the approval phase, if any, are coordinator internal only and are not visible for the participant.

- **ECR interaction scenario 4: Participant detailing and comments**
  This ECR interaction scenario is similar to ECR interaction scenario 2 with the following exception: the participant is already involved in the technical phase of the ECR process. Therefore the participant needs more information about the ECR and is more closely coupled with the ECR process at coordinator site. ECR updates from the coordinator, rollbacks in the ECR process, and revisions of an ECR in the approval phase visible for the participant may occur.

The following Figure 7 illustrates the interaction protocol, i.e. the set of ECM messages and their allowed sequence for ECR interaction scenario 1.

![Figure 7](image-url)

*Figure 7: Illustration of the ECM messages and their allowed sequence in ECR interaction scenario 1*

As stated above, ECM messages are sent at the respective synchronization points for the particular interaction scenario. Every message is referred to by its message name and contains the message content representing the payload and the message header, representing the synchronization point, i.e. the context of the ECM process. The following
Figure 8: Illustration of the ECR messages within ECR interaction scenario 1 in the context of the ECR reference process and their message content.

The message content describes the ECM related payload that may be communicated at the particular synchronization point within that ECM interaction scenario. It refers to information classes defined in the ECM data model. Thus, every ECM message defines the (mandatory or optional) data to be communicated at a synchronization point in the ECM reference process. Figure 9 illustrates the definition of the payload of an ECM message for the example of the Request_Initial_ECR message.

Figure 9: Illustration of payload of an ECM Message
The content of each ECM message is described in more detail in a tabular form. The following table contains, as an example, the description of the Request_initial_ECR message.

<table>
<thead>
<tr>
<th><strong>Request_initial_ECR</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>This message from the participant contains a request to create an initial ECR.</td>
</tr>
<tr>
<td><strong>Parameters:</strong></td>
</tr>
<tr>
<td>• ECR_header: ECR_header</td>
</tr>
<tr>
<td>contains the identification and the master data, including a description of the requested ECR including [mandatory]</td>
</tr>
<tr>
<td>• ECR_details: OPTIONAL SET [1:?] OF ECR_detail</td>
</tr>
<tr>
<td>If present, the participant may include already existing details (e.g. affected parts) of the requested ECR [optional]</td>
</tr>
<tr>
<td>• ECR_comments: OPTIONAL SET [1:?] OF ECR_comment</td>
</tr>
<tr>
<td>If present, the participant may include already existing comments (e.g. statements from logistics or manufacturing) of the requested ECR [optional]</td>
</tr>
</tbody>
</table>

To enable a sound communication between partners in a common ECM process, any implementation must fulfill certain requirements by providing control information in the ECM message header. The main requirements are:

- The organization of the sender and of the designated receiver needs to be uniquely identified globally or at least between coordinator and participant.

- Every message exchanged between coordinator and participant must be uniquely identifiable on a technical level, i.e. on the level of ECM context information such as the message name and interaction scenario. This is needed to determine the significance of the message in the context of the Reference Process and the interaction scenario.

- It must be possible to uniquely assign every Respond message to the corresponding Request message in order to identify the request data to which the response data refers.

- It must be possible to assign every message uniquely to an interaction scenario flow. This ensures, for example, that it is possible to exchange information simultaneously about different change requests with the same participant even using the same Interaction Scenario. At the same time, the assignment of the message to the context of the preceding messages relating to a change is retained.

- It must be possible to reconstruct the sequence of messages for each sender in an interaction scenario flow. This is needed with respect to the order in which the messages were sent and to their completeness. This ensures that communication errors such as incorrect sequences or lost messages can be detected.

Based on these requirements, a detailed model for the header of ECM messages reflecting a solution to these requirements has been developed.
5.4 Mapping the major results onto existing Standards

As already mentioned in section 4.2, the mapping from the ECM application level to existing standards like AP214 (ISO 10303-214) [31] is recommended. This implies that when an ECM standard is implemented within a typical engineering environment, such as an environment where besides the ECM system other IT-systems like PDM/PLM, BOM and Document Management systems are used, the ECM implementation can be based on standards that support those application domains. AP214 of the STEP standard is designed to cover the data generated and managed by various engineering IT applications during the automotive product development chain (see Figure 10).

Therefore the ECM data model, representing the complete set of ECM data being communicated as the message payload, was also mapped onto this product data standard. Figure 11 outlines the mapping of the object types of the ECM data model to the object types of the AP214 data model.
In order to realize the ECR message exchange, the OMG PLM Services standard was chosen because this standard is designed to operate on the objects of the AP214 data model using web-services technology. For implementing the ECR interaction protocols, established workflow standards like BPEL can be used.

Figure 12 summarizes the exploitation of existing standards for the realization of the major ECM concepts.

---

**Figure 11:** Outline of the mapping of the major ECM data model object types to those defined in AP214 (black: Object types and associations in the AP214 Data Model, red: Object types and associations in the ECM Data Model)

---

**Figure 12:** Illustration of the mapping of the major ECM concepts to existing standards
6 Pilot Implementations, Standardization and Dissemination

The vision of the working group is a joint automotive OEM and suppliers effort leading to a more efficient Engineering Change Management collaboration throughout the global automotive supply chain. The achieved results were used for an appropriate bottom-up standardization strategy, and the generic approach was verified by case studies in automotive pilot projects.

6.1 Standard dissemination strategy

In order to guarantee a sustainable and useable standard the following bottom-up approach for the development of the ECM recommendation was taken:

- Development of a first draft of the ECM standard in a small working group consisting of leading experts from OEM suppliers. They were supported by methodology experts from consultancy companies, adding the necessary in-depth knowledge of the engineering processes as well as the know-how about methods and experiences in applying these methods in the ECM application area. This very first draft of the ECM standard was published as a ProSTEP iViP recommendation.

- Dissemination of the draft ProSTEP iViP ECM recommendation to a broader audience of automotive manufacturers and their supplier companies for review and commenting within the German association of automotive industry (VDA). This resulted in a VDA ECM recommendation. In 2007, two VDA Recommendations for Engineering Change Management (VDA 4965) and Engineering Change Request (VDA 4965-1) as well as a ProSTEP iViP Recommendation for Engineering Change Order (PSI 3-2) were published. [27], [32]

- In order to ensure a broad international acceptance, the VDA ECM recommendation was issued to SASIG (Strategic Automotive product data Standards Industry Group) in order to turn the VDA ECM recommendation into an internationally acknowledged and accepted SASIG ECM recommendation.

- SASIG comprises of automotive industry organisations from around the world (AIAG [USA], GALIA [France], JAMA [Japan], Odette Sweden [Sweden] and VDA [Germany]). It acts as a forum for the development of global standards, guidelines and recommendations, and it promote implementation of these automotive engineering standards. The primary focus is in the area of product data including neutral data formats, common engineering processes, quality metrics, naming conventions, and exchange and management of technical data. To achieve this aim, the following recommendations are being drawn up on the basis of the results achieved so far.

- SASIG ECM Recommendation Part 0 (ECM), providing an overview of the processes required to implement ECM. It describes the ECM reference process, its modeling and the underlying partner model. In addition, it describes the basic principles of the corresponding subprocesses (change request, change order, etc.). [33]

- SASIG ECM Recommendation Part 1 (ECR), supporting the communication of engineering change requests (ECR) and decisions relating to these requests. It is based on Part 0 and defines an ECR reference process which allows the neutral
The adopted bottom-up standardization approach ensures a sound and stressable result with respect to its practical suitability in contrast to the top-down approach often taken within standardization committees.

6.2 Implementation scenarios

Parallel to the development of the ECM guideline, early pilot implementations in member companies of the project group were conducted to ensure that the ECM guidelines address the issues properly. Each ECM pilot project was required to evaluate the evolving ECM guideline with respect to suitability in a cross-company ECM communication. Experiences and feedback were reported in detail. These reports aimed at improving the quality of the ECM guideline at an early stage in development, thus enhancing its applicability.

The following basic (independent) categories of implementation scenarios for the engineering change requests phase were realized during the development of the ECM standard:

- Server – Server vs. Client – Server based implementation scenarios
  - Server – Server based, if both partners use their own (internal) ECM system for managing engineering changes.
  - Client – Server based if the external partners do not have an ECM system of their own. These partners can use thin clients (e.g. a web browser) which do not need any installation effort. Just the Coordinator (e.g. the automotive OEM) is required to provide an ECM server which needs to be accessible by web services.

- Asynchronous vs. Synchronous ECM implementation scenarios
  - asynchronous process integration of ECM back-end systems between an automotive OEM and a prime contractor as well as between an automotive OEM and one of its system suppliers.
  - synchronous process integration of the ECM back-end systems of an automotive OEM and two of its module suppliers using a system-independent, neutral web-client communicating with the back-end ECM system of the OEM using web-services.

- Process oriented vs. Data oriented implementation scenarios

The combinations of these three basic categories lead to 6 possible implementation scenarios. All of them are proven to be realistic.

6.3 Pilot implementations and results

The approach has been implemented in pilot implementations at various automotive OEM's and their suppliers, supporting different scenarios described in the ECM standard. Details (e.g. experiences, challenges, realized benefits, and lessons learned) about the conducted pilot implementations were reported and published at several conferences, see e.g. [35],
The results of these pilot implementations have been analysed by an external consulting firm and lead to the following conclusions [39]:

- Setting up a cross-company change management process between two engineering partners that use the ECM standard saves about 10 person days per new project.

- Per single ECM communication, 0.75 person days are saved by automated information exchange using the ECM communication protocol. Assuming a supply of 200 parts per year with 5 changes per part’s lifecycle in average, this leads to an additional time saving of 750 person days.

- Further advantages of using the ECM standard are higher data quality, higher transparency of the engineering change process, shortened process lead time, and a higher reliability of decisions on engineering change requests.

These benefits clearly justify the initial investment in appropriate solutions to implement ECM based on the developed guideline.

In addition, there is one ongoing pilot project for the engineering change order (ECO) phase of the ECM process which focuses especially on the connection of the ECO process with PLM/PDM driven CAD assembly data exchange.

7 Discussion and Outlook

The expected impact of the proposed solution is a reduction of lead time of the engineering change process and an improvement on the quality of the product (i.e. the car) itself. The lead-time reduction will be between 20% and 40%, as shown by company internal analyses. The improvement of quality itself is expected but is not yet quantified. Other potential benefits can be found in increased predictability of the product, reduced risks, and/or reduced (legal) conflicts between OEM and suppliers.

The proposed solution focuses on engineering changes, i.e. changes of the existing engineering specifications/solutions. Engineering changes may be needed to correct errors, but they will in most cases contribute to optimizations of product quality, production, disassembly and reuse processes. These aspects were also successfully evaluated in pilot projects, taking changes of production process, and changes of production resources into account.

The whole concept of improving the EC-process contributes to making design more dynamic. If the costs and time per change reduce, the number of ECs may increase, because most ECs aim at improvement. So, ECs must not only been seen as factors that cause costs and time delays - this is how project managers often look at them - but also as factors that add value to the product and/or the process. The art of process management is to find the right balance between allowing changes (and thus to reward the learning enterprise) on one hand, and to respect schedules and budgets on the other hand.

An additional and important benefit of a well-organized ECM process is the accumulation and capturing of engineering knowledge, even across the whole supply chain. ECs are a handle and a carrier to find, capture and manage product life cycle knowledge.
In practice, engineering changes are often positioned against the actual design (i.e. the product definition information, already generated by the engineers) and not against the specification (i.e. the specification is still valid, but the actual solution for the specification needs to be changed). As the actual product definition information of a part or an assembly is often represented by geometry files and/or accompanying meta data of these geometry files, the engineering change requests are mainly positioned against this kind of information. The majority of the requested changes do only change the actual solution for the same specification, without changing the specification at all. In a few cases, the engineering changes are positioned against the specification itself. In all cases the actual configuration hierarchies need to be taken into account. This is one of the tasks of the so called EC manager (which is the owner or responsible person for that engineering change). A further task of the EC Manager is to collect all relevant information for the proposed change, such as by inviting the identified stakeholders for analysing and reviewing the proposed change. This allows them to add further relevant information about, for instance, affected parts, actual documents and figures, and statements about implications.

A business motivation and a standard are not sufficient to implement the envisioned solution in engineering practice. For example, STEP is intended to be implemented through pre- and post-processors for computer applications. This requires commitment of application vendors. Changes in standards and changes in systems penetrate only slowly into practice, as users can only use the version of the standard that they both have in common. There exist today completely different solutions, such as self-configuring and self-updating applications (e.g. Adobe reader for pdf files, codecs for media players, automated updates for operating systems and virus scanners) which enable users to work always with the same and most recent system specifications. But even these solutions require the commitment of application vendors. The penetration of changes in the standard as well the penetration of changes in the systems depends to a high degree of that commitment. The mechanisms of self-configuring and self-updating applications can be applied for the proposed solution as well. The ECM standard provides some of these mechanisms. For example, as soon as an ECM server provides a new/updated list of permissive values for certain attributes, the ECM client automatically updates local definitions with the new ones provided by the ECM server – this is done transparently for the end-user. We try to avoid or at least water down the current problems with the uptake of STEP by using a bottom-up approach. A solution is directly driven by end-users who have committed themselves to undertake pilot projects for implementing the standard (or at least parts of it) and for exploiting these pilot implementations in actual car line projects. The ECM workflow (i.e. the ECM interaction protocol) is likely to be integrated with existing Workflow systems (either stand-alone systems or workflow systems that are integrated into existing systems, e.g. PLM/PDM systems). Nevertheless, that integration can not be done “automatically” – it will always require some customization/adaptation effort.

Change management frameworks for ITC (Information and Communication Technologies) like ITIL and ISO/IEC 20000 and other frameworks like e.g. ASAM AE ISSUE for the issue and change management for automotive electronics have also been discussed within the working group, but it was decided that automotive, especially the mechanical orientated part of the automotive development process and ICT differ too much in scope and requirements. In addition, the working group decided to have a first release available with limited functionality in order to gain experience by the practical use of the ECM recommendation. Future versions may incorporate more functionality like those listed by ITIL.
This paper focuses on the method of deriving an implementable solution from end-user driven use-cases step-by step. As its aim is to present a general methodology that can be applied to other domains or subject areas, implementation scenarios have not been described here. ECM is just one example of application.

8 Conclusions

In this paper, an approach is presented that combines a standardized data model with a reference process ensuring a common understanding of the underlying business process, the various stakeholders in that process, and the needed interactions between these stakeholders at predefined milestones. This approach has been used to define a communication protocol for cross-company processes in the ECM area. Adopting this communication protocol does not require the parties involved to change their internal processes. It focuses on defining the needed synchronization points during the process and the required communication of information.

Analyses conducted within member companies of the ECM project group have shown a potential lead-time reduction of 20 - 40%. These findings were confirmed by the ECM pilot projects. These pilot implementations have shown that setting up a cross-company change management process between two engineering partners using the presented ECM standard reduces the effort with about 10 person days. And per single ECM communication, 0,75 person days are saved using automated information exchange based on the ECM communication protocol. Assuming a supply of 200 parts per year with 5 changes per part's lifecycle on average, this leads to an additional time saving of 750 person days.

Further advantages of using the ECM standard are higher data quality, higher product and process quality, improved transparency of the engineering change process, shortened process time, and a higher reliability of decisions on engineering change requests.

These benefits clearly justify the investment in solutions to implement ECM based on the developed guideline.

Although the presented approach has been defined and used for cross-company ECM processes, it can easily be transferred to other types of business processes in which process oriented collaboration is needed throughout the supply chain.

The methods and technologies used (e.g. UML, XML, SOAP, web-services) are state of the art and leverage existing developments on both the data model (e.g. by adopting existing standards such as STEP) and the communication protocol side. Implementing companies can build their ECM solutions on top of an existing technical infrastructure. This increases the value of earlier investments, such as in the mappings of proprietary or application specific data to standardized data models, application interfaces, and/or web-service and SOAP based system environments.

References


[27] VDA 4965 - Part 0: Engineering Change Management (ECM); Overview general recommendations for the overall ECM Reference Process, and VDA 4965-1 - Part 1: Engineering Change Request (ECR); ECM Reference Sub-Process used to


