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The Challenges of Engineering Change Order Management Systems in Modularization Firms

A Closer Look at the Intricacies of Scania's Bygglåda

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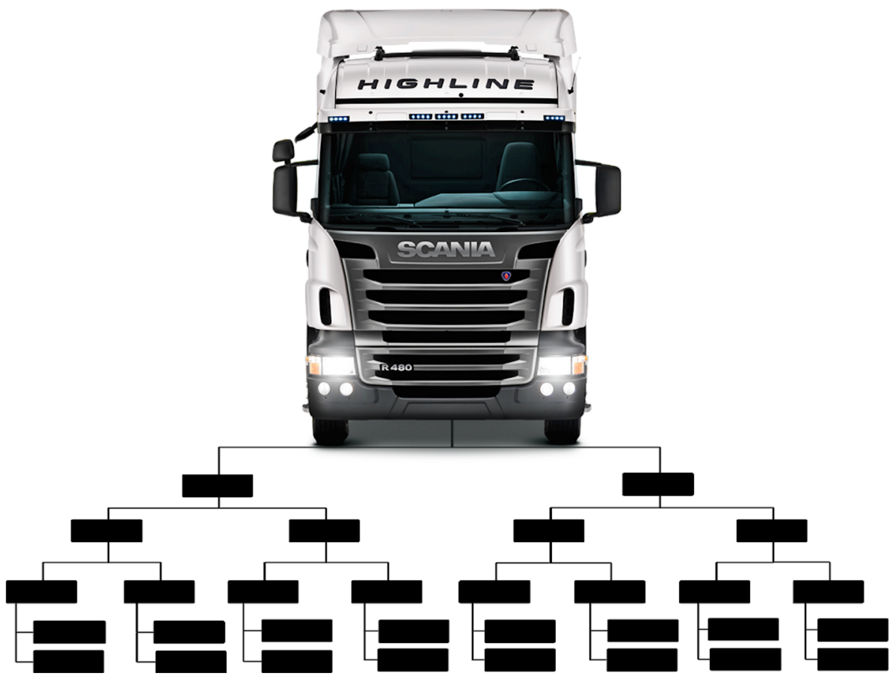

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KTH Industriell teknik och management	Examensarbete ITM-EX 2020:404 **Utmaningarna med ingenjörsändringshanteringsystem i modulariseringsföretag** **En närmare titt på Scanias bygglåda** Abdul Hameed Noor Taki	
Godkänt 2020-06-22	Examinator Sofia Ritzén	Handledare Susanne Nilsson
	Uppdragsgivare Scania AB	Kontaktperson Jonas Arkman

Summary (Swedish)

Denna rapport undersöker och identifierar viktiga utmaningar förknippade med ECM-implementeringar (ECO-användning) i modulariseringsföretag. Dessutom presenteras ett ramverk som syfter till att underlätta hanteringen av de presenterade utmaningarna. Analysen av befintlig litteratur avslöjar behovet av ökad förståelse för de empiriska utmaningar i företags implementering av ECM . Dessutom påvisar litteraturanalysen ett behov av att förstå kopplingen mellan användningen av ECM-system och modulariseringsbaserade produktarkitekturer. Resultaten visar att ECO-relaterade problem härstammar från både otillräckligt tvärfunktionellt samarbete och bristen på relevanta ECM-åtgärder. Några av rapportens viktigaste slutsatser visar ett orsak-och-effekt-förhållande mellan brister i ECM och tvärfunktionellt samarbete och på en en koppling mellan organisationsstrukturen och tvärfunktionell prestanda. Resultaten baseras på en studie gjord på FoU-avdelningen i Scania AB.

KTH Industrial Engineering and Management	**Master of Science Thesis ITM-EX 2020:404** **The Challenges of Engineering Change Order Management Systems in Modularization Firms** **A Closer Look at the Intricacies of Scania's Bygglåda** Abdul Hameed Noor Taki

Approved	Examiner	Supervisor
2020-06-22	Sofia Ritzén	Susanne Nilsson
	Commissioner Scania AB	Contact person Jonas Arkman

Abstract (English)

This thesis investigates and identifies key challenges associated with ECM implementations (ECO usage) in modularization firms. In addition, a 3-tier conceptual framework is presented as a mitigation to some of the presented challenges. A gap in existing literature reveals the need for better understanding of empirical challenges in industrial companies' implementations of ECM. In addition, light is shed on the linkage between the use of ECM systems and modularization-based product architectures. ECO-related issues were found to originate from both insufficient cross-functional collaboration and lacking ECM measures. Some of the key findings allude to a cause-and-effect relationship between ECM insufficiencies and cross-functional collaboration and also a link between the organizational structure and cross-functional performance. The results were based on a study done in the R&D department of Scania AB.

Preface

This thesis report centers around the ECM system of Swedish truck manufacturer Scania AB and investigates the key challenges as well presents ways to address the identified issues. The results are based on an investigation done at the R&D department of Scania in Södertälje.

Firstly, we wish to thank our supervisor at Scania AB Jonas Arkman and group manager Sara Ekman who assisted and guided us during the entire 20 weeks of our work and helped us when we had questions and doubts about understanding the process flow.

Secondly, we would like to extend our gratitude to everyone who devoted their time to participate in interviews and surveys for the purpose of this research. Furthermore, we also want to thank those who we observed during the initial phase and provided us with practical examples and demonstrations.

Thirdly, we want to thank our supervisor at the KTH Royal Institute of Technology, Susanne Nilsson, who assisted us during the duration of the thesis study and provided us with insightful feedback during the course of the project.

Lastly we want to thank our friends and family who supported us whenever we needed it.

Abdul Hameed and Noor Taki
Stockholm, June 2020

Nomenclature

Presented here are the acronyms and abbreviations used in the report.

Sl. No	Acronyms	Full Form
1	CAD	Computer Aided Design
2	CAVA	Calculation and Visualization Applications
3	CF	Cross Functional
4	CFT	Cross Functional Teams
5	CO responsible	Change Order Responsible
6	COIN	Coordinated Introduction
7	CO2	Carbon Dioxide
8	DDS	Dynamic Delivery Schedule
9	DE	Design Engineer
10	DSM	Design Structure Matrix
11	DWG	Drawings
12	ECM	Engineering Change Management
13	ECO	Engineering Change Order
14	F-gen	Functional Generation
15	FPC	Functional Product Characteristics
16	GANTT	Generalized Activity Normalization Time Table
17	GPs	Geometric Positions
18	KS	Konstruktionsstruktur
19	MBD	Model-Based Definition
20	MFD	Modular Function Deployment
21	MONA	Monteringsadministration
22	NPD	New Product Development
23	OAS	Object and Structure Tool
24	ODF	Object Definition

25	OLs	Object Leaders
26	PC	Product Coordinator
27	PCL	Product Class
28	PD	Product Development
29	PDF	Project Definition
30	PFtools	Project Follow-up tools
31	PMI	Product and Manufacturing Information
32	POIA	Project and Object Involvement Approach
33	R&D	Research and Development
34	SEPS	Simple ECO Planning System
35	SoS	Start of Sales
36	SOP	Start of Production
37	SOCOP	Start of Customer Ordered Production
38	SPP	Scania Project Planning
39	TCR	Translation Code Register
40	TS	Technical Specifications
41	VCR	Variant Code Register
42	VIP	Vehicle Integration Point
43	V-gen	Verification Generation
44	WC	Weight Calculation

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1. Background

In today's dynamic world, product variety is driven by both diverse and changing customer requirements which, in themselves, adhere to environmental factors such as market trends and societal values [86]. Hence, this need for product variety creates challenges for companies, most of which can be addressed using product modularization. More and more firms are implementing modularity in their product development, a trend that has been growing in the last decade [82] [2]. Modularization is not limited to one industry as empirical evidence shows that modular principles are used in multiple different business areas such as automotive, electronics, computer and construction where they benefit from product modularization in the form of improved sales performance [85] [83].

Precedents in the personal computer industry show how modularization can be used to gain competitive advantages and yield positive financial results. When Compaq briefly overtook IBM as the market leader in the personal computer market, they embraced the newly introduced modular structure of PCs to create competitive products at a lower price [2]. Their market results commenced a shift in the industry toward adoption of the modular architecture as an industry standard which led to several new entrants. Later, when Dell outcompeted Compaq, they too adopted both modular design and modular production processes but to a greater extent than Compaq [81]. Evidently, application of modular principles can result in great industry turnarounds and strategic shifts.

Principally, product modularization is based on the theorem that a large variety of products can be produced by combining a large number of segmented modules [1]. According to Baldwin and Clark, modularization has three purposes, to make complexity manageable, to enable parallel work and to accommodate future uncertainty [2]. The concept of "modular design" is to break down complex systems into manageable modules in order to organize complex designs and processes [3]. Thus, modules can be considered building blocks in a structural product system. Another dimension is the interdependence aspect which also introduces a hierarchy in the modular architecture. However, modules can only be interchanged if they have compatible interfaces and interactions. Interfaces are the boundaries of the modules connected to each other whilst interactions describe the input and output between the modules [1]. Naturally, this results in a complex interface-dependent system, a challenge which requires the employment of modular design methods from the ground up - of which there are plenty already prescribed [84.] [4] [5].

The other challenge is managing and maintaining the product architecture which is commonly done via the utilization of systematic change order management systems. ECOs (Engineering Change Order) are documents that describe a product property change in a system or complex product. They are used for traceability in complex product systems that have a defined structure or architecture and require maintenance of a catalog of items, which most often are quoted as being modular. ECOs are commonly used when introducing new elements in the structure but may also be used to update or edit structural components [48]. Examples of real-life domains include automobiles, electronics and microprocessors, just to name a few [49].

Some issues regarding the implementation of ECOs such as long lead times, communication problems and unclear roles have been discussed in literature [50] [51]. For example, Jokinen et al. highlight issues regarding the prioritization of ECOs and summarize some of the underlying reasons for delayed ECO processing. They found that 41% of ECOs at the case company were either delayed or had not been followed up, suggesting that follow-up procedures of ECOs were inadequate [52]. Studies centered around the development of ECM (Engineering Change Management) methods are far from few, but seldom highlight empirical implementation issues resulting from real-life applications in product development firms [63] [64]. As such, there is an apparent gap between literature-prescribed methodology and practical applications.

This is further accentuated by the recognized difficulty in implementing company-adoptable ECM methods since intricate details in the organizational practices, processes and routines often act as barriers [65]. Therefore, more knowledge about practical applications, limitations and tensions is needed in order for theoretical frameworks to be implementable in product development firms. Furthermore, existing literature has identified and called for more research to be dedicated to bridging the knowledge gap pertaining to empirical adoptions of ECO systems and their challenges [54].

In addition, the modularization element is mostly unnamed or implicit in most literature about modularization and ECOs [59] [60]. For instance, a study by Lee et al. presents a method for gauging propagation of design change impacts in modularization projects. However, despite the close linkage between modularization of complex systems and the systematic usage of ECOs, very few articles have focused on the challenges related to the ECO implementation in modularization firms. This correlation is vital due to the modularity-induced interdependencies and strong association between modularization and product complexity [61], which theoretically benefits from the employment of an ECO system. Rather, most papers have been fixated on the development of general ECO methodology that is compatible with interface management frameworks such as DSM [59] [60].

Scania is one of the biggest truck manufacturers in the world [87]. What characterizes Scania and serves as the main competitive advantage over their competitors is the extensive implementation of modularization to tailor and create trucks for a range of different customers. Scania's success is partly due to its "Bygglåda" principle which they make use of during their development of commercial vehicles. By having a fully modular vehicle structure, Scania is able to build countless different variants and tailor specific portions of the truck to the needs of the customer [88]. As trucks are multi-disciplinary architectural systems that require cooperation between a number of different functions, difficulties in coordinating deliveries naturally erupt as a result. Furthermore, as previously established, due to the complexity of modular systems, managing products that feature modularization requires an implementation of a sufficient change order management system. Therefore, identification of issues in Scania's change order system provides value to the company as it makes up the core competitive advantage of the firm. More specifically, challenges related to ECOs and how key ECO deliverables are coordinated make up the focal point of this study as they outline the essence of the architectural ecosystem.

1.1 Purpose

Although a handful of papers have focused on deriving a method for managing design ECOs, there have been few that have explicitly correlated the ECO process with modularization and platform development. Despite some studies implicitly implying that their case studies employ a modular product architecture, they rarely analyze the linkage between the adopted modularization system and ECO coordination challenges. In fact, some analyses of causes for long lead time of ECOs have suggested mitigations but little research has been done on studying change order challenges pertaining to ECO-related coordination in multi-disciplinary modularization firms. Moreover, there is a recognized knowledge gap in literature about practical implementations of ECM and subsequent issues. This gap has been highlighted in a multitude of studies which have called for more empirical attention to practical challenges.

Thus, the purpose of this study is to further enrich the knowledge about practical implementations of ECO practices as well as identify the empirical challenges in modularization-based firms. A framework detailing how to mitigate the identified issues will also be presented and tailored to Scania's ECM implementation since the objective is to aid Scania in identifying their most central ECO-related challenges.

Therefore, this thesis aims to answer the following questions:

- How are ECOs and ECMs implemented in modularization firms?
- What are the major ECO-related challenges that modularization-based firms face in their ECM implementations? What are the underlying reasons?
- What can be done to address those challenges?

1.2 Delimitations

The research was primarily anchored in the R5A department with the objective to devise solutions to be utilized by the groups within R5A. The R5A branch, which is part of R&D, is responsible for product coordination, geometric assurance, weight calculation and bodybuilder drawings. R5A branch consists of product coordinators who are responsible for maintaining the modular architecture of scania. Furthermore, the investigation was limited to hardware-based ECOs and further set to focus on their conception until their structural implementation. Hence, analysis of the ECOs' use and potential challenges after publishing and use by, for instance, production and other late-stage functions was not fully done. In addition, only the ECOs connected to industrialization projects were considered (green arrow), omitting projects and linked ECOs focusing on cost optimization from the thesis' scope.

2. Method

In this section, the applied research method is presented as well as the chosen methodologies for data collection and analysis. Lastly, the chosen methods are discussed and evaluated. The chosen research design followed a sequential process as illustrated in figure 1.

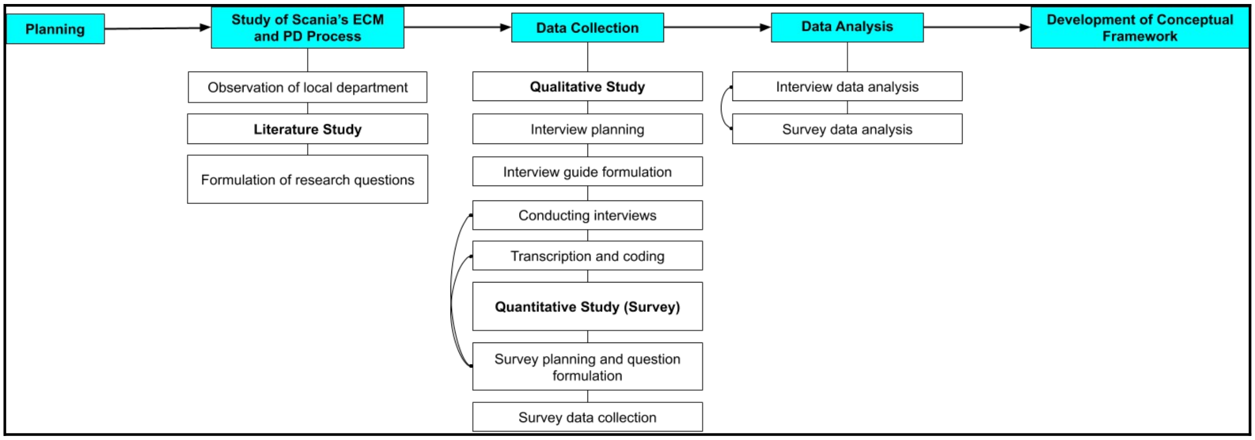


Figure 1. Simplified overview of applied research process that shows the literature study, data collection, analysis and framework development.

Initially, the Scania-specific tools and processes such as their ECM and R&D product development process were dissected and analyzed, which included initial observation of R5A groups. Concurrently, a literature study was conducted to both establish the literary gap and identify existing findings of the chosen topic which culminated in the formulation of the three research questions (as shown in 1.1 Purpose). The data collection consisted of conducting interviews and surveys (not counting the study of Scania's tools and processes) which were then analyzed. Finally, after synthesizing the data, a set of solutions were made to tackle the found problems.

2.1 Study of Scania's ECM and Product Development Process

Initially, unstructured interviews and educational observations were carried out in the beginning when interacting with various team members to learn about the company's ECO process and each individual's daily routines such as their interactions with other functions. Observations, considered a source of qualitative data, serve as additional sources of insights aside from verbal communication since they allow for studying of actual practices as opposed to the perception-based personal views relayed in verbal interaction [70]. Firstly, compared to the semi-structured interviews, the observations were primarily conducted to help familiarize with the applied routines of select roles and thus mostly used for educational rather than analytical purposes. Secondly, the insights recorded in the observations aided in understanding the differences between R5A groups and were instrumental in shaping the interview plan. Table 1 shows the departments that were observed prior to the commencement of the interviews.

Table 1. Overview of the roles and their respective groups that were observed prior to the in-depth interviews

Role	Department Group Acronym
Weight calculation truck	R5A1
Weight calculation bus	R5A1
Chassis drawings truck	R5A1
Chassis drawings bus	R5A1
Product coordination	R5A1
Product coordination	R5A3
Geometric assurance	R5A5
Geometric assurance	R5A5
Product coordination	R5A2
Product coordination	R5A2
Product coordination, electrics	R5A4
Product coordination, cab	R5A4

Access was also granted to the company's document repository and internal social network which made it possible to analyze spreadsheets, presentations, standards, departments and similar data. These analyses made up the preparatory work that was heavily done in the front-end of the investigation. For instance, documents about modular principles, strategies and architectural roadmaps aided in analyzing the products' modularity and the synergies with the company's ECO implementation. Furthermore, issued standards of various activities were thoroughly analyzed as a way of getting acquainted with the expected routines for a specific functional task.

In addition to internal documents and standards, the company-specific ECM, OAS (Object and Structure Tool), was studied. An entire week was dedicated to familiarize with the OAS format in order to build an understanding of the modular structure and adjacent sources of information. By doing so, comprehension of the department's tasks was made easier since they could be related to the shown examples and discussed issues. The week-long study consisted of taking digital OAS courses and question papers that were intended for employee training. Furthermore, the company's employed R&D process was also analyzed and broken down. An in-house digital course and a scheduled seminar presentation with one of the R&D process developers helped offer valuable insights about the process model's theoretical aim and function.

In addition to access to repositories and tools, permission was given to visit different inter- and intra-department meetings. The three meetings which were observed were the Scania pulse meeting (inter-department), R5 pulse meeting (intra-department) and local group technical meeting (inter- and intra-department). Through the local group meeting, observations were made regarding the groups' weekly activities and responsibilities, discussion of topics which were problematic to the team and spreading general information that the manager receives from members from higher up in the organization. The R5 pulse meeting was exclusive to all R5A teams. Through this meeting, observations of activities such as status updates from each manager regarding project status, delivery time, resource requirements etc. were relayed for the R5 manager to bring up at the Scania pulse meeting.

2.2 Literature Study

A literature study was conducted to establish a theoretical frame of reference and served as a background chapter. The study included elements from literature about management of modular systems, organizational structures and processes as well as ECO and ECM systems. Moreover, existing empirical results and literature reviews (research papers) were used for contrasting the case findings but also served as sources of inspiration when devising solutions. Keywords included (but were not limited to) engineering changes, change order management, modularization, system engineering, organizational structures and product platforms.

2.3 Data Collection

The conducted study was in the form of an empirical investigation and was built on the foundation of acquiring data and comparing it with existing knowledge, in this case existing literature. Per definition, empirical methods are based on the systematic acquisition and evaluation of data and are thus applicable in quantitative and qualitative research [66]. Moreover, using a combination of quantitative and qualitative methods results in a more robust study if both methods are properly applied and there is a clearly defined purpose [67] [68] [69]. Hence, the conducted empirical study was based on both semi-structured interviews and a supplemental survey. Worth adding is that observations and more casual dialogs were used in the initial phases of the study as a way to get acquainted with the case environment and applied routines.

2.3.1 Qualitative Data - Semi-Structured Interviews

Semi-structured interviews were used as the primary data collection source, allowing for in-depth investigation of individually encountered problems and process-induced symptoms. The adopted approach was modeled after the synergically common elements in the processes proposed by Bryman, Adams and Boyce and Neale [71] [72] [73]. Slight adjustments were made to tailor the process to the circumstances and conditions of the company, such as interview time and extent of follow-up interviews. As such, the interviews followed a 5-step plan according to table 2 below.

Table 2. Implemented qualitative model based on Bryman, Adams and Boyce and Neale [71] [72] [73]

Step	Description
Interview planning	Scheduling interviews by contacting interviewees, finding available time slots and booking rooms. In addition, creating an interview guide after defining the desired outcome of the interview.
Data collection (interviewing)	Conducting the interview with the chosen interviewee and recording it. Also, updating the interview guide based on the feedback and insights from the interview.
Transcription and coding	Transcribing the recording of the interview as well as thematically categorizing key findings.
Data analysis	Analyze codings and transcripts of all interviews and identify synergies, patterns, misalignments etc.
Verification	Follow-up interviews with select interviewees to assure accuracy of information.

Furthermore, the interviews were conducted with the help of a prepared interview guide that was constructed using input data from initial observations, process research and literature study. As discussed by Mathers et al., making the interview feel like a conversation is key to establishing a comfortable interview mood which often results in the interviewee becoming less reluctant to delve into specifics. Paired with that, assuring that proper research is done before conducting the interview is equally as important to ensure that there exists no knowledge barrier that might deter interviewees from going into specifics [74]. As such, an adaptive approach was adopted where the topics of discussion would be adapted to the responses given by the interviewees. Hence, utilization of probes as prescribed by Boyce and Neale played a major role in identifying problems [73]. Also, the interview guide was revised after every interview and adjusted accordingly to ensure that interviews would center around relevant topics and questions originating from newly acquired insights [76] [77].

Relevant respondents (based on observations and study of ECM) were contacted ahead of time and the interview time was set to 60 minutes. Moreover, the conducted interviews were, with the permission of the interviewee, recorded and subsequently transcribed. In order to assure the highest level of accuracy in preparation for the data analysis, the transcriptions were done manually. Complementary notes were taken during the interview in order to aid in the post-processing and data analysis. For instance, statements of note or major insights were highlighted by noting them during the interview (recording) for quick reference, being useful during interview guide refinement which occurred immediately after each interview. Other visual elements such as explanation of conceptual frameworks were captured by letting the respondent sketch it on paper or physically demonstrate it on a monitor. In those cases, the visual elements were either photographed or collected and appended to the digital transcriptions. A total of 24 semi-structured interviews were conducted.

The interviewees were selected on the basis of their role, experience and knowledge level. The aim was to include at least one person from each product coordination group and roles from adjacent functions outside of R5A. In some cases, appropriate interviewees were provided by managers who made the evaluation based on the topic information provided by us. Table 3 below shows the selected interviewees including their department, role and number of follow-up interviews.

Table 3. Summary of department groups and roles that were interviewed

Department Group Acronym	Role	Interview Time and Channel	Follow-Up
R5A1	Weight calculation trucks	In-person interview	
R5A1	Weight calculation bus	In-person interview	
R5A1	Chassis drawings (ICD)	In-person interview	
R5A1	Product coordination	In-person interview	
R5A1	Process developer/Product coordinator	In-person interview	
R5A1	Group manager	In-person interview	
R5A2	Product coordination	In-person interview	Yes
R5A2	Product coordination	In-person interview	
R5A2	Group manager	Voice call interview	
R5A4	Product coordination	In-person interview	
R5A4	Product coordination	In-person interview	
R5A5	Geometric assurance	In-person interview	
R5A5	Group manager	In-person interview	
R5A3	Product coordination	In-person interview	

R1DB	Object leader	In-person interview	
R3D2	Design engineer/Object leader	Voice call interview	
R3D2	Design engineer	In-person interview	
R3D1	Design engineer/Object leader	In-person interview	
R3D1	Group manager	Voice call interview	
R3A1	Object leader	In-person interview	
R4D1	Object leader	In-person interview	
P02	Project management	In-person interview	Yes
P01	Project management/ COIN coordination	In-person interview	
T01	Test vehicle coordination	In-person interview	

2.3.2 Quantitative Study - Survey

In addition to qualitative studies in the form of semi-structured interviews, a complementary cross-sectional survey of a correlational character was also distributed to capture quantitative data on a bigger scale [80]. Compared to interviews, surveys yield quantifiable data that can be used to statistically generalize a studied population [74]. The aim was to use the survey as a means to both verify and compare data to the qualitatively recorded insights from the conducted semi-structured interviews. Also, the purpose was to cover a larger scale of respondents to capture insights from departments outside of the interview sample. The chosen survey platform was Google forms and the questionnaire was distributed to all departments with DE and object leader roles in order to increase the generalizability of the answers [69].

As the focus was on the ECO value chain, the survey was mainly aimed at design engineers (including object leaders) and product coordinators. Thus, the survey consisted of two “tracks” and, depending on the role of the respondent, would redirect the respondent to either the designer or product coordinator tracks respectively as each track consisted of a number of sections with questions tailored to each respective function. This setup was preferred over separating the questionnaires since it simplified the distribution and allowed for easier processing of the data as the results were compiled in one file. The survey was estimated to take 5 minutes to complete to ensure retention of interest and engagement [80].

Random and non-random sampling are the most common sampling types which describe the preferences one has for respondents. For specific market studies, for instance, it may be important to specify age range ranges and habits among other characteristics as the objective might be to investigate a certain customer archetype [74]. In this case, theoretical access to all the desired respondents was granted but the actual reflection of the entire population relied on the response rate. Hence, the survey contained a field for entering the department acronym, which was used for both comparative purposes and to check the response rate per department group.

The measures used in the survey were 5-step Likert scales, multiple choice questions, open answers and rank-based grading of predefined alternatives. The open answers factored into the analysis of the qualitative results due to the similarities between both data forms. Table 4 below summarizes the type of measures used in each respective questionnaire.

Table 4. Overview of measures and number of questions per questionnaire

Survey target group	**Total number of questions** Graph-based questions (total)	**Measures**
Design engineers/object leaders	11 **(18)**	5-step Likert scales Open answers Ranking of choices Multi-choice questions
R5A (product coordination/geometric assurance/ICD/weight calculation)	25 **(34)**	5-step Likert scales Open answers Ranking of choices Multi-choice questions

Tables 5 and 6 below list the departments that participated in the survey along with the supporting data such as number of respondents and response rates. Also, figure 2 shows the distribution of roles in the DE questionnaire.

Table 5. Participating design engineer departments (survey) and the number of responses per group (out of a total of 173 responses)

<table>
<tr><th></th><th>2-letter acronym</th><th>3-letter acronym</th><th>Total responses</th><th>Total responses in %</th></tr>
<tr><td rowspan="4">Design engineers and others</td><td rowspan="4">N1</td><td>N1A</td><td>2</td><td rowspan="4">6.35%</td></tr>
<tr><td>N1B</td><td>4</td></tr>
<tr><td>N1C</td><td>4</td></tr>
<tr><td>N1D</td><td>1</td></tr>
</table>

	R1	R1A	13	16.76%
		R1B	1	
		R1C	8	
		R1D	7	
	R2	R2A	11	30.05%
		R2B	24	
		R2C	2	
		R2D	2	
		R2E	6	
		R2F	6	
		R2G	1	
	R3	R3A	12	23.12%
		R3B	5	
		R3C	8	
		R3D	13	
		R3E	2	
	R4	R4A	1	14.45%
		R4B	6	
		R4C	3	
		R4D	8	
		R4E	7	
	R5	R5B	16	9.24%
Product coordinators and geometric assurance	R5A	R5A1	8	See table 6 below.
		R5A2	11	
		R5A3	8	
		R5A4	5	
		R5A5	6	

Table 6. Participating R5A groups (survey) and the number of responses per group (out of a total of 38 responses)

Product Coordinators and Geometric Assurance (R5A)			
Group	**Total number of people**	**Number of responses**	**% of responses w.r.t individual groups**
R5A1	17	8	47%
R5A2	16	11	69%
R5A3	13	8	62%
R5A4	17	5	29%
R5A5	11	6	54%

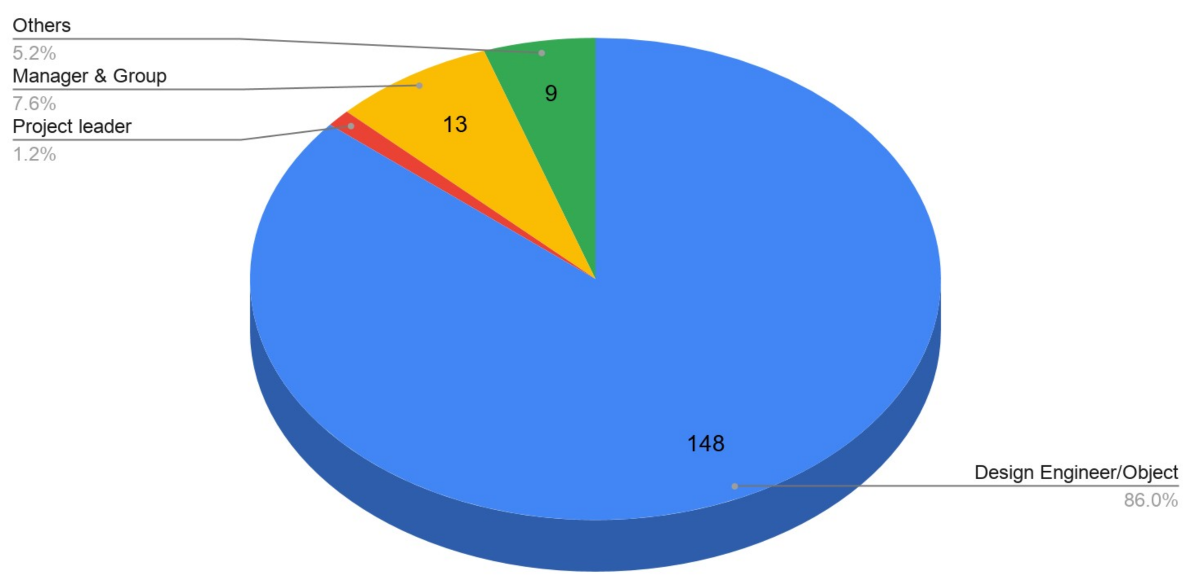


Figure 2. Pie chart of DE and OL survey responses that shows the specified roles of the respondents.

2.4 Data Analysis

As shown in table 2, the interviews were transcribed as a preparation for a string of post-processing activities. According to Bryman, a thematic analysis entails categorizing codes into separable themes which simplifies the overview of the data by compiling it in one common framework. Modeled after Bryman's approach, the first step of the analysis was coding each interview separately by writing and inserting summarized interpretations of topic-relevant statements [71]. The preparatory work for the thematic analysis was done by visually tagging the codes using preliminary themes. Statements of note were also highlighted for future reference. Once every interview had been coded, the written summaries were compiled in a common environment and comparatively analyzed.

Though, as remarked by Bryman and Adams, coding should preferably be done in iterative phases [71] [72]. For this reason, the focus of the initial step was to code as many statements as possible to reduce the risk of neglecting information that may be correlatively important. Then, with every iteration, the codes were convergingly summarized into more encompassing gists. In that analysis, the focus was to identify similarities and dissimilarities across all coded interviews. Based on the identified differences and deviations, the findings were evaluated and grouped into adequate themes that were refined over the preliminary ones set earlier. Once thematically organized, a full assessment was done to analytically determine synergies, patterns and symptoms that were then compared to relevant literature.
The findings from the 24 interviews were thematically categorized into separable challenges, summarized in figure 3 below.

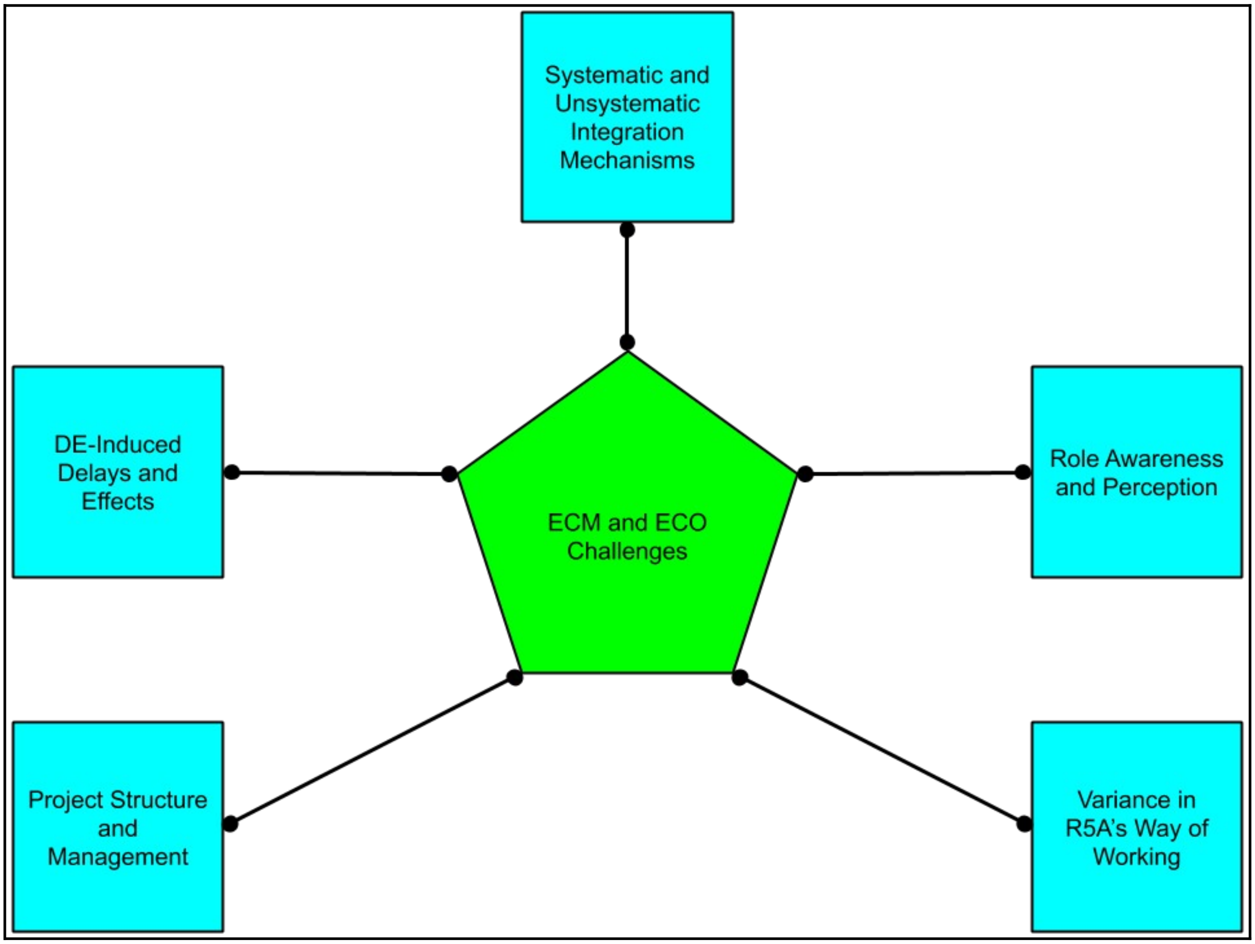


Figure 3. Overview of the themes identified in the interviews.

2.5 Development of Conceptual Framework

The proposed solutions were primarily based on the collected data, more specifically the synthesized results. In addition, the experiences from being at meetings, conversations and observations of functions also played a part in the concept development. The goal was to propose constructive solutions that were based on existing tools but also new solutions in the form of dissimilar methodical concepts. Thus a 3-tier framework structure was adopted with different visions and focus areas according to table 7 below.

Table 7. Overview of the 3 tier levels of the proposed conceptual framework

Tier	Focus Area	Vision
1	ECO information and role awareness	Short-term
2	ECO coordination and analytics. Minor group-based process changes.	Short- and long-term
3	PMI and major group-based process changes.	Long-term

2.6 Method Discussion

Empirical research efforts in general are noted as being time-consuming but are attractive due to the amount of in-depth information that can be extracted from single individuals [75] [73]. Since every product coordinator was assigned a domain, utilizing qualitative methods enabled the identification of the unique aspects of the selected individuals' subsystems, something considered by Agee to be a focal point of semi-structured interviews [76]. This made it possible to attribute certain challenges to vehicle domains and explore the dynamics between designers and product coordinators. Also, as stated earlier, the interview guide aided in providing a structure for the interview but in practice, the interviews emulated the format of a regular conversation and were adaptive to the interviewee's answer. The benefits summarized by Mathers et al. were fully realized by forgoing the need to physically type down the answers hence devoting full attention to the interview, enabling adequate usage of probes as detailed by Boyce and Neale [73] [74].

By doing so, a few risks had to be managed which included getting relevant data out of the interviews. This was mitigated by falling back to the interview guide to ensure that the conversation could be steered back to issues of interest and avoid extensive off-topic discussions. Relatedly, the interview guide was continuously adjusted after every interview and the questions were reassessed based on the responses from the interviewees. The changes were a result of either the interviewees revealing a topic that was previously unaccounted for in the guide or because certain questions were insufficiently formulated. Hence, the active revisions helped streamline the interview guide to cover more practically relevant topics within the allotted interview time. As insisted by Adams, the repeated evaluation and alteration of the interview guide questions generally increased the quality of the interview as a whole allowing for more valuable content to be extracted [72]. Also, due to the adaptive nature of the interview approach, interviews that preceded the identification of a new interview guide addition (questions or topics) weren not followed up with the new insights. Hence, surveys were utilized as cumulative validation mechanisms to verify issues that were gradually uncovered during the interview stage.

The choice of two primary data sources helped validate the research model and complement each respective approach. Combining both qualitative and quantitative methods aids in capturing intricate details from individual perspectives as well as generalizationable opinions from a wider audience. Essentially, mixing of the two methods can most simply be done in one of two ways - for use as a way of either confirming or to complement the findings of the other study. The latter implies using both studies to reap the benefits of qualitative and quantitative studies since, as mentioned previously, both studies have their strengths and weaknesses [68]. More specifically, by combining the use of both methods, the aim is to maximize meticulousness made possible by interviews and simultaneously expand the scope, breadth and scale to increase generalizability [67].

However, as discussed by both Östlund et al. and Kaplan, simply using two study types may not result in the achievement of their combined benefits if the purpose is not clearly defined [67] [68]. This risk was managed by identifying the research need at an early stage after detecting limitations of exclusively using qualitative methods. In this case, the sheer amount of design departments and groups which roughly outnumber product coordinator groups by a factor of 10, made it impossible to explore every design domain via semi-structured interviews within the time frame of the project. Moreover, general time limitations acted as a barrier for interviewing all members of R5A since post-processing of the interviews would take a considerable amount of time to complete. These encountered issues associated with solely utilizing interviews as a data collection source align with the limitations discussed by Gagnon, Adams among others [77] [75] [73], who unanimously view the time factor to be a major detriment. Thus, the conducted survey was constructed to bridge those gaps.

However, generalizability, which is an actively debated topic, is considered to be a weakness with quantitative methods. Validity of results may be questionable if the chosen sample is not adequately selected and its representation of the population is inaccurate [69]. Although over-generalization is a definite issue in some applications, Lewin and Somekh argue for the strengths of quantifiable data and deem that the benefits are fully realized when proper attention is paid to the context of the studies [78]. The emphasis on context is also highlighted by both Kaplan and Östlund et al. who deem that combination of qualitative and quantitative methods yield, in best-case scenarios, broader data coverage via triangulation [67] [68]. Since the chosen survey sample was theoretically representative of the entire studied population, the results' potential generalizability can be considered high.

It should be mentioned that although the total number of employees per department (2-letter acronym) was given, the number of ECO-related stakeholders (primarily design engineers and object leaders) within each department was not fully known. Accurate reference values for qualified roles could therefore not be estimated due to the nature of the internal social network which did not explicitly list the number of different roles for each department. Also, despite being referred to as "design engineer departments", not all members of the inquired departments were design engineers nor were actively working with ECOs, making it more difficult to obtain reference values for the total number of valid respondents per group. Nonetheless, in this instance, the diversity of answers from a wide range of different design departments shows that most design engineer groups that are considered stakeholders to R5A are represented in the data.

As there is no clear-cut measure for assuring validity based on survey response rate, Morton et al. conclude that transparency is to be regarded over calculated response rate numbers [79]. With that in mind, survey-based conclusions are to be related to the contextual factors. In this particular study, the initial insights were recorded in the interviews and subsequently derived and used in a survey to reach a bigger group, the target population, for generalization purposes. In this regard, the interview data, which the survey was based on, was used to affirm or denounce the results from the survey. As discussed by Kaplan and Östlund et al., the combination of both studies functioned as a way to verify and validate findings [67] [68]. Paired with that, select follow-up interviews helped assure the accuracy of the acquired information. However, the survey results acted as the primary verification mechanism utilized to validate the findings in the interviews.

2.6.1 Discussion of Quantitative Results

Due to a relatively low response rate, evident by percentages in table 5, it is difficult to draw general conclusions with great certainty about all design engineer groups. However, aspects highlighted in both the quantitative and qualitative data denote the synergy and validity of some of the identified themes via triangulation, as implied by Kaplan and Östlund et al [67] [68]. Whilst a higher response rate would further validate the findings, it should be noted that the prevalence of these themes in both studies indicates that they are verifiably present.

The inclusion of a "no opinion" option in addition to the neutral "neither agree nor disagree" may have skewed some of the results in the DE survey. Initially intended as an option for roles that were not qualified to answer specific questions, the alternative "no opinion" may have been used to indicate either neutrality or abstention, with the former clashing with the already existing option of "neither agree nor disagree". Certain charts such as statements 7, 8 and 9 clearly show an influx of "no opinion" responses which imply that the option was not consistently utilized throughout the survey. Relatedly, interpretation of charts with an abundance of "no opinion" answers was made difficult due to said reasons. Hence, future surveys should either completely omit the item from the list of answers or replace it with a more unambiguous alternative that clearly reflects the nature of the response.

By comparison, the treatment of neutral responses was mainly situational, primarily considering it a sign of uncertainty, especially when contextualized and compared with a significant amount of negative responses. However, neutral responses to statements that were based on current practices such as question L, "*Object leaders and design engineers actively want to involve me in their work by inviting me to their meetings"*, were mainly interpreted as an indication of a mild objection, suggesting that, in this case, they were mostly not being actively involved in the object and design meetings.

Moreover, certain statements could have been interpreted in different ways. In particular, statement G ("*If I feel overloaded with work, I can rely on colleagues for assistance*") could have been interpreted as either referring to local colleagues within the same group or outside the group boundaries. Because of the informal retention of the team divisions that previously made up the R3X1 group before being split into R5A1 and R5A2, the term “colleagues” might have insinuated any collaborational peer, regardless of group belonging. The same thing can be said about the 3 subgroups of R5A4, especially the cab subgroup which only recently merged with R5A4 (post Sep-2019). Nevertheless, the intention was to gauge the collaboration within individual groups as opposed to cross-group collaborations, which may not have been received as such by the respondents. Therefore, future studies should conduct small-scale testing before publishing the survey to ensure that the provided statements are as unambiguous as possible.

Worth highlighting is that all participating respondents were referred to as DEs although a sizable amount indicated non-DE roles in the survey. Whilst object leaders and DEs were considered as one unit because of the close association and role-based relationship, responses from department and group managers with little-to-no hands-on experience with ECOs was unavoidable due to the way the survey was distributed.

3. Literature Study
The following chapter relays the theoretical frame of reference, covering the topics of modularization, organizational structures and ECOs and ECM. Primarily, empirical findings on these topics are dissected and presented where the relationship between these themes is also established.

3.1 Modularization
Modularization principles are widely used in a range of different industries to achieve product variety but are also considered the core of Scania's competitive advantage. Many different methods exist for implementation and, correspondingly, a handful of challenges that have to be managed to ensure a successful adaptation. The sections below cover the basics and implementations of modularization as well as the empirically investigated challenges.

3.1.1 Modularization and Product Platforms
Principally, product modularization is based on the theorem that a large variety of products can be produced by combining a large number of segmented modules [1]. According to Baldwin and Clark, modularization has three purposes, to make complexity manageable, to enable parallel work and to accommodate future uncertainty [2]. The concept of "modular design" is to break down complex systems into manageable modules where each module has a number of module variants that are used to give the product distinguishable features with varying properties [3]. Thus, modules can be considered building blocks in a structural product system. Another dimension is the interdependence aspect which also introduces a hierarchy in the modular architecture, making certain modules spatially and geometrically dependent on each other. However, modules can only be interchanged if they have compatible interfaces and interactions. Interfaces are the boundaries of the modules connected to each other whilst interactions describe the input and output between the modules [1]. Figure 3 below visualizes the relationship between module variants and interfaces. Naturally, this results in a complex interface-dependent system, a challenge which requires the employment of modular design methods from the ground up - of which there are plenty that have been prescribed [84] [4] [5]. Interestingly, general concepts of modular principles are not exclusive to technology and organizations as they are also prevalent in completely dissimilar industries. Psychology, biology and American studies are examples of such applications. The common elements shared across all implementations, however, are the hierarchically nested dependencies and the segmentability aspect [6].

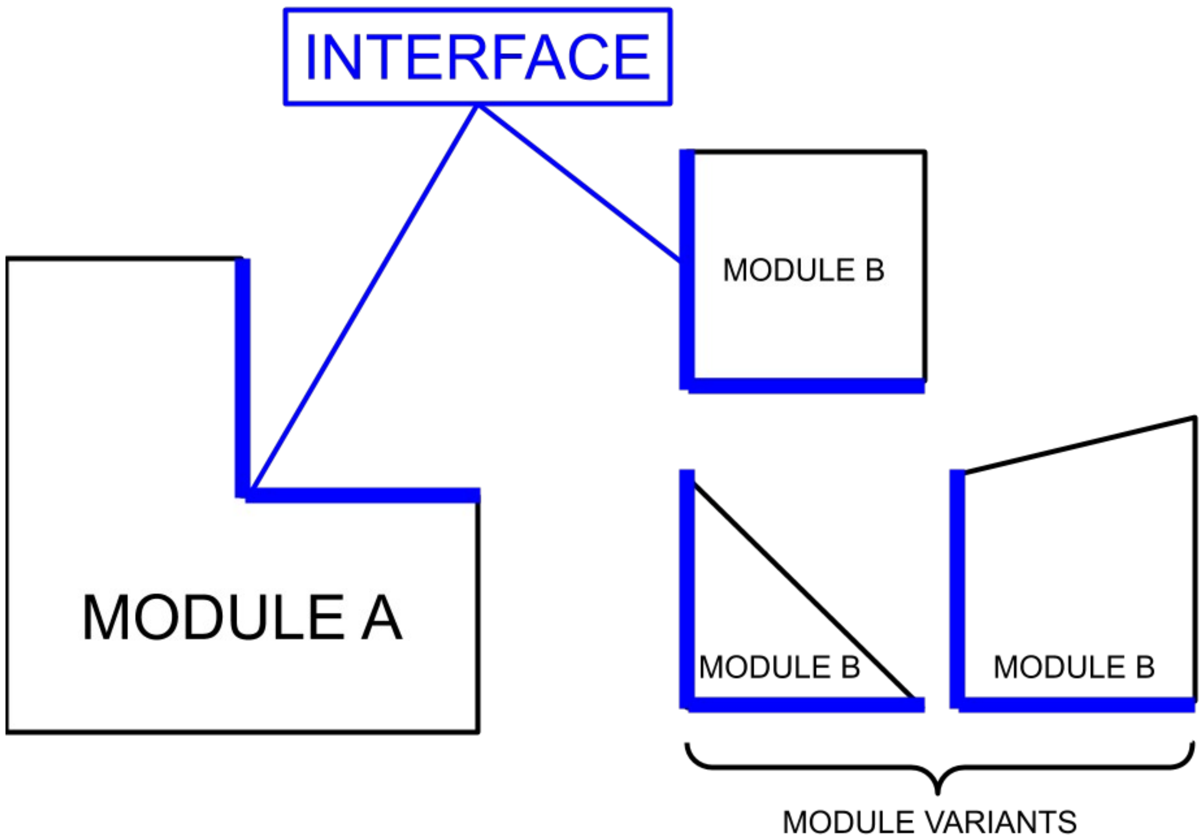


Figure 4. Simplified overview of relationship between modules, module variants and interfaces. In this example, module A and B share a common interface highlighted in blue. Module B has three distinguishable variants.

3.1.2 Benefits of Modularization and Product Platforms

In practice, modularization principles outline the core concept of a modular product architecture. Product platforms are applications of modular principles that function as core structures of a modular system. According to Robertson and Ulrich, product platforms serve as commonality structures that enable components to be reused across an established product family and thus results in a reduction of unique parts. Also, by having a common product platform, testing of common parts is eliminated which cuts down development time. This is especially apparent in automotive and personal computer applications where platforms are extensively used to commonalize a range of product variants [7]. The first main benefit of modularization is the ability to achieve economies of scale by commonalizing a large part of the product architecture. Consequently, the financial benefits are gained in the form of lower production costs due to a decreased need for additional warehousing, manufacturing and assembly [8].

The second benefit is the product differentiation potential that can be realized via generation of diversified module variants tailored to different customer profiles. This aspect is attributed to the module flexibility which is made possible via the interchangeability characteristic of a modular product architecture [9]. Therefore, in contrast to the external value disciplines of Michael and Wiersema which strictly categorize firms based on three main value strategies, modularization may enable the adoption of multiple strategies on a module level [12]. Using modules as strategic enablers have been widely covered by multiple studies that assert the correlation between multiple value disciplines and module-specific strategy formulation [13] [14] [15].

A common approach to modular design is the application of matrix-based methods that function as management tools for interface dependencies and interactions among modules [16]. Module segmentation, which is an essential part of modular product design, can be done in a variety of ways. The most common methods are based on the use of DSM (design structure matrix) by Pimmler and Eppinger and MFD (modular function deployment) by Ericsson and Erixon [17] [18]. More recently, methods have been introduced that are partially based on the fundamentals of DSM and MFD, but with new angles [3]. Examples include holistic and heuristic approaches that are founded on general-level breakdown and trial-and-error respectively [19] [9].

3.1.3 Challenges of Modularization and Product Platforms

Despite the well-recorded architectural challenges, modular products are still widely implemented in different industries as the benefits have been shown to outweigh the detriments [20]. Existing literature has pointed to the front-end as a source of challenges and uncertainties, highlighting platform planning which includes market segmentation and product family creation as points of contention [21]. Implementing modularity in product development is challenging for a variety of reasons. However, product management and coordination-related challenges have stood out as the most significant from a project process point of view [11]. In those instances, tensions have been attributed to the structural interdependencies which characterize modular product systems [84] [22].

This is especially noticeable in project environments of multi-disciplinary type where modular systems are split and responsibilities are delegated to dedicated teams [23]. As a result of employing a modular structure, most firms often base their organization on a functional model where each module is dedicated to a specified unit. However, as shown by Tee et al., increased unit specialization is positively correlated with increased integration needs in the form of coordination and communication [11].

Moreover, Harland et al. underline the importance of cross-functional synchronization as a determinant for platform development success, alluding to the need for different functional units to be involved and updated about changes in the modular structure, which is further accentuated by the complexity of the modular dependencies [23]. The emphasis on cross-functional coordination is concurringly highlighted as a cruciality by both Sköld and Ostrosi et al. who conclude that appropriate change management in modular product development requires multi-disciplinary integration [24] [25]. Thus, cross-functional integration can be viewed as a core component for a successful implementation of modularization. In addition to common and well-researched project phenomena such as mid-project changes in customer requirements [26], certain project-related issues have been found to induce uniquely critical challenges in modular product development projects [10]. Due to the hierarchy introduced by module interdependencies, an evolving project may lead to architectural changes and spawn difficulties in maintaining a continuous synergy between modules.

Despite there being plenty of devised product family design management frameworks, the associated intra-level issues have not received as much attention or coverage. In addition, Tee et al. also explicitly state that identification of interdependencies of evolving work would contribute to the demystification of modularization-related coordination issues [11]. Similarly, managerial and organizational implications of modularity is another topic that has been highlighted as a topic worth investigating [86]. However, worth noting is that identifying such interdependence-related issues and developing preventative methods to counteract them is an area that still requires more empirical investigations [11].

3.2. Organizing Principles

Organizations can be structured in a variety of ways to achieve different performance attributes. As there is a synergy between a firm's product development process and organizational structure, which includes cross-functional mechanisms [34] [35], knowledge about archetypal is needed to fully understand how a modular product influences an organization's structures and processes [42]. Daft highlights four major archetypal organizational structures, those being [29]:

- Functional (vertical) structures
- Divisional structures
- Matrix structures
- Horizontal structures

More recently, hybrid structures and derivatives of the aforementioned four have been tested and used in real-life firms [27]. Thus, it is worth noting that practical applications often feature slight modifications of the archetypal models of organizational structures. As concluded by Gareth, the choice of organizational structure is dependent on a range of different external and internal factors. Therefore, there is no universal structure that can facilitate the needs of all organizations but, rather, it is a matter of tailoring the structure to the task at hand and the environment of the firm [28]. Building on this logic, Rishipal argues for five main determinants, those being [30]:

- Size of business
- Nature of business
- Geographical span
- Work flow
- Hierarchy

Nonetheless, each organizational structure has its fair share of strengths and challenges. On the opposite ends of the spectrum, however, are the vertical and horizontal structures respectively. In a strict sense, the two can be considered polar opposites in that they are founded on radically different principles [29]. Vertical organizations feature a strict hierarchy, are well suited for specialized tasks and often have many rules to adhere to, promoting explicit knowledge. Overall, a vertical structure is designed for efficiency, exploitative development and is focused on functional specialization [31].

A horizontal structure, on the other hand, features many teams and so-called "task forces". The organizational map is horizontal with a lax hierarchy and rules. Integration mechanisms are primarily based on face-to-face communication and centered around tacit knowledge. In essence, horizontal organizations are designed for learning and thus structurally compatible with explorative development. As shown by Sicotte and Langley, horizontal integration mechanisms are most effective when project equivocality is high. More specifically, horizontal communication has a positive effect on project performance but has little-to-no effects when both uncertainty and equivocality are low [32].

Most literature use these two major structural archetypes when mapping out other structures to gauge their leniency toward specialization and learning, with vertical organizations being most often associated with hardware-focused companies [29] [30] [33] [31]. Figure 4 below illustrates the mapped out differences between the two most archetypal structures.

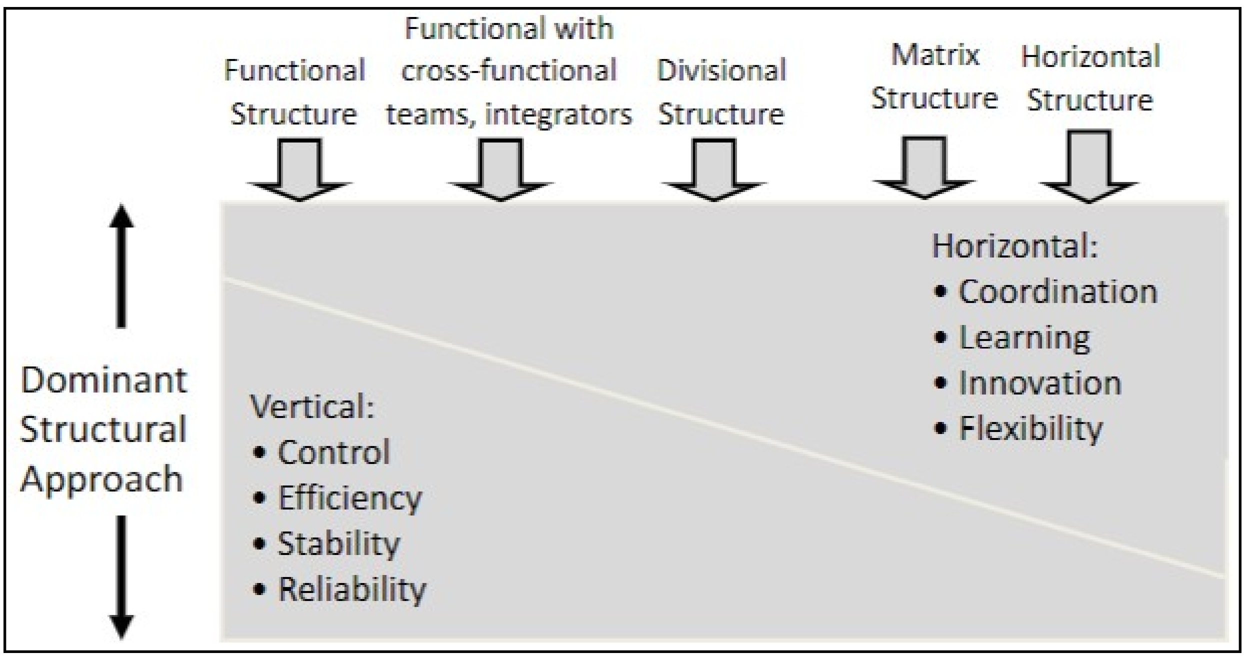


Figure 5. Dissection of the relationship between organizational structure and desired focus area, using vertical and horizontal structures as reference points [29].

Structure-to-process alignment is a topic that has been covered in a range of case studies where it has been shown that the relationship between product development process and organizational structure is contingently synergic [34] [35]. In one example, a division of American semiconductor giant Texas Instruments transitioned from being a vertical organization to fully employing a matrix model. Concurrent with the structural conversion was the employment of a new product development model that sought to reduce the time-to-market lead time. Some of the major results included a tighter structure-to-process alignment that aided in facilitating the new process. Additionally, the lead time was halved and cross-functional involvement and individual commitment were cited as major benefits brought forth by the new process. However, challenges pertaining to the volume of simultaneously ongoing projects were observed as one department in particular found it difficult to engage themselves due to their involvement in multiple projects [36].

Moreover, coordination across specialized departments in vertical organizations is noted as a significant challenge due to the inability to see the perspective of connected functions. In particular, the consequence is in the form of an inability to detect problems and changes that will affect corresponding functional units or other stakeholders [37]. Worth highlighting is that this premise is predicated on the assumption that formal integration mechanisms between functions are absent. Rather, if one is to view it from a strictly vertical perspective, the sufficient information about related departments is to be provided by management [39]. Thus, the responsibility of maintaining and establishing coordination between units rests on the shoulders of the department heads. Furthermore, as a result of the narrow focus of each department, a common understanding about the product that is being worked on is often lacking, which is directly linked to the lack of communication with related departments [37]. Also, the use of sequential engineering-based process flows (traditional engineering) has historically characterized vertically organized firms due to their focus on specialization [38].

This issue is further highlighted by the inherent nature of physically separating units, making coordination harder to establish and often results in more impersonal alternatives. Allen asserts that organizations with a product development focus must adopt a structure that facilitates both cross-functional communication and coordination of complex technical tasks [37]. He further notes that, to do so, it is required that a full understanding of the circumstances of the project in question is possessed. Similarly, Ulrich and many other authors collectively view the organization as the main enabler of coordination and communication between business units and that the structure and management are the key elements required to realize that [28] [29] [30] [32] [40].

Building on that, whilst concurrently viewing coordination as a highly central part of a successful firm, Sosa theorizes that the decomposition of people also plays a major role in determining the success of the company [41]. He further claims that challenges that firms face when organizing their product development can be boiled down to two major elements, those being integration and decomposition. In other words, the tensions stem from how groups of people are organized and how they communicate with each other. Hence, Sosa separates an organization’s formal structure from its informal structure. In that sense, the formal structure refers to the enforced group organization, work boundaries and scope whilst the informal structure makes up the links between individuals that originate from communication ties during development efforts. In essence, organizational structures serve as boundaries for the members of the firm to adhere to.

The aforementioned organizational boundaries may also be a delimiting factor that hinders teams from communicating. This assertion is affirmed by Bai et al. who empirically show that the organizational structure is the main component that influences whether or not cross-functional integration can be implemented [35]. In addition to that, Sosa et al. found that modular interfaces are more difficult to identify across system boundaries , often resulting in unpredicted interactions. The results, in turn, were based on an empirical investigation of group collaborations in a product-architectural design system [42]. By adopting a modular product architecture, the design activities for each respective module can be done in parallel, hence making it possible to assign specialized competence to each module. Though, as part of managing these parallel tasks, it is crucial to maintain sufficient system-level coordination to maintain performance and quality standards [43].

Coordination in organizations working with modular product architectures is unanimously viewed as an imperative prerequisite for implementational success by a multitude of authors [42] [43] [44]. Moreover, Schuh et al. note that for vertical organizations in particular, the need for integration mechanisms is essential to assure cross-functional collaboration across subsystems [44]. Another dimension is highlighted by Olson et al. who demonstrate that an adequate functional coordination mechanism is practically the most important factor for the enabling of cross-functionality. They further note that the better the grasp a firm has over its coordination mechanisms and product concept, the better the project will be on a variety of different performance dimensions [45]. This is especially interesting since the organizational structure is often directly related to the subsystem division of the product architecture [46].

Ideally, firms strive to achieve high differentiation and high integration, which in turn ultimately results in optimal firm performance [47]. This conceptually ideal ambition is unlikely to be fully realized unless the tensions resulting from the two initiatives are appropriately managed. Although the need for specialists with defined focus areas is further accentuated in an organization producing a complex product, making sure that those functions are integrated with the units of the overall system of which there is a codependence is equally as important [47].

3.3 ECOs and ECM

ECOs (Engineering Change Order) are documents that describe a product property change in a system or complex product. They are used for traceability in complex product systems that have a defined structure and require maintenance of a catalog of items. ECOs are commonly used when introducing new elements in the structure but may also be used to update or edit structural components [48]. Examples of real-life domains include automobiles, electronics and microprocessors, just to name a few [49].

Issues related to the implementation of ECOs such as long lead times, communication problems and unclear roles have been discussed in case study-based literature [50] [51]. Jokinen et al. highlight issues regarding the prioritization of ECOs and find underlying reasons for delayed ECO processing. More specifically, they found that 41% of ECOs at the case company were either lagging or had not been followed up and that they accounted for the most serious project delays. Furthermore, tacit knowledge is presented as a point of concern in the case of lagging ECOs since human factors may affect how well the person in question remembers the specific issue when it has been stuck in a loop for an extended period of time. Adding complementary material in the form of visual attachments (3D model, image or similar) was shown to reduce lead time by functioning as a clarification aid [52]. Similarly, Terwiesch, summarizes 5 main sources of ECO delays, which he breaks down and accredits to:

- **Complex ECO approval process** - multiple steps and organizational units involved in the ECO approval process
- **Capacity and congestion** - time allocation dilemma being faced with two major activities: ECO backlog and daily workload
- **Batching** - solving and addressing multiple ECOs at a time
- **Snowballing** - ECOs leading to changes in other interfacing subsystems
- **Organizational issues** - problems and incompatibilities in the corporate and managerial structure

The above challenges were derived from a case study at a department in an automotive company, thus insinuating that the ECOs were used to manage a modular product system. Much like Jokinen et al, some of the issues presented by Terwiesch are caused by lagging ECOs and interface or interdependence problems [51]. Noteworthy is the batching issue, which refers to addressing an excessive amount of already delayed ECOs. Contrastingly, however, Bhuyan et al. show that batching ECOs leads to a significant reduction in overall processing time but also note that it is to be done by incorporating defined batching logics by, for instance, working on ECOs that share structural relations [53]. Thus, excessive and unplanned batching can be viewed as a source of delays whilst structural batching can be considered as a remedy to avoid delays.

In addition, ECO rework, which entails reprocessing an already submitted change order, has been noted as another source of delays that directly affects overall ECO lead time [54]. Related is also how early ECOs affect project time and resources which, evident by Becerril et al., is a negative correlation. Preventative propositions include closer integration between units in the early phases in order to eliminate late changes of unnecessary character, which often occur due to miscommunication or lack of cross-functional knowledge [55].

Challenges stemming from the early phases of NPD (new product development) have been shown to affect ECO work. Those tensions are positively correlated with a range of common front-end issues that, as shown by Becerril et al., yield problems mostly due to incomplete and dynamic product information. More precisely, the challenges highlighted by Becerril are summarized as [55]:

- **No complete product model** - Projects in early stage developments mostly start with no or little knowledge about the product to be implemented. Therefore, only a basic product model exists at the beginning. Consequently, it is important that the underlying product model is easy to extend during the project.
- **High amount of changes** - The uncertain environment of early stage development results in many changes.
- **Changes often arise from stakeholders** - To steer the product development in the right direction, stakeholders are closely integrated in the development process.

- **Customers with no technical background** - A suitable method needs to deliver easy understandable output and serve as a communication platform

Delays have also been found to originate from designers' insufficient awareness of module interactions and state of development, consequentially leading to unoptimized design changes. This can also be linked to the dynamic state of the product in development which, in turn, generates uncertainties. Solutions to combat those issues have been proposed in the form of impact analysis frameworks that are made to visually map out change propagations and thus keep the designer informed about cross-interface impacts [56]. In addition, usage of MBD (Model-Based Definition) tools has been shown to cut ECO lead time by up to 11% compared to exclusively using 2D drawings when communicating changes. The method, postulated by Quintana et al., specifies the integration of PMI (Product and Manufacturing Information) in 3D models [57]. The application of PMI integrated in 3D models is a growing standard since most of the ECO implementations are based on communicating the changes by visualising them in 2D drawings [58].

Furthermore, the modularization element is mostly unnamed or implicit in most literature about ECOs and ECM implementations [59] [60]. Despite the close linkage between modularization of complex systems and the systematic usage of ECOs, few articles have focused on the empirical challenges related to the ECO implementation in modularization firms. This correlation is vital due to the modularity-induced interdependencies and strong association between modularization and product complexity [61], which theoretically benefits from the employment of an ECO system [62]. Rather, most papers have been fixated on the development of general ECO methodology that is compatible with modular interface management frameworks such as DSM, MFD and similar.

Likewise, studies centered around the development of ECM (Engineering Change Management) methods are far from few, but seldom highlight empirical implementation issues resulting from real-life applications in product development firms [63] [64]. As such, there is an apparent gap between literature-prescribed methodology and practical applications. This is further accentuated by the recognized difficulty in implementing company-adoptable ECM methods since intricate details in the organizational practices, processes and routines often act as barriers. In other words, ECM implementations differ from company to company and have to be localized and tuned to be compatible with firm-specific processes and routines [54]. Pikosz and Malmqvist view it as a tradeoff since tailoring an already constructed ECM framework results in customization costs in the form of time and training required to adapt it to company practices and values. On the other hand, directly adopting an ECM process may lead to increased efficiency but most likely results in challenges in the implementation process [65].

4. Scania Background

This section is dedicated to explaining Scania's modularization system, R&D product development process and project management. This chapter serves as a background chapter to the detailing of the company-specific ECM implementation in chapter *5.1 ECM Implementation and Cross-Functional Collaboration in Modularization-Based Firms*.

4.1 Scania's Modularization Principles and Modular Product Architecture

Scania trucks are based on a fully modular product architecture known as "bygglådan". This allows them to tailor their products to unique customer preferences, allowing hundreds of possible customer choices. This ground-up approach is favored over a rigid platform-based product model approach which is used by their competitors. Unlike their competition, Scania's extensive customer choices enable the creation of uniquely specified trucks and buses that are not sold under a common model name. Nevertheless, there exist certain segmentation elements in the product configurator (see figure 6 below) such as application (cargo truck, firetruck, etc.) and operation (urban, off-road etc.), though most features of the truck remain customizable despite choice of application and operation. Some of the customer choices include cab type, engine, wheel configuration, axle gears and much more. An abridged illustration of the customer choices can be seen in figure 6 below.

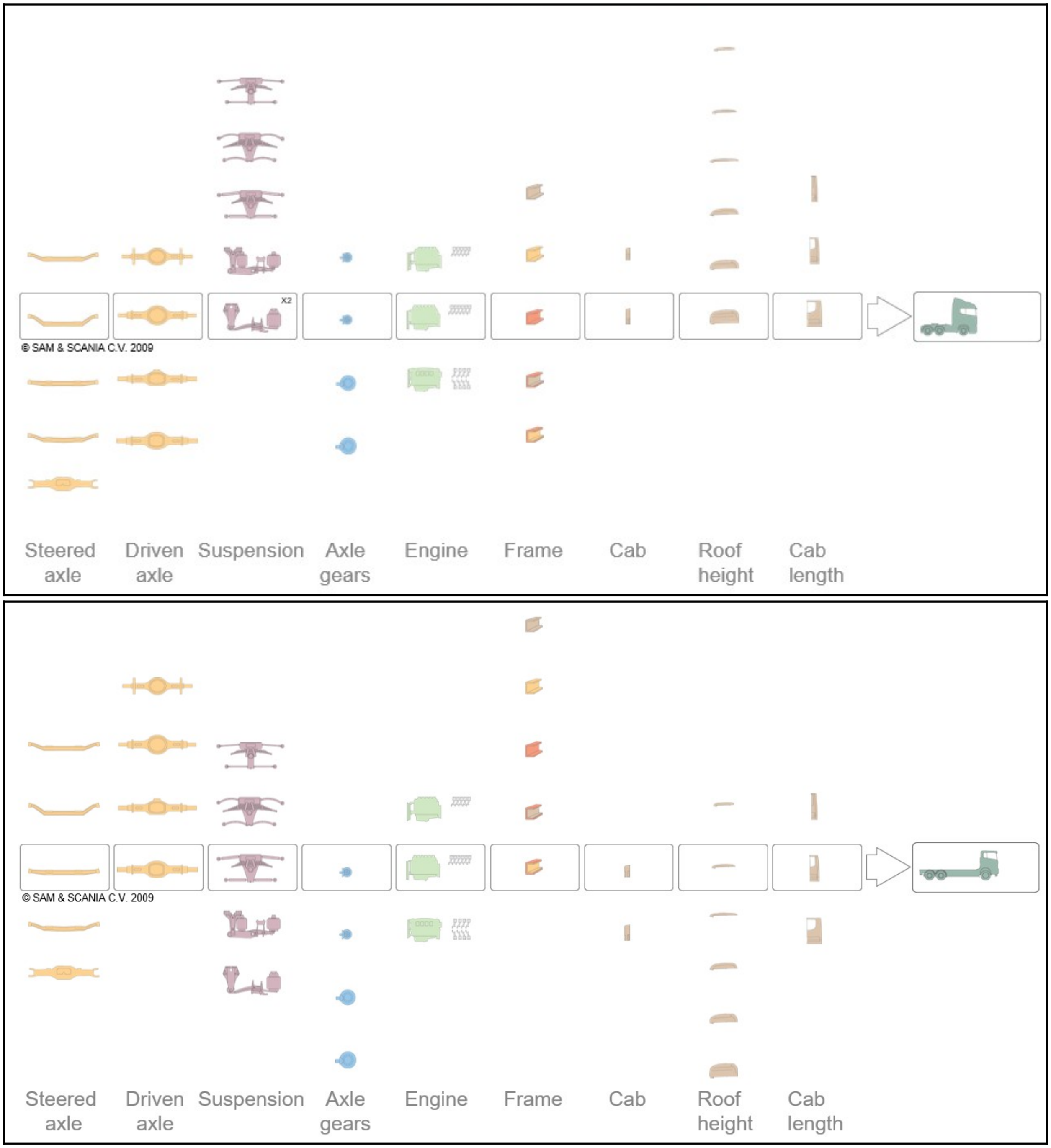


Figure 6. Visualization of a few of the available customer choices and their implications on the end truck (top and bottom images of different truck configurations)

Modularization principles and variant formations are both not strictly limited to major component systems as individual components of smaller scale may also have modular subvariants. Figure 6 below illustrates the usage of such subvariants. Despite the roofs in figure 7 being different, the roof structure can still be used for both thanks to the use of a common modular interface.

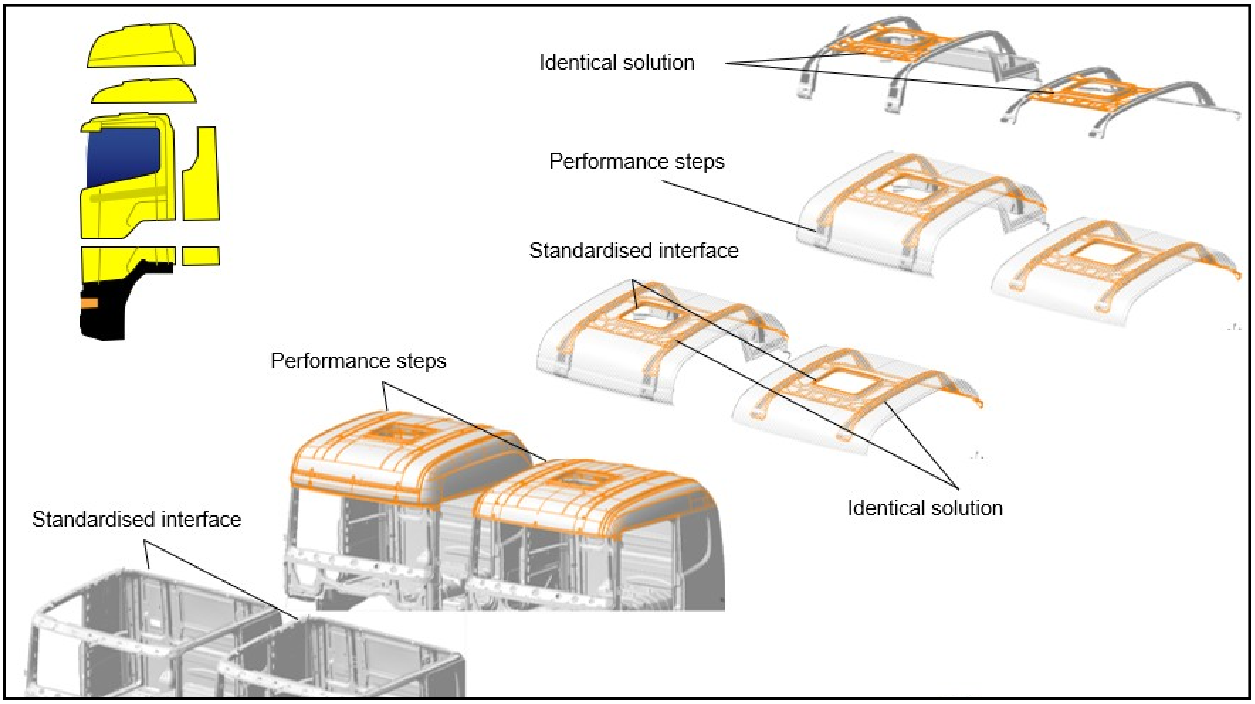


Figure 7. Illustration of different variants of cab roofs with common subvariants of roof structures.

By utilizing a set of common interfaces, the variants can be scaled to fit several of those variants. Interestingly, Scania refers to module variants as *performance steps,* as seen in figure 6*,* which have different product strategies since certain module variants are considered more premium and are found in pricier configurations whilst others are standard-issue components. Though, there is a hierarchy of variants that have gradual performance steps with the most notable example being engines. For a selected base configuration (specified application and usage conditions), the customer may have a choice of more than 10 compatible engines with different properties and performance data. All compatible engines are guaranteed to fit the truck since they share a common interface.

However, since the interface compatibility is determined by the spatial and contact fits, certain performance steps are not fully compatible with all customer options. In the case with the engines, a high-performing engine may be bigger than a lower performance step which would render some customer choices that were compatible with the lower performance step invalid when used in the configuration with the high performance engine.

Scania's fully modular architecture also enables gradual product updates as opposed to platform-based introductions and revisions in archetypal automotive firms that are frequently released on a yearly basis. Strategically, it makes it possible for the company to make frequent product updates and release them more often than a traditional platform-based automotive manufacturer. Figure 8 below shows Scania's product-strategic difference between themselves and the typical product introduction strategy of platform-based companies.

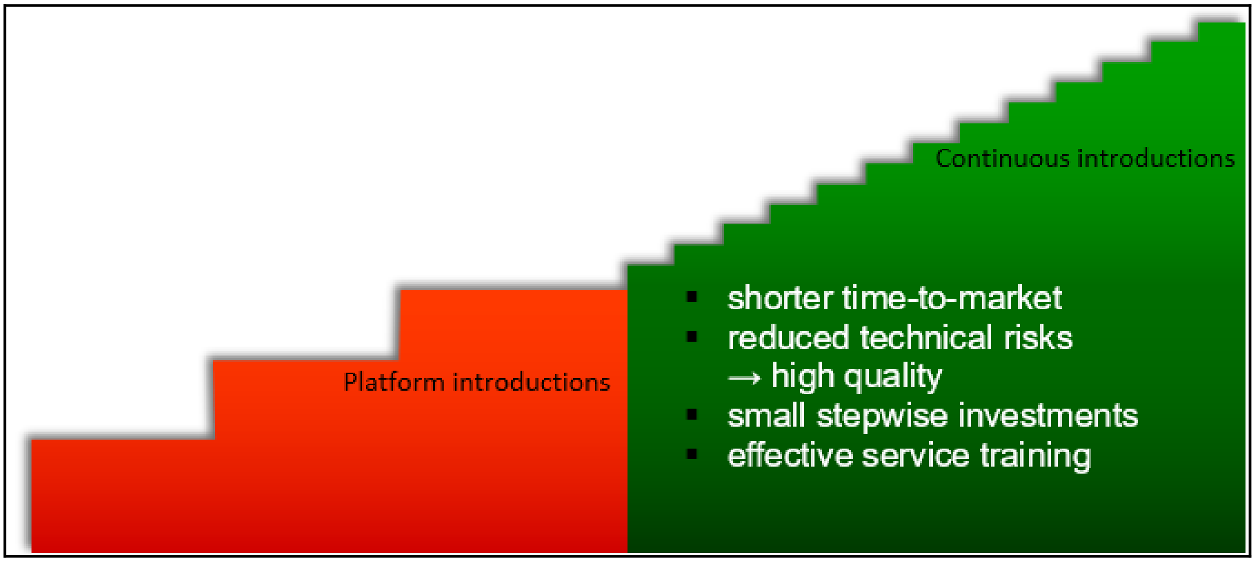


Figure 8. Product-strategic difference between Scania's modularization implementation and platform-based competitors

To govern the compatibility of customer choices, they use a digital structure management system called TCR (translation code register) which is part of the company's internal product description support system OAS (object and structure tool). In the TCR system, each choice type is codified with a unique identifier known as an FPC code or variant code. Each code describes a feature of the truck, for instance FPC4 is related to engine technology and FPC37 gearbox type. This number also indicates a variant family. The variants of the subsystem (variant options) are distinguished using the letters A-Z, for example a turbo-charged engine is categorized as FPC4 B, a naturally aspirated engine is FPC4 A etc. By specifying the appropriate conditions in TCR, the system will be able to validate the chosen combinations of the FPC codes. Worth highlighting is that the FPC codes describe both modules and features. In actuality, the system is verifying the feasibility of the specified module variant combinations. Figure 9 visualizes the relation between variant family and variant option where each variant family is a specified feature in the truck, this case roof height. For that feature, a number of variants exist. In this instance four variants are available.

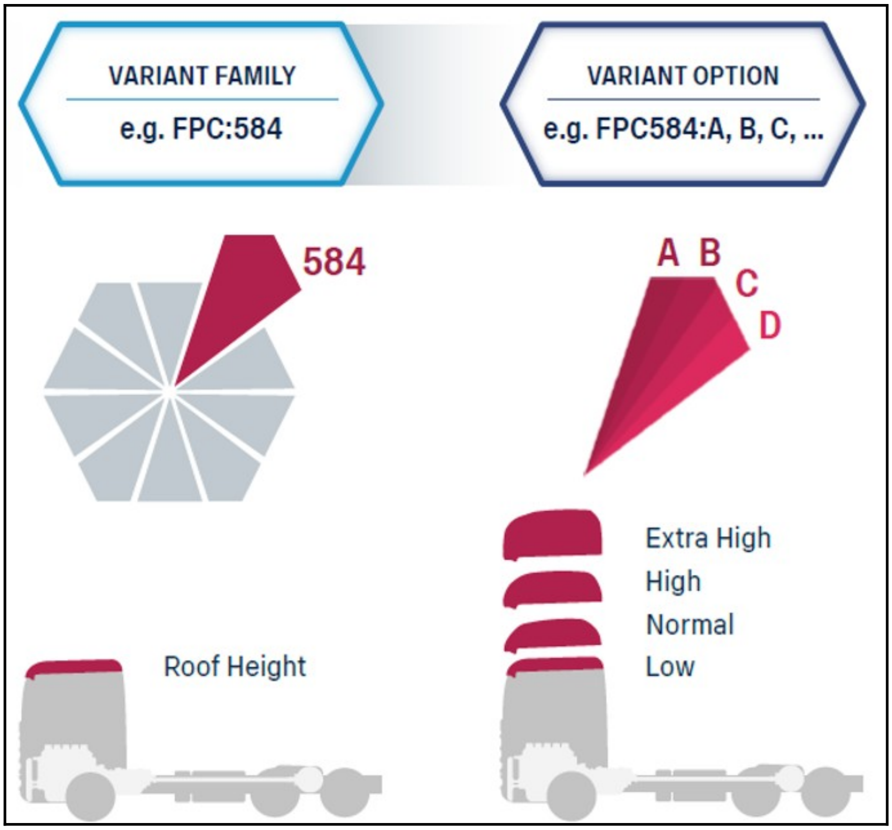
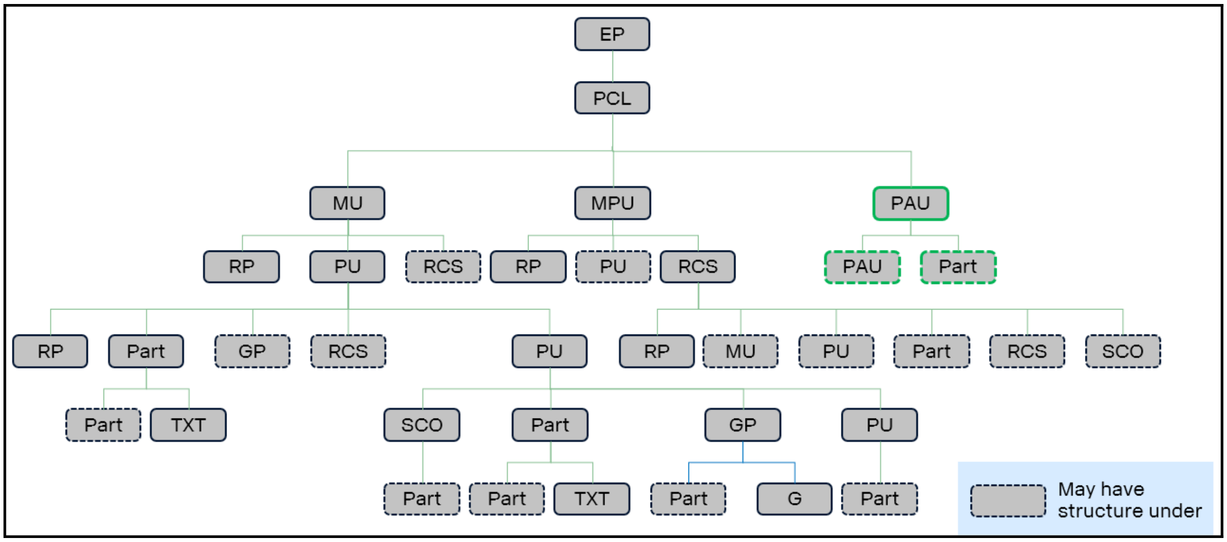


Figure 9. Clarification of the difference between variant families and variant options.

In addition to the customer choices, there exists an additional set of codes that control to-the-customer invisible internal features and layouts. For example, harnessing length, plastic pipe setup and positioning of fuel tank refill cap are some of the parameters that can be specified using FPC codes. This information is specified in the VCR (variant code register) which also includes rules that control the validity of feature and module variant combinations. There are thousands of such codes and new ones are continuously introduced to help express truck configurations when new features are introduced. Although the TCR/VCR regulate the conditions of truck and bus components, the geometric part data is stored in a different structure known as KS (konstruktionsstruktur). The KS structure contains the hierarchical division of the vehicles' subsystems down to part-level which follows a standardized structural logic. The structural hierarchy follows the logic illustrated in figure 10 below.



Object type	Stands for	Description
EP	EnterPrise	The top level object type for all product structures at Scania.
PCL	Product Class	Object type for products
MU	Module Unit	A main object type directly under PCL. A module unit can be ordered separately and works as an RCS (see below).
MPU	Main Product Unit	A main object type directly under PCL. An MPU cannot be ordered separately or work as an RCS.
RCS	Reference Coordinate System	Has the same function as an MPU, but also works as a reference coordinate system.
PU	Product Unit	Is used to divide the structure into suitably sized portions.
GP	Geometrical Position	Is used to describe a parts position in relation to the coordinate system it is placed in.
RP	Reference Position	Describes a reference coordinate system's position in relation to another.
SCO	Single Choice Option	Holds one and only one valid part per product individual.
Part	Part	Used to identify parts, including documents.
CTD	Certificate Document	Used to identify certificates
PAU	Product Adaptation Unit	Used to identify parts that are mounted on FFU line (Fit For Use)

Figure 10. Graph-based view of the structural hierarchy (Top).
Partial nomenclature of the structural hierarchy (Bottom).

Worth adding is that the choice of PCL (product class) determines what branch of the modular structure that is viewed. In other words, there is a separate product class for bus chassis and complete bus as well as for truck chassis and complete truck. That means that the PCL for complete trucks contains all the structural conditions for all possible variants of a complete truck whilst the PCL for bus chassis contains all the parts and their structural relationship for all possible bus chassis. Relatedly, trucks and buses share many common parts and components that are featured in each different branch. Figure 11 below shows an illustration of some of those commonalities.

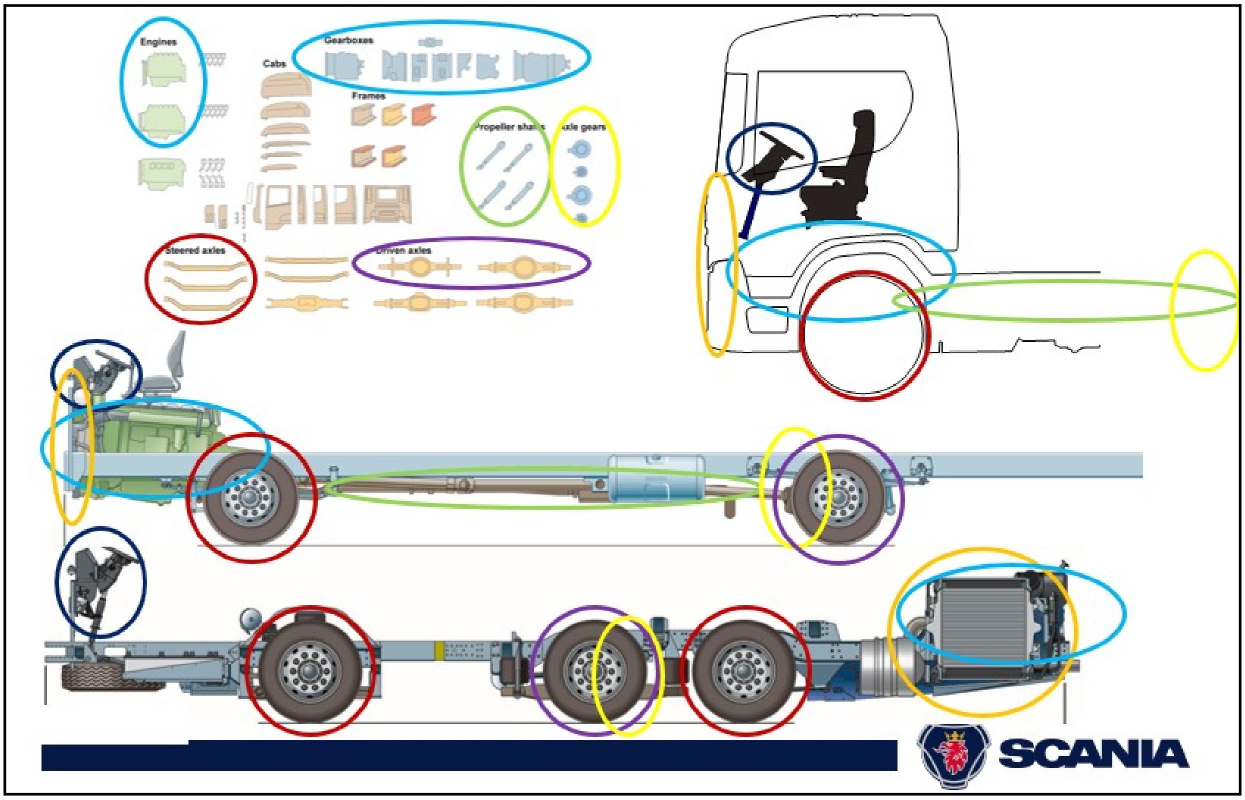


Figure 11. Common components in a bus chassis (top) and truck chassis (bottom).

The object type “parts” are the barebones elements of the defined architectural modules. Examples of parts include screws, brackets, seals, frames, gaskets etc. They are information carriers in OAS as they contain data about part supplier, procurement, weight and more. Also, parts have their own milestones that indicate their maturity level in terms of how defined they are, something that constantly develops as components are tested in the product development process. Spatial data in the form of GPs (geometric positions) in the model space is also included in the product structure and synchronized with the CAD environment (computer-aided design).

In addition to the modular structure, OAS also contains a number of other tools such as CO2 emission, bodybuilder drawings and weight data. With OAS, the company aspires to centralize vital product information and support systems as it is currently scattered across different corporate functions. Production, for instance, uses a parallel system (MONA) that extracts its core data from OAS. Similarly, marketing uses another structure (CAVA) that also pulls its data from OAS. The current vision is to gradually move toward a common platform that contains all information in one synchronized place.

4.2 Modularization - Customers' Point of View

Since Scania's competitive advantage is rooted in their ability to tailor-make trucks based on specific customer preferences, much of their business stems from customers' interaction with the conditions of the modular structure in the form of a simplified UI. When the customer orders the truck through the online portal *product configurator*, they can select the features and components that they prefer to have in their truck. Below is the image of the product configurator website which shows all the specifications, where the customers can specify their desired truck from a list of options. Figures 12, 13 and 14 show the interface for selection of operation type, axle configuration and cabs which together make up the basic structure of the truck.

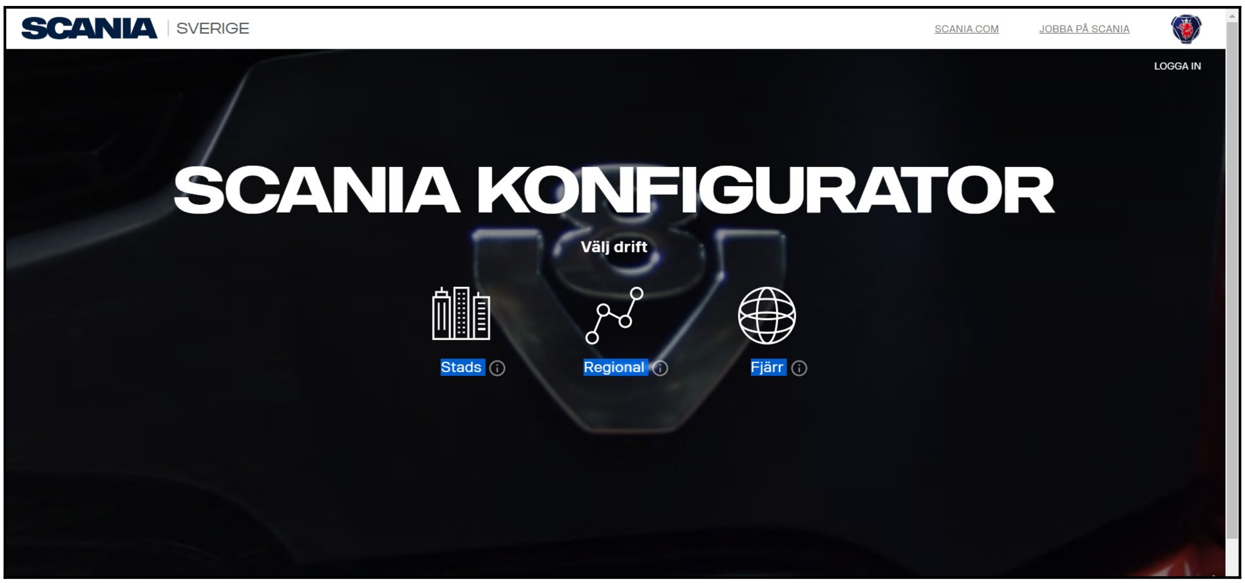


Figure 12. Specification of truck operation type

Figure 13. Available axle configuration for a chosen operation type

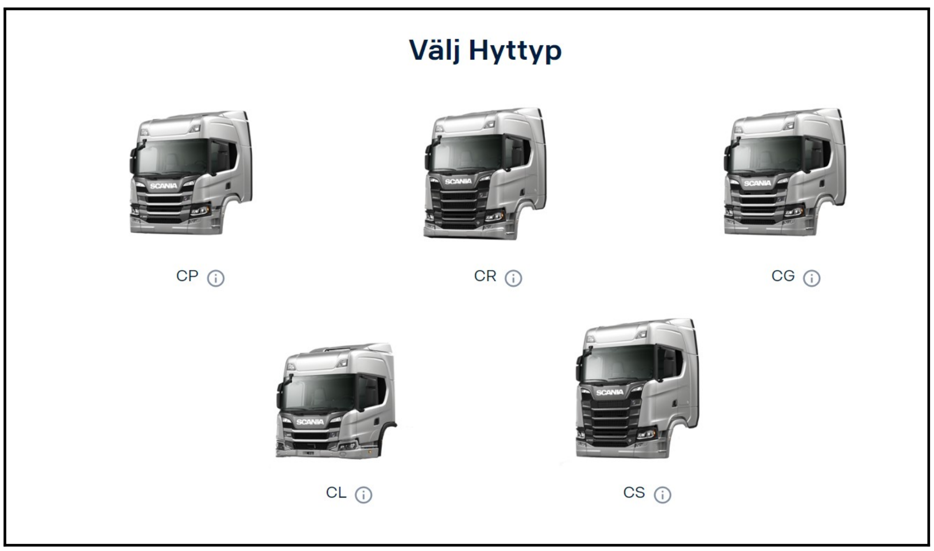


Figure 14. Available cabs for chosen axle configuration and operation type

After defining the basic structure of the truck, the customer is then allowed to configure other features of the truck such as the engine, interior, performance packages etc. A preview of the truck is displayed after each selection and is fully interactive in 360 degrees using both interior and exterior views.

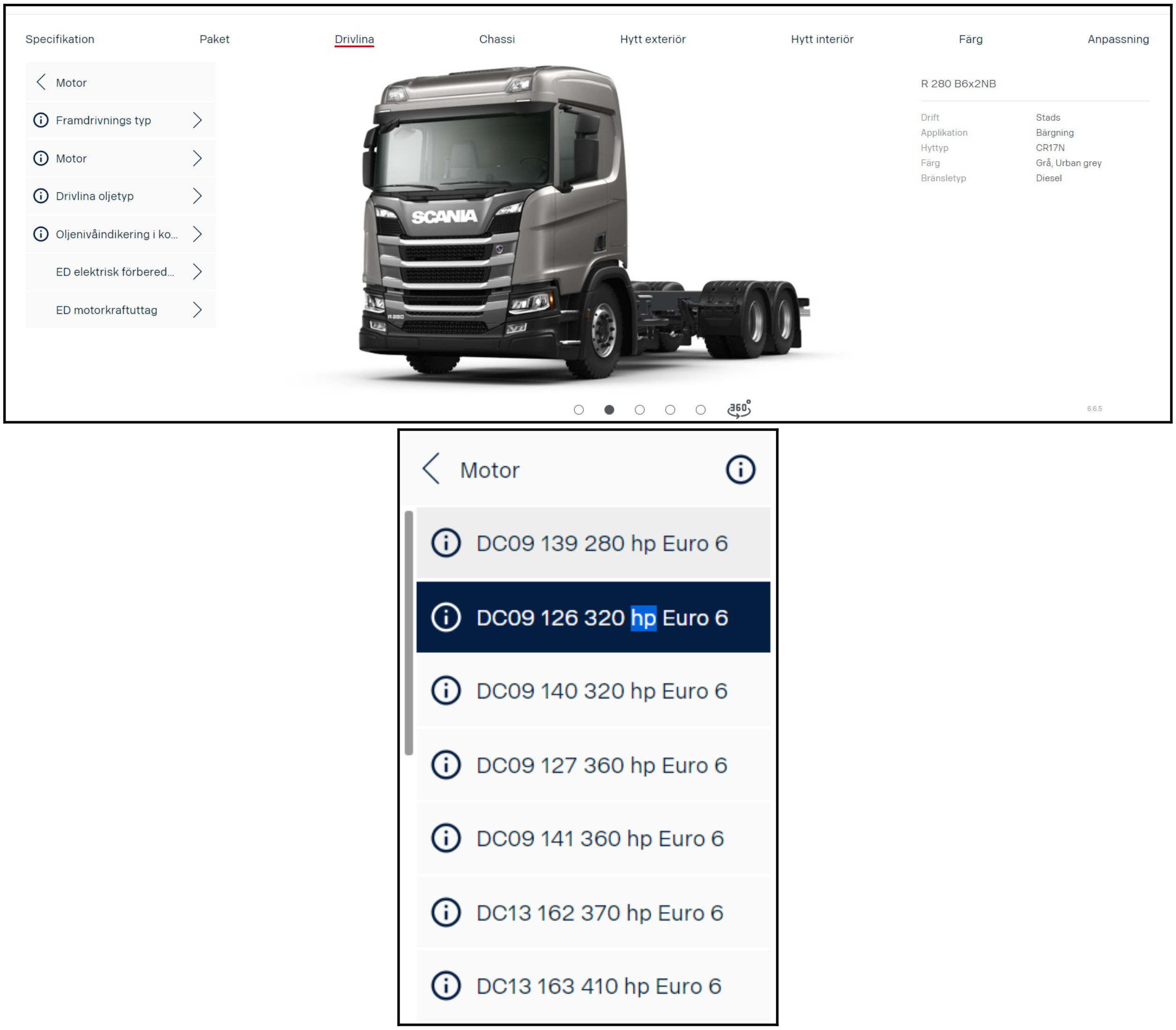


Figure 15. User interface for choosing other truck features (top) and selection of available engines for chosen truck configuration (bottom).

4.3 Product Development Process at R&D

New development projects in Scania follow a predefined process from when they are first initiated until they are completed and undergo a series of phases. Figure 16 shows the formal division of the R&D process.

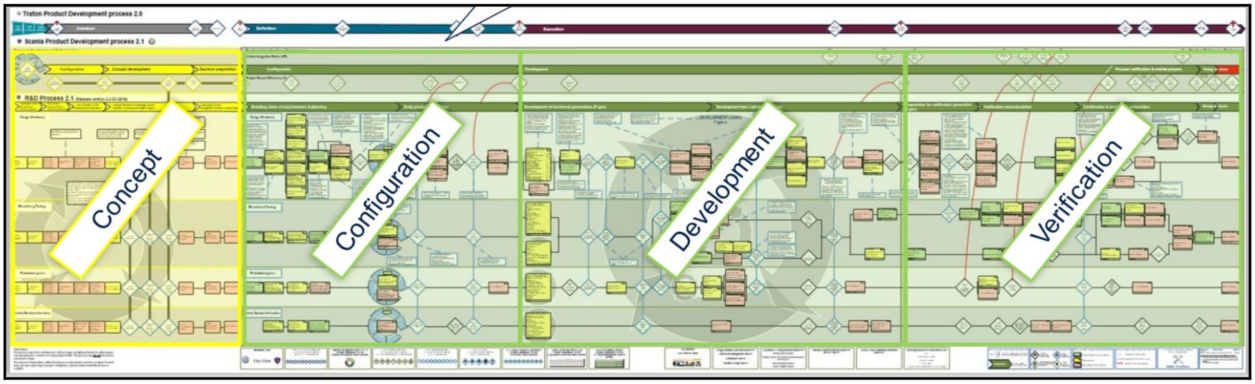


Figure 16. Overview of the R&D process showing the yellow arrow (configuration) and green arrow (configuration, development and verification).

Scania claims that it is a cross-functional process that is customer-focused, something that is directly tied to their modular bygglåda and continuous introductions. The aforementioned phases are referred to as *arrows*. The yellow arrow encompasses the conceptual phase where products have preliminary properties and are not fully developed. At the end of the yellow arrow process, a choice is made whether to proceed with the project or scrap it. In the case where it is agreed for the project to be industrialized, it officially transitions to the green arrow where the product is further developed and prepared for production, which commences at the end of the green arrow process. After the official start of customer-ordered production (**SOCOP**), maintenance and additional work on the products is done in the so-called red arrow which deals with products that have already been industrialized.

In this study, the delimitation was set to only focus on ECOs of green arrow projects in order to realize the goals of the thesis within the specified time frame. To navigate the yellow and green arrow phases, the company uses an in-house-developed R&D process map which prescribes a series of milestones and activities that the major functions are part of during a project. The structure follows a horizontally sequential milestone-based model reminiscent of hardware-focused product development processes such as phase-gate. Subphases in the green arrow are referred to as configuration, development and verification and entail certain differentiable activities. In the configuration phase, the activities are centered around project planning and setting dates whilst the development phase is focused on iterative development of the proposed concepts.

Visualized in the process chart are all the R&D functions, which are divided into four subprocess "lanes". The four major functions are design hardware, simulation and testing, embedded systems and vehicle service information. Other non-R&D functions such as purchasing, production, marketing and others are omitted from the map but their presence and involvement is implied in certain milestones. Moreover, the milestones are intended as cross-functional check-ups where all R&D functions and other major functional units such as production and purchasing are involved to synchronize their progress. Worth noting is that the digital process map is fully interactive and features clickable elements that direct the user to separate documents containing complete information about each major milestone and select activities. In those documents, lists of expected participants (functions) are included.

4.4 Objects and Projects - Modular Project Setup

Each project is divided into a series of objects that each encompass a specific domain of the whole truck. Because of this, the objects are to be viewed as subsystems that have interfaces with other subsystems. Every object has an assigned object leader who is tasked with coordinating local deliveries, ensuring that the work is on track and synchronizing their group's progress with interfacing objects. In addition, the object leaders have a representative role in that they regularly attend project meetings where they update the project manager and other objects on their progress. Figure17 below illustrates the project-to-object structure.

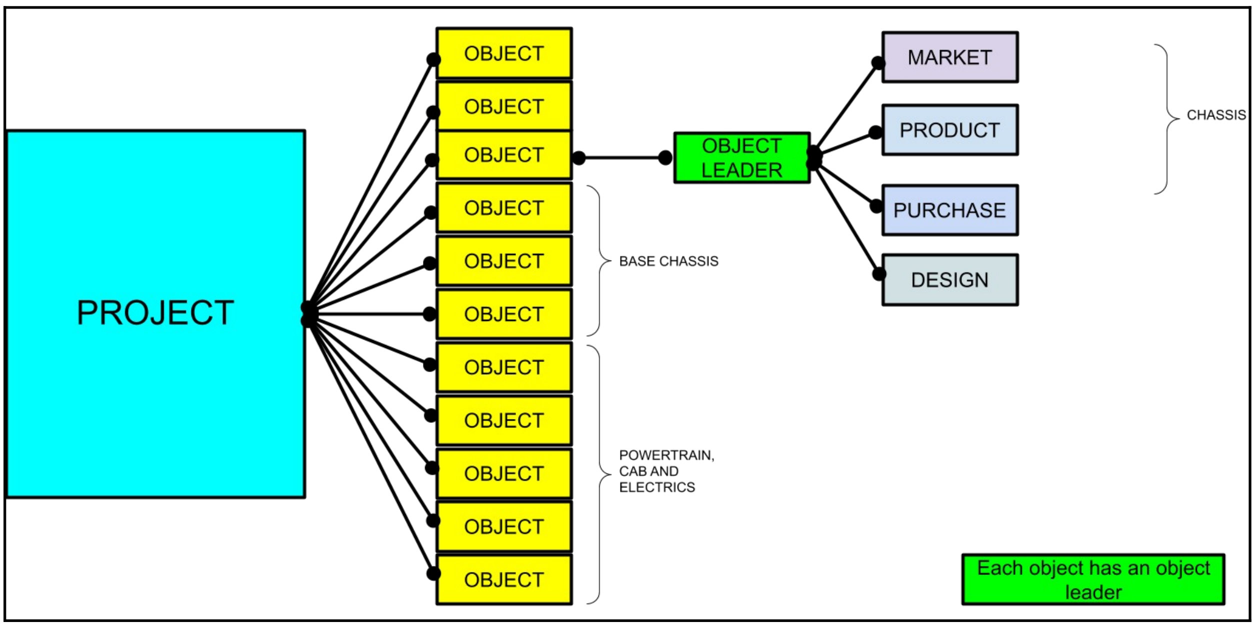


Figure 17. Illustrative overview of the project-to-object relationship

The object leaders have a number of DEs in their group which make out the primary members of the object. With a DE background, the object leaders formally belong to design groups but, as opposed to their former roles as DEs, mainly have coordinational responsibilities. Thus, with the object leader role comes the responsibility of ensuring cross-functional synchronization of deliveries, more specifically between DEs and related stakeholders as well as between their own object and interfacing objects. For instance, their core activities include delegating tasks that designers need to work on and also make sure that their object is synchronized with production and purchasing. In the case where a change that affects the object interfaces is proposed, they will be required to check with the object leaders of the interfacing subsystems to make sure that it is doable.

4.5. Organizational Structure and Cross-Functional Links

The company has a vertical organizational structure with functional branches. In addition to R&D, other major branches include purchasing, production and logistics, sales and marketing. Within R&D there are a total of 8 divisions, each with their own assigned areas of responsibility. The organizational structure of R5A is visualized in figure 18 where only the branch containing the groups of R5A is broken down from top management-level.

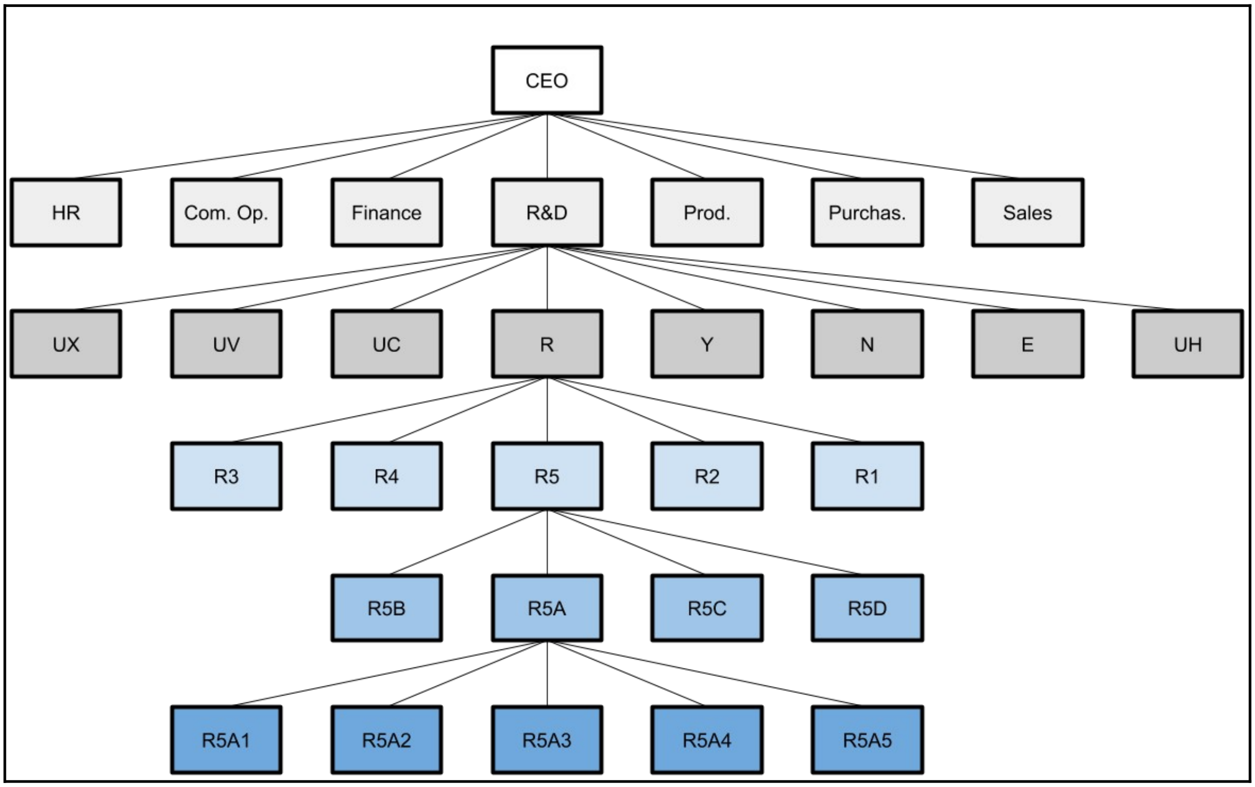


Figure 18. Structural overview of the organizational hierarchy, broken down from the CEO. The second tier only includes the core functional groups involved in new product development. Project office, maintenance and regional divisions have been omitted from this structural breakdown.

In figure 18, every rectangular block represents a function and has an assigned manager. The R division is responsible for truck, cab and bus chassis development which includes product coordination, the role that is most closely associated with ECOs and the modular architecture. Evident from the organizational breakdown, the company has a vertical power structure with a functionally focused setup. As such, the level of specialization increases with each structural breakdown.

Aside from the cross-functional milestones specified in the process map, few cross-functional integration mechanisms exist. From R5A's perspective, some meetings are routinely scheduled where selected individuals from local R5A groups sit together and discuss technical or process-related issues. An example is technical process meetings which are held to discuss encountered technical issues and usually, depending on the issue at hand, feature representatives from non-R5 functions. Also, group-exclusive meetings, “daily steering”, are held every morning to check-up on the progress of both ongoing and incoming work. R5-specific meetings, “R5 pulse” are also held weekly and act as a way for the R5 department manager to probe the R5 groups’ managers and check the progression of ongoing projects. Another R&D-exclusive meeting is the so-called “Scania pulse” where R&D functional groups, most commonly managers within the R&D divisions, present their progress in the project and inform if they are experiencing any issues or delays.

In R5A’s case, the R5 manager is informed about the R5 departments’ ongoing progress at the R5 pulse and then relays that information at the Scania pulse meeting. Additionally, the R5 manager also notes down any R5-relevant issues or delays that other groups bring up at the Scania pulse which he then presents for all the managers of the R5 groups at the R5 pulse. All the above-mentioned meetings occur outside of the product development process and are ongoing. Table 8 below shows some of the design engineer departments which make up some of R5A’s main stakeholders.

Table 8. Some of R5A’s main stakeholders (DEs).

Design Department (2-Letter Acronym)	Responsible Domains	Total Members
N1	Emission Solutions.	114
R4	Cab development. Responsible for development of cab body, exterior, cab suspension, mechanical testing, technical simulations, cab interior, including cable harness layout, climate system development and testing.	165
R1	Bus development.	293
R2	Responsible for developing customer tailored Scania Trucks according to customer needs. Also responsible to develop complete trucks and support body builders.	180
R3	Truck chassis development. Responsible for developing complete vehicles and business opportunities for the customer.	56
R5B	External operations. Responsible for development of both chassis and cab components in several different projects. Also responsible for delegating tasks to external consultants.	101

5. Results and Analysis

Since the employed product development process was built and based on the ECO maturation flow, most ECO problems originated from symptoms in the development process. Hence, the core ECO issues were contextualized with the process-related tensions. Presented below are the results from the study of the company’s ECM system, conducted interviews and surveys respectively.

5.1 ECO and ECM Implementation and Cross-Functional Collaboration in Modularization-Based Firms

This section is dedicated to explaining Scania's ECM implementation and how the modularization system and other systems are linked to it (as explained in *4. Scania Background*). In addition, contextual information about organizational makeup and structural division of ECM-related roles is given to establish a frame of reference.

5.1.1 ECO and ECM

Hardware ECOs contain information about structural, geometric and part changes of a specific subsystem and are communicated via the company's internal product description support system OAS (Object and Structure Tool). In essence, OAS houses the modular architecture and the structural conditions of the parts that make up the vehicles and can therefore be viewed as the company's official ECM system. There is a range of different ECO types, but as part of the delimitation in this project, only the hardware ECOs are of interest and therefore it is implicitly implied that ECOs are hardware-based. In OAS, all ECOs share a common template with information about the change order responsible, product coordinator, structural implications, part information and much more. Although ECOs might be used for different change types such as drawing updates and change of part supplier, the majority of ECOs pertain to hardware-related design changes. Therefore, the CO (change order) responsible is most often a design engineer of a specific domain such as truck chassis or engine.

The CO responsible is not permitted to make any structural changes in KS and TCR/VCR as that responsibility is entirely reserved for the product coordinators. Essentially, the product coordinators are tasked to structurally describe additions to the modular architecture and update the conditions when new parts are introduced and old ones are phased out. Thus, the CO responsible is theoretically expected to send the ECO to an assigned product coordinator who then uses the information in the ECO to describe the structural and conditional implications of the proposed change.

In a product development project, ECOs are used to either specify the introduction of new parts (that make up components) or revise an already existing solution. The development process consists of several design loops where parts undergo rounds of testing and reviews. Because of this, the ECO has a number of status level milestones that indicate the maturity of the hardware design change from a range of set criteria. As such, the time between each status milestone requires certain work to be done in the structure and definition of part conditions (FPC codes).

A dedicated timeplan is featured in the ECO and is entirely created by the CO responsible. The idea is for the plan to communicate when the designer aims to have the ECO in different maturity levels - formally referred to as statuses. The status levels can be viewed as milestones. In total there are 4 major milestones, namely 2:3, 3:3, 3:4 and 4:4 which are directly related to the milestones of the developed components but more specifically the parts that make up the components. Table 7 below details each status raise including the process milestone which it is connected to. Similar to ECOs, there are four milestones for part maturity and, much like the ECOs, the milestones are connected to how ready the parts are. Knowledge about the planned status levels is of importance to the product coordinators as they are the recipients of the ECO and are the ones who will describe the changes in the structure and develop relevant structural conditions. Figure 19 below summarizes the essential steps of the ECO process flow.

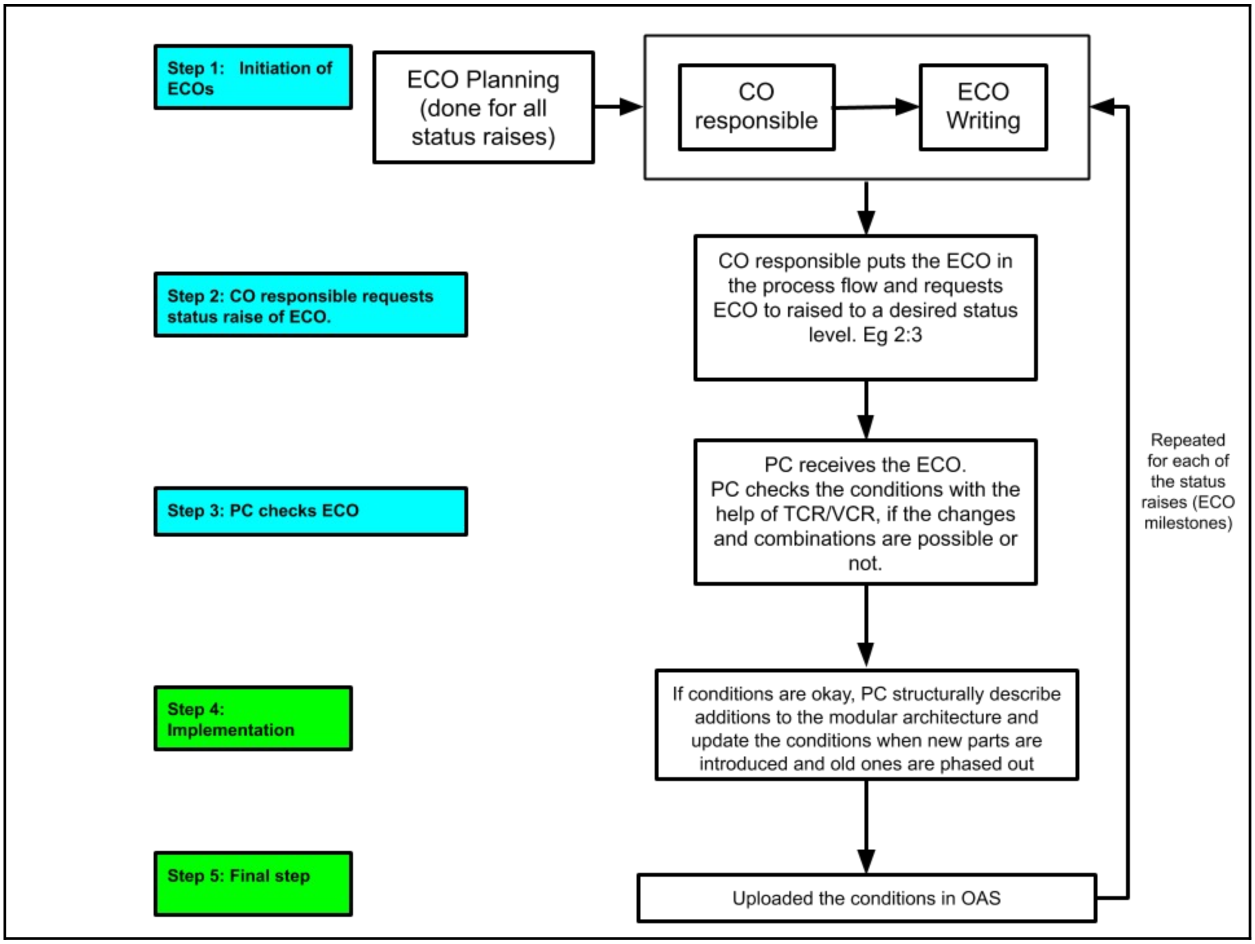


Figure 19. Simplified overview of the ECO workflow

Table 9. Relationship between part maturity levels and ECO milestones and their connection to the R&D process milestones

Part Status	R	P	PR	S
Corresponding ECO Milestone	2:3	3:3	3:4	4:4
Associated R&D Process Milestone and Phase	R&D20 F-gen	R&D75 F-gen	R&D80 V-gen	R&D90 V-gen

Since the product development process is project-based up until the so-called V-gen phase, the maturity levels of ECOs follow the timeline of the projects that they are attached to. This means that they also converge when the COIN-enveloped projects reach VIP1 where the ECO milestones will be synchronized across all projects in the COINs. More specifically, the project milestones, both in the F-gen and V-gen are intended as integration events along the way. For instance, milestones R&D20, R&D75 and R&D80 all precede ECO status milestones 2:3, 3:3 and 3:4 respectively.

An issued company standard exists for writing ECOs, but it does not fully govern all aspects of ECO writing. Similarly, a devised guide for describing structural changes exists for product coordinators, though it also does not fully cover all angles of product description. Intricate details such as how to describe the introduction of a part with specific conditions are not standardized. As such, individual preferences and creative thinking are the prime navigation tools of choice in this grey area.

From the R5A5 perspective, the ECO flow is different in that they do not work on the structural layout (KS) nor the conditions (TCR/VCR). Instead, they depend on the availability of the geometric data supplied by the structured parts in the design structure (KS) as well as the structural conditions. The conditions are used to determine if the geometric clashes are valid, as the test environment pulls data from the KS-derived parts encompassed by the ECO in question. The geometric models are in the form of assemblies that consist of multiple parts in a CAD file format. Figure 20 below visualizes the workflow of the R5A5 group.

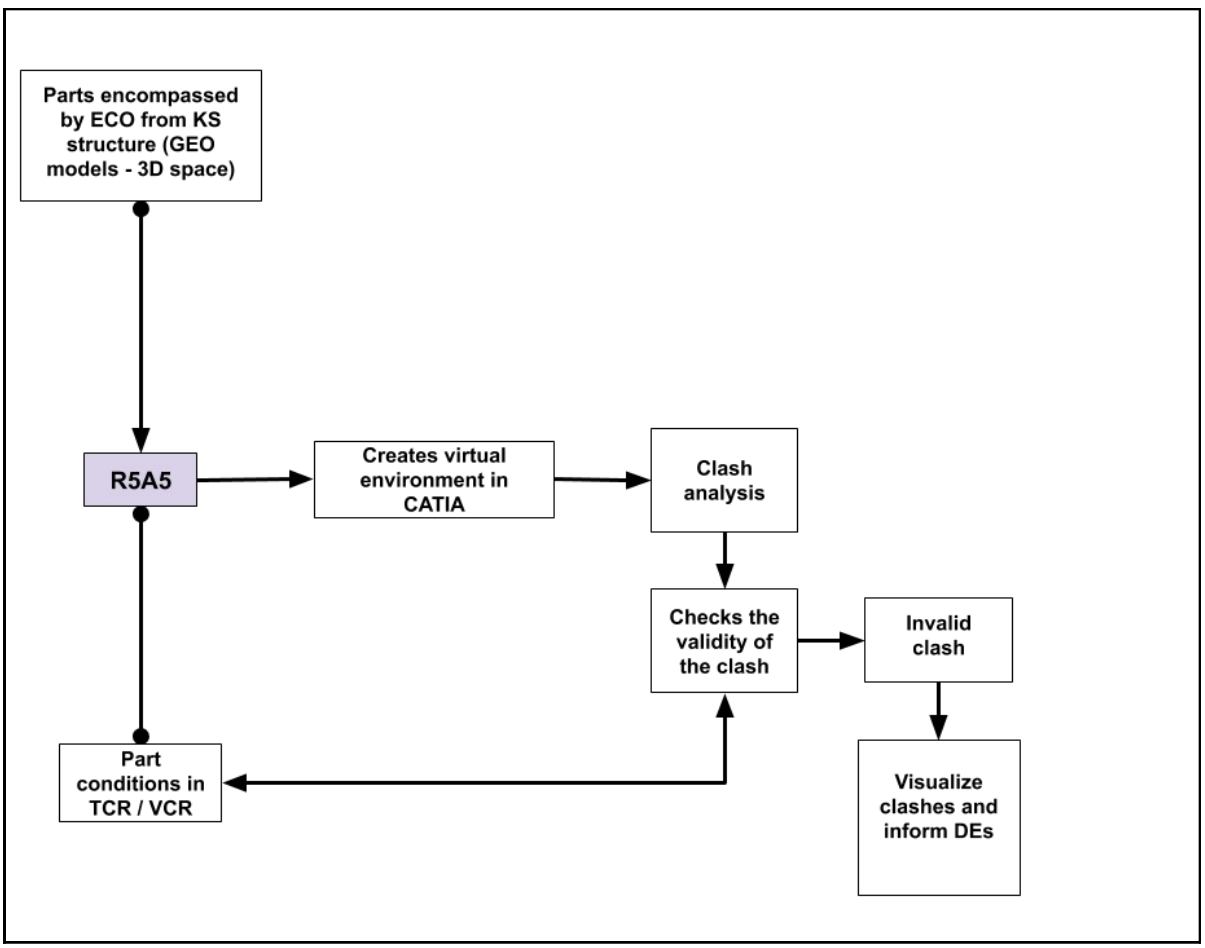


Figure 20. Simplified process flow of R5A5's main task (geometric assurance)

To coordinate ECO deliveries, the ECO stakeholders make use of different coordination tools. *PFtools* is one such tool which is widely used by almost all the stakeholders (design team, project office and product coordinator groups) in the product development process. PFtools is a large database (an Excel sheet) which consists of a list of ECOs of all the active yellow, green and red arrow projects which are being worked on in Scania. The tool gets its core data from both the OAS software and a central database and displays information about each ECO's CO responsible, ECO planning status, COIN, SOP date etc. The R5A groups mainly use the information in PFtools to see the list of ongoing projects, forecast and predict which ECOs are scheduled to arrive to the corresponding groups and to plan the work and resources in the groups accordingly based on the workload. Worth noting is that the tool is flexible and can also be used for other non-ECO-related means.

5.1.2 R5A - Product Description and Product Assurance

The R5A branch, which is part of R&D, is responsible for product coordination, geometric assurance, weight calculation and bodybuilder drawings. The product coordinators' main responsibility is to process ECOs and define structural conditions in OAS. Three R5A groups (R5A4, R5A1 and R5A2) are responsible for different subsystems of the truck whilst R5A3 is solely responsible for buses. The last group, R5A5, geometrically assures CAD installations of different subsystems to check for undesired clashes and use the full conditions of the modular structure as a basis for doing so (TCR/VCR). Noteworthy is that the functions of R5A are involved in all ongoing R&D projects and therefore rely on deliverables from all design groups. The chart below (table 10) shows the domain and key roles of each R5A department.

Table 10. Overview of R5A departments and their respective domains

Group Acronym	Group Domain	Functional Roles	Number of Employees and Individual Domains
R5A1	Chassis installations	Product coordination, weight calculation (bus and truck), chassis bodybuilder drawings	17
R5A2	Base chassis installations and special vehicles	Product coordination	16
R5A4	Powertrain, cab and electrics	Product coordination	17
R5A3	Bus	Product coordination	13
R5A5	Geometric assurance, bus and truck	Geometric assurance	11

In September 2019, all vehicle property groups merged into a new department named R5, vehicle design. With that change, all product coordinator and geometric assurance groups in Scania were officially grouped into a dedicated department, R5A, which is a subset of the R5 branch. Prior to September of 2019, the R5A wing did not formally exist. Instead, the groups that now belong to R5A were scattered in different departments. Most of them, however, were part of the now-defunct R3X wing. The idea behind the merger and creation of a new dedicated department was to have all product coordinators in one place in order to simplify resource allocation and knowledge exchange. Figure 21 illustrates the organizational chart before and after the creation of R5.

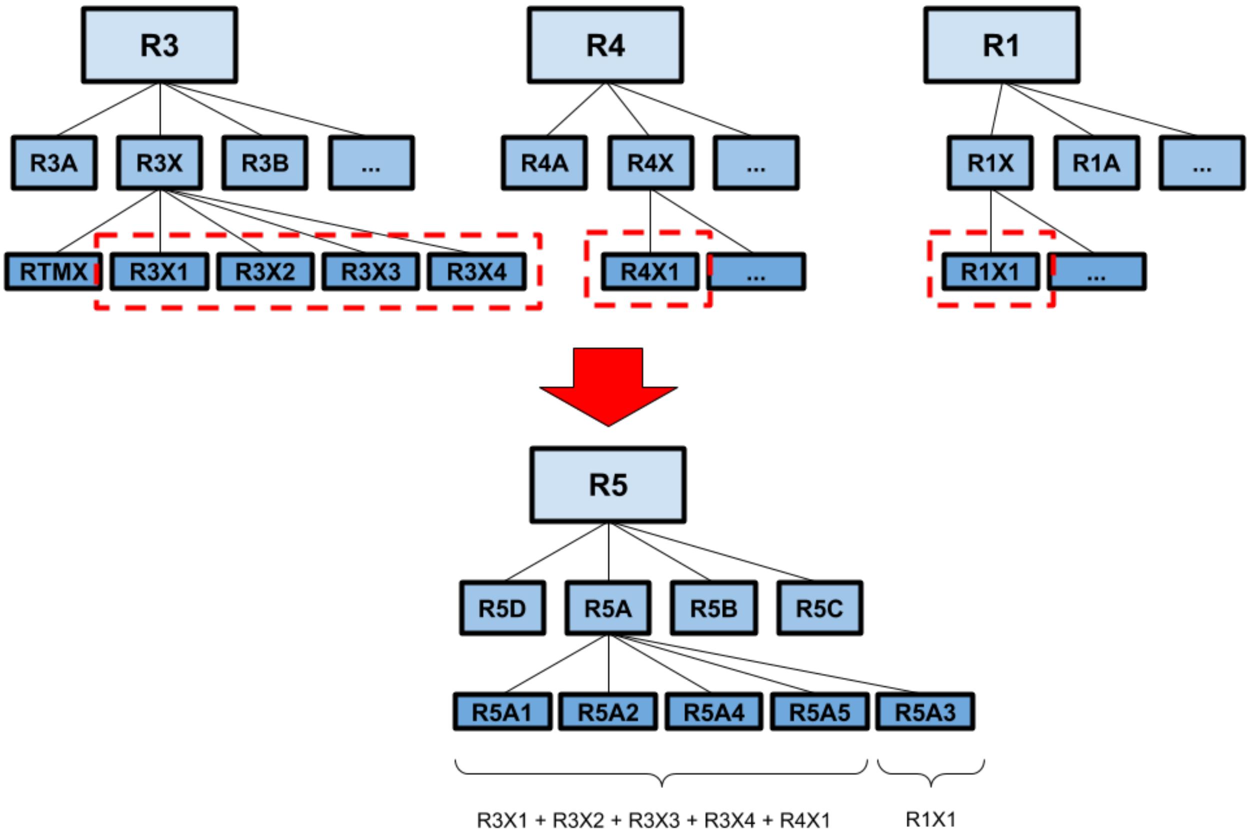


Figure 21. Organizational chart of the departments that make up R5A prior to and after September 2019 (top and bottom respectively). Only parts of the main departments' complete breakdown is visualized, dotted boxes indicate more groups under the same branch (R3, R4 and R1).

The product coordinators, which roughly make up 80% of R5A, are responsible for product coordination of all projects in both green and red arrows. However, non-product coordinator teams specializing in bodybuilder drawings and weight calculation of buses and trucks also belong to R5A (R5A1). R5A5 stands out from the rest as it is the only R5A group that does not formally have any product coordinators. Instead, R5A5's focus is geometric assurance of all system installations, something they do as part of the ECO flow. Also, R5A roughly has 74 employees.

Whilst product coordinators mainly rely on part and component relationships as a basis for the structural description work, R5A5's input data primarily stems from the geometric changes that are introduced by ECOs. Particularly, ECOs that contain changes in GPs are of relevance to them. Process-wise, the product coordinators are expected to complete the structural layout (KS) and part conditions (TCR/VCR) in VIP1 and VIP2 respectively. After this point, the ECOs reach status 3:4, which is the second highest maturity level.

Prior to the organizational restructure in September 2019, R5A1 and R5A2 were part of the same group named R3X1. While working under R3X1 they had set team routines, divisions and collaboration practices. Despite moving to the new department in R5A, R5A1 and R5A2 still retained some of the same team divisions, collaboration practices across their boundaries which, at the time of the study, was something that was still being practised. Also, worth noting is that the R5A4 group has three subgroups, those being electrics, cab and transmission with each subgroup focusing on different areas of the powertrain. Thus, there exist differences in ways of working between individual subgroups. For instance, the electric subgroup is responsible for specific ECO-related tasks that none of the other subgroups can perform.

5.2 Qualitative Study

The core ECM and ECO challenges were found to be directly related to and induced by a slew of different underlying factors, as illustrated in figure 46. This section will cover each aspect (branch) individually and address the second research question pertaining to the ECM- and ECO-related challenges.

5.2.1 ECO and ECM Challenges

A significant amount of ECO-related information was noted as being either missing or lacking and the limitations were said to be frequently recurring in projects. This information can be summarized as limitations of *ECO awareness*, primarily impacting the PCs' ability to plan their work which consequently affects the ECO lead time. A significant portion of the covered aspects were based on the reported limitations of currently employed ECO coordination tools. The following aspects were highlighted as being either essential or problematic for ECO-related work:

- ECO planning - when ECOs will be delivered (forecasting beyond 14 days)
- Undispersed ECO deliveries
- ECO criticality and priority (how critical an ECO is)
- ECO delays - delays and changes made to a planned ECO
- Incomplete or missing ECO information
- ECO-encompassed product knowledge
- Estimated ECO size - amount of work and time required for an individual ECO
- GEO ECO - if an ECO requires geometric assurance
- ECO updates - if an already processed ECO changes
- ECO transparency - when an ECO is being worked on by PC or DE (vice versa)
- ECO follow-up responsibility

ECO Planning

Despite there being an official ECO time plan built into the ECM, which is decided by the DEs in the *configuration phase*, most interviewees noted that in most cases, the time plans either change or are not followed by the DEs. A separate sheet, known as *PFtools*, was used to extract all published ECO time plans and put them in a collective overview to forecast upcoming work, which theoretically enabled an ECO prognosis. Nevertheless, some PC groups purposely abandoned their ECO projection routines because of the unreliability of the time plans, making *PF tools* a grey area. In most cases, the DEs did not account for the product coordinators' workload when setting the ECO time plan. As affirmed by object leaders and DEs, the PCs often get forgotten because they are not viewed as direct stakeholders. In the words of one object leader, PCs and R5A5 were seen as “gatekeepers” rather than a function relevant and involved in “ongoing DE work”.

This view was commonly expressed by the interviewed DEs and object leaders and clearly reflected the functional distance between PCs and DEs. Most DE groups believed that the 14-day lead time was sufficient to process their ECOs and did not recognize any direct issues with their ECO planning routines. In fact, the R3D2 DE confirmed that the ECO plan was entirely decided by them and that their group’s ECO planning routines accounted for the 14-day lead time of the PCs. Furthermore, they claimed that upon sending the ECO, the PCs would have all the necessary information to be able to process that ECO and raise it within 14 days. Evidently, the DE was not aware of the issues related to undispersed ECO deliveries (see *Implications of Perception-Based Challenges* in chapter 5.3.4)

The time planning issue was also highlighted by the project office (P0) who had organized cross-functional workshops (also referred to as “follow-up days”) to spread awareness about the importance of publicizing group delivery plans. According to the project manager, the workshops were organized because of an expressed need that stemmed from difficulties in knowing the delivery status of different groups. The workshops were exclusive to the stakeholders (primarily DEs and PCs) of a specific project that had a lot of late deliveries and centered around ECO planning routines. The aim was to both spread awareness about the importance of ECO plans but also establish common routines for ECO deliveries.

Undispersed ECO Deliveries
Relatedly, inconsistent concentrations of ECO deliveries were also brought up by PCs as being major issues since ECOs from most DEs were often sent in around the same time, which created backlogs for the PCs. Most PCs stated they would get overwhelmed by the amount of ECOs that were received and could not complete them in time, rendering them unable to honor the 14-day ECO lead time. Also, a handful of PCs stated that the ECOs were mostly addressed one at a time but that if two or more ECOs were related, they would be worked on at the same time. However, the relation between one or more ECOs is mostly unclear unless one is familiar with the product, requiring in-depth evaluation of which the complexity varies on a case-to-case basis. Because of the PCs’ involvement in all ongoing R&D projects, the implications of the resulting backlogs included an inability to work at the desired capacity. As such, undispersed ECOs stood out as being a core issue faced by all interviewed PCs.

ECO Criticality and Priority
In many cases where PCs were overloaded with ECOs, most claimed that they prioritized each ECO based on market strategic importance for the company. However, the priority levels of both individual and groups of ECOs (MECOs) were not explicitly stated in the ECM (OAS) which required the PCs to conduct that research and acquire the information from different sources in an unstructured fashion. In most cases, however, the information was provided by their group managers who in turn get notified by the department manager via the managerial pulse meetings (Scania and R5 pulse meetings). As stated, ECO criticality was necessary to factor in

when faced with a situation where backlogged work had to be prioritized and thus constituted an important aspect of the ECO value chain. The DEs also affirmed that they would be faced with similar problems, effectively resulting in them suspending the progress of certain ECO (see DE-induced delays further down).

ECO Delays

Multiple PCs claimed that the DEs would also not routinely inform them about changes made to the time plan, which contained information about when the ECOs were going to be delivered to them. As such, each case was often reactionarily tackled when the problem occurred. This often involved the PCs contacting the DE in question via various different communication channels to obtain this information. Many PC groups had totally abandoned the practice of using PFtools because of a handful of consecutive inaccuracies, two of them being the R5A4 electrics and transmission subgroups.

One of the R5A4 respondents spoke about the common scenario of anticipating big ECO batches, referred to as “big bangs”, via PFtools but at the end only getting a fraction of the projected deliveries sent in. They attributed this problem to the inaccuracy of the ECO time plans and an inability to get up-to-date plans that reflect the current state of the design change process. In their extended experience, this was, historically, a commonly occurring predicament that would consistently happen over the course of many projects.

Similarly, the other R5A4 PC made identical remarks about their experience with PFtools, stating that they were mostly unreliable and, at best, could only be used as rough estimates of incoming deliveries. As a result, the PC claimed that their group was employing a purely reactive approach where they purposely remain passive and wait for ECO deliveries adding that previous attempts at using PFtools for ECO forecasting had been unsuccessful for the same reasons.

Incomplete or Missing ECO Information

ECOs with missing or incomplete ECO information were said to be a big cause for ECOs being sent back, causing a hold-up in the process chain, with most of the interviewees emphasizing that it was an issue of DEs not having a good grasp of how to write ECOs. The R5A3 PC gave multiple examples of situations where ECOs had to be returned due to the absence of fundamental data. In fact, the problem was so common that their group had proposed an automated ECO checking system that would automatically scan through the ECO for the DEs to ensure that essential information was included before being sent in to them. The PC explained that the manual “hard checks” were time-consuming and redundant since the ECOs should theoretically be complete with all the required data when sent in by the DEs. Consequently, information about a specific ECO was said to get forgotten over time when the ECO linger in the PCs’ inbox for an extended period of time. This means that if a PC works on an ECO in their backlog that was sent in 6 months ago and needs additional information from the DE, they will have a hard time remembering the details, resulting in delays stemming from the DEs having to reacquire and reacquaint themselves with the data.

Other PC interviewees also referred to this as being a problem within their domain, often forcing them to initiate direct contact with the CO responsible to ask for information that should have been included in the original ECO. However, some groups had a common approach for what to do when faced with this issue. Some groups would only contact the CO responsible and collectively fix the issue only if it was minor and constituted a few missing elements. However, more severe cases where the ECO lacked elementary information would always result in the ECOs being sent back. Though, since the company's KPIs were partially based on the amount of ECOs returned, some PCs stated that they were lenient and therefore prioritized the approach of patching the ECOs by directly contacting the CO responsible to the greatest extent possible.

Another issue was related to the authoring of the structural description of the change order. Many PCs mentioned that some DEs would insist on defining the structural implications of the change order, which was technically the responsibility of the PCs. As asserted by almost all interviewed PCs, the DEs were not regarded as qualified to define structural conditions since their knowledge about the product structure was limited in comparison to the PCs. Hence, some back-and-forth communications would be triggered by this specific reason. This issue was said to originate from a flawed perception of the PCs' role (see *5.2.4 Role Awareness and Perception*).

ECO-Encompassed Product Knowledge

Product knowledge was commonly linked to ECO processing time as it was deemed to be a determining factor for how well the PC could understand and relate to hardware changes. Since 2D drawings represented the primary visual aid and often included assemblies of a large number of parts, prior knowledge of the change was often needed to fully comprehend the context of the ECO. The initial observations revealed that all PCs relied on these drawings and based their structural conditions on both the 2D drawings and the given change order descriptions. However, highlighted by a multitude of PCs was the common scenario of having to contact CO-responsible DEs to get additional information about the change order. One of the R5A2 PCs specifically stated that they believed that it was a symptom of lacking knowledge exchange. According to the R5A2 PC, they would purposely acquire information about the change order before receiving it to avoid doing it later after it had been sent in by the DE.

Moreover, one of the R5A1 PCs noted that early familiarization with the product enabled them to start working on defining TCR/VCR conditions early in the development phase, which would otherwise be done at a later stage.

Estimated ECO Size

Moreover, ECO workloads were viewed as difficult to gauge. The PCs collectively viewed it as an experience-based approximation that was made more challenging when coupled with unfamiliarity with the product change that the ECOs encompass. One PC in particular stated that there is practically no direct way of knowing if the delivered ECO will take 2 or 20 hours to complete. They further insisted that existing ways to get that information is via dissection of individual ECOs that are available in the system and look for their part and structural implications, as they are usually the indicators of how much time and work that will be required to process the ECO. Multiple PCs and managers of the PC groups highlighted the usefulness of being able to more accurately estimate the required resource commitment for each ECO before it is received, viewing it as beneficial for their forecasting initiatives.

In particular, variance in required ECO processing time made up one of the reasons why the R5A4 transmission group had abandoned the core use of PFtools as it did not provide any data about complexity of the ECO and thus the time required for processing it. Hence, when combined with undispersed ECO deliveries, a lack of knowledge about both the amount and size of ECO of deliveries made it difficult for other R5A groups to “trust” the data in PFtools.

GEO ECO

Another limitation, which primarily affects R5A5, was the inability to automatically fetch ECOs that require geometric assurance. Instead, each ECO has to be manually scrutinized and individually assessed. As previously established, since R5A5’s work relies on 3D parts being published in the design structure (KS) and structural conditions being formulated (TCR/VCR), there is a dependency between them and DEs. Therefore, information about whether or not parts have been published in the design structure is vital for them but is however not systematically supplied. This challenge is strongly related to delayed deliverables where DEs fail to deliver their parts in time for the geometric assurance deadline. Rather, as described by a member of R5A5, the group has no way of finding this information and exclusively rely on communications with and from DEs regarding the availability of 3D parts. Because of this setup, setting up the geometric assurance takes a relatively long time, being largely affected by both back-and-forth communication with DEs about missing parts and manual checks of ECOs.

ECO Updates

Coupled with the ECO processing difficulties, staying informed about changes made to ECOs that have already been geometrically assured was another challenge that mainly affected R5A5. After geometrically assuring and green-lighting the installation of the components covered by the ECO, there is no way of organically getting notified about changes made to the ECO unless the CO responsible contacts R5A5. Much like the tensions resulting from the manual assessment of ECOs, the inability to sense changes to already processed ECOs strains the geometric assurance group’s time budget as it leads to problems having to be solved late in the process. As asserted by the chassis DE, changes cost more the later they are done and, as noted by the R5A1 PC, the implications are inherited by R5A since they are “dragged” into the problem because of the nature of the process’ task delivery system. Hence, this was a problem that directly affected the ECO lead time in the process chain.

However, other R5A groups had been facing similar issues, such as the truck weight calculation team. To stay updated about changes in weight data, they used a subscription feature built into OAS to get updated information about changes made to weights of parts connected to ECOs and had delegated the responsibility of checking that to the team leader. Worth adding is that the bus weight calculation responsible was in the midst of creating a weight database and had not yet practically used their weight calculation system. Because of this, as noted by them, challenges related to keeping track of changes made to published ECOs may affect the bus weight calculation team in the future when their weight calculation system has been published and is actively maintained.

ECO Transparency

Something highlighted by both DEs and PCs was the transparency of ECO work. From the design engineers' point of view, awareness about if the assigned PC has received and started working on the ECO was of importance for their local stakeholders, especially at the lower maturation levels. Likewise, the product coordinators valued the activity status of the ECO as it aided their ECO forecasting abilities. Both sides claimed that PFtools was not being sufficiently used to communicate ECO processing progress. The R3D2 object leader specifically noted that they had no way of quickly getting information about the processing status of their group's ECOs without having to manually contact the assigned PCs. Similar comments were made by the PCs who on the other hand claimed that they had little-to-no knowledge about the ECO progress until the very last minute.

The R5A1 PC stated that some design engineer groups would wait until the last possible time to inform others about their delivery status. In addition, continuous status updates of individual ECOs were not consistently or systematically provided leading to PCs having to manually check the status via direct communication with the CO responsible.

ECO Follow-Up

There were also uncertainties about the accountability aspect of delayed ECOs and broken time plans. Recognized by the R5A1 manager was the need to improve the reliability of the time plans but more importantly press for ECO-information to be published in time. They added that the PCs should be more active in driving the follow-up efforts since support from project management was limited. By taking it upon themselves to follow up ECOs with missing time plans, the manager explained that it would hypothetically simplify their long-term planning as unreliable and missing time plans were the key factors that hindered them from adopting a broader outlook on incoming deliveries.

The R5A2 manager shared the same view on following up deliveries, especially in the long term, and further stated that it requires a change of mindsets in R5A being that it entailed a different way of working compared to what they were used to. Furthermore, they added that although special ECO follow-up days had been organized in individual projects by the P0 respondent and were received positively, they expressed the need for these efforts to become a permanent and continuous part of the projects to prevent issues from occurring and escalating.

The follow-up days (ECO workshops) were only organized because of the excessive amount of unplanned ECOs at the time. Identically, individual follow-up initiatives by the PCs were viewed in a similar way, calling for them to instead be standardized as an integral part of ongoing projects (see ECO pulse meetings and workshops below).

5.2.2 Variance in R5A's Way of Working

The R5A interviewees all claimed that more can be done to improve their collaborative efforts across the group boundaries. In particular, establishing standards for structural definitions in KS stood out as the aspect that most interviewees agreed constituted a limitation in their cross-group collaboration efforts. Also, the specifics of how structural changes were defined and indicated in the system varied between groups and individuals, something that was recorded on both an inter- and intra-group level. In summary, the following aspects were commonly brought up:

- Variance in technical work (KS/TCR/VCR)
- Limitations in cross-group collaboration
- Local planning routines
- Variance in cross-functional routines

Variance in Technical Work (KS/TCR/VCR)

The PCs acknowledged that there were inconsistencies in their groups and referred to other compatibility issues pertaining to their way of working. On a more technical level, there were noticeable variations in the way structural conditions were defined which varied from PC to PC even if they were within the same group. Despite there being some set guidelines and standards for structure and ECO work, the way of describing a change in the system and design structure (KS) could be done in a variety of ways where personal preferences and accustomed routines determined the way structure changes were described. As a result, cross-domain flexibility was limited making it difficult for one PC to cover the domain of another without prior familiarization. Consequently, in case one R5A group needed additional support in the form of temporarily placed PCs from other R5A groups, it would require them to be educated on the local way of working for the domain they would cover.

Many PCs called for the adoption of a common way of working, something that was also echoed by the department managers. Whilst the PCs were primarily interested in a unified ECO work process, the managers were more keen on finding a common project involvement approach. Interestingly, all interviewed R5A group managers agreed that adopting a collective and standardized approach would allow them to more effectively involve themselves in projects, yielding more bargaining power. Highlighted by PCs and managers alike, there was still an ongoing debate how to find their voices and systematically insert themselves in project discussions as some believed that being part of the newly established R5 branch would grant them more organizational influence.

Limitations in Cross-Group Collaboration (R5A)
However, since the underlying reasons for the organizational change were to promote knowledge exchange and cross-group resource allocation, the limitation in that aspect was viewed as a major detriment. The R5A5 manager was vocal about the need for more versatility in the R5A department, more specifically to enable PCs to step in and assist R5A5 by temporarily switching to geometric assurance when needed. That was however not the case since no PCs possessed the knowledge required to work on geometric assurance. Despite proposing to educate select PCs to make them deployable in R5A5 when needed, the manager stated that most R5A managers claimed that they did not have the time to commit to such a change. The R5A managers asserted that they were consistently inundated with work leaving no opening for realizing the cross-group initiative proposed by the R5A5 manager.

Local Planning Routines
Further differences were noted in the R5A groups' daily meetings, especially the ECO forecasting practices. For instance, R5A2 and R5A1 stood out as the only groups that sported a 30-day outlook on incoming ECOs deliveries, an approach that was adopted almost 6 months prior (relative to the time of the interview). The use of such prognoses was not as common in the remaining R5A groups. Prevalent in all groups, however, were the limitations of looking ahead beyond 14 days resulting from a track record of reliability issues with DE time plans and other factors (see 5.2.5 *DE-Induced Delays and Effects*). All interviewed PCs stated that PFtools was loosely used because of that reason and that it impacted the R5A groups' planning approach.

All in all, the differences in the way the R5A groups worked were considered by the object leaders, DEs and other non-PC respondents to be an issue that affected the quality of their work. Similarly, the variance in the way of working was acknowledged by the interviewed R5A managers who also recognized it to be a hindering factor for R5A's cross-functional influence. In addition, the absence of PCs in object meetings was considered detrimental as structural issues in the design would potentially be left undetected until much later in the process when the PCs officially receive the ECO which carries the information about the design change.

Variance in Cross-Functional Integration
Staunchly apparent were also the differences in cross-functional collaboration, in particular the DE-to-PC partnerships. Most PCs agreed that they have a reactive approach and a traditionally established habit of waiting for deliveries to be sent to them with little-to-no project involvement. This was seen as a mindset issue that originated from their historically passive project involvement routines. Some PCs actively involved themselves more than others and the level of engagement varied from one PC to another. For instance, an object leader explained that design engineers have varying experiences with PCs and that some were more constructive than others in their feedback about insufficient ECOs. In those cases, some DEs had noted how certain PCs were reluctant to interact and commit to fixing issues in a collaborative way, especially when an ECO was deemed insufficient and sent back. This inconsistency among PCs was further highlighted by the R3D1 manager who claimed that their DEs had brought it to their attention on multiple occasions.

5.2.3 Systematic and Unsystematic Integration Mechanisms (Product Coordinators and Design Engineers)

Even though there was a variance in how each individual PC crossed the functional boundaries, there were common outlooks on the challenges and benefits of cross-functional collaboration and inclusion. Moreover, there were different ways of establishing cross-functional links through both organic and non-organic means. Predominantly, the following integration methods were tried and commonly highlighted by the interviewees:

- Involvement in local DE process meetings
- Involvement in object and project start-up meetings
- ECO pulse meetings and workshops
- Direct communication - via in-person conversations, voice chat or Email

Involvement in Local DE Process Meetings

What became evident from speaking with PCs, object leaders and DEs in the chassis domain, was that design groups of the R3D wing were using a local process that was significantly different from other design groups' processes. This local process was modeled after the scrum method and, similarly, based on planning and working for a few weeks at a time (sprints). In the interim between those sprints, the groups would organize so-called "demo days" where select stakeholders from a range of different functions were invited to attend the meetings. The sprints were strongly connected to the objects and represented the design group's unanimous way of working, despite there potentially being multiple ongoing projects with a number of object leaders in the group.

Also, because of the domain-based links between R5A1 and the R3D groups, the object leaders of the R3D groups would often include PCs in their meetings to discuss issues. Therefore, as reflected in the qualitative differences between the PC groups, the PCs of R5A1 were more responsive to PC-DE involvement initiatives and, similarly to the R3D interviewees, mentioned comparable benefits of being cross-functionally involved in the meetings of select R3D groups. All respondents from R3D collectively asserted that, since adopting the sprint-based method, their quality of work had improved with benefits being reaped by managers and individual DEs alike. Thus, expressed benefits of sprint-based methods from the R3D managerial, object leader and DE point of views included improved cross-functional collaboration, higher productivity and higher group autonomy.

The manager, process developer and PC of R5A1 all considered their participation in the R3D demo days and planning meetings to have improved familiarization with the product. Also, according to the R3D object leaders, including the PCs in their meetings also helped them identify structural issues and allowed PCs to give feedback on ECO delivery plans. However, the PC from R5A1 noted that although working with early concepts had improved his knowledge of the product, there were difficulties in defining the structure for immature concepts which were often complexed by volatile designs. Ideally, the product coordinators need as much input as possible of the design change so that they can formulate adequate conditions in the product structure (KS). This was made more challenging to do in the conceptual phase of the design process when most information is underdeveloped and prone to changing.

Involvement in Object and Project Start-Up Meetings

In general, the object leaders are tasked to organize meetings for the objects that they are in charge of, giving them the freedom to include stakeholders that they deem to be relevant to their objects. Although some stakeholders are implicitly mandatory to incorporate, such as representatives of contiguous objects which share interfaces and have certain cross-depencies, the remaining participants are determined by the object leader. Speaking from experience, all object leaders shared the same view regarding the inclusion of PCs, stating that they were mostly neglected and rarely considered in the meetings but also highlighted some limitations when it came to the few instances where attempts were made to systematically involve them. Most commonly, when the object leaders would reach out to invite PCs to their meetings they would be met with the PCs claiming that they did not have enough time to attend, specifically alluding to an overabundance of work.

Nevertheless, they all mentioned that the PCs' presence in the object meetings would be favorable and beneficial to their work. In their experience, having them involved had always resulted in a positive outcome, often in the form of preventative or constructive feedback. However, there were varying views regarding the current involvement initiatives of product coordinators among the object leader respondents. Although most added that their inclusion was needs-based, one object leader in particular conceded that she would be unaware of issues unless they were explicitly brought up and communicated by PCs. They clarified that even though they strived to be as inclusive as possible, there was a reliance on all sides being transparent and communicative, referring to the poor representation of the PCs which made their incorporation into the object more difficult. In the view of the R3D2 object leader, receiving feedback on the progress of ECO processing was an example of a desirable outcome of including PCs in both the design group and object meetings. Other object leaders also highlighted the processing status of ECOs as a definitive limitation that impacted their ability to plan ahead, especially when ECOs are in the early status levels.

Touching on the topic of PC inclusion, one of the object leaders stated how having both a PC and a member of the geometric assurance team present in one of the object meetings resulted in the detection of a geometric clash before tools were ordered. Hence, future problems were prevented thanks to the insights from the, in that particular case, the member of the geometric assurance team. The object leader claimed that the PCs and R5A5 consistently provided valuable feedback when involved in object meetings and were therefore always considered in his own priority list. Worth noting is that the object leader in question was, at the time, in the early phases of an object upstart and emphasized the importance of including PCs and R5A5 in object meetings that he would be tasked to organize.

Still, as pointed out by one of the R5A4 PCs, knowledge about the schedule of the object-related activities and checkpoint meetings was limited. In fact, the PC claimed that they had no idea when or where the meetings would take place unless contacted by the object leaders which, in turn, did not necessarily seek to contact every domain-bound PC. In their experience, the object leaders with knowledge about the value of having PCs in the meeting would invite them but that it was generally uncommon for most object leaders to do so. Having attended a couple of object meetings, the PC spoke positively about the results especially when the meetings took place before the ECO status raises since it allowed them to discuss structure-related issues and dispersing ECO deliveries.

This was also the case for most other R5A interviewees who stated that they had little-to-no connection to object meetings. One of the R5A2 respondents highlighted that one had to be the one to take the initiative to be included in object discussion as there was a generally inaccurate perception that was attached to PCs. Elaborating more on said perception, the R5A2 PC explained that most object leaders and DEs view product coordinators as “administrators” and most likely do not know what knowledge they possess or what they can offer. As a personal “safeguard” and to assert his knowledge, the R5A2 PC claimed that they actively gave feedback and asked critical questions to DEs and object leaders pertaining to ECO details that were otherwise not mentioned.

ECO Pulse Meetings and Workshops
Meetings dedicated to the follow-up of ECO plans and statuses of ECO were said to be occasionally organized by the R5A2 and R5A1 groups. The respondents noted that they would only be organized when there was a need, typically motivated by a large amount of undispersed, unplanned or delayed ECOs. The pulse meetings would be entirely organized by individual PCs who were also tasked to invite desired attendees, those often being the DEs responsible for ECOs in question. Agenda-wise, the meetings would center around a walkthrough of ECOs in PFtools with the PC leading the conversation and asking for complementary and missing information not provided in PFtools. The expected results after the meeting are that ECOs get updated with an accurate time plan and other missing information be provided and added to PFtools.

All R5A2 and R5A1 PCs claimed that the pulse meetings yielded positive results in the form of changes done to correct the, at the meetings, highlighted issues. At the same time, the respondents felt that the pulse meetings were a more organized form of “hunting” their deliverables that should ideally be delivered to them without the need for back-and-forth checkups. In particular, the R5A1 PC, much like other R5A respondents, added that they would rather see these types of checks being systematically enforced by the project managers as organic checkup activities within the project.

Direct Communication
All PCs claimed that they had established rapports with most of the DEs that would frequently send them ECOs but collectively asserted that they were not systematic, routinely occuring or official PD process activities. Instead, a large portion of the interviewed PCs were relying on informal integration mechanisms to bridge knowledge and information gaps. Common was the use of voice communication to address incomplete ECOs and occasionally meeting up to collaborate to solve more elaborate structure-related issues. In addition, difficulties in

deciphering drawings and identifying individual parts in assembly drawings would also serve as common reasons that would lead PCs to contact DEs.

For instance, the R5A4 PCs of the electric subgroup purposely left gaps in their schedule which were allocated to 1-on-1 sit-down collaborations with their assigned DEs. As a result, the R5A4 PC claimed that the quality of their domain's structure was very high, measured by the amount of errors returned upon checking modular variant compatibility. Likewise, the R5A4 PC of the transmission subgroup had informal agreements with some of their DEs where they would drop by their desk to discuss issues that required close collaboration. Relatedly, a strong majority of respondents preferred in-person interaction over Emailing but added that because of the physical distance between the departments, especially after the Sep-19 restructure, voice communication was the most commonly used channel for communication. This was expressed by both object leaders, DEs and PCs.

However, a concern expressed by one of the R5A2 PCs was that the agreed routines could diminish over time as new designers join the DE groups, which was said to happen relatively often. In those cases which were said to have occurred in the past, the PC and DEs would have to reach out to each other and reestablish local standards for coordination routines and ECO writing.

5.2.4 Role Awareness and Perception

This theme deals with the cross-functional understanding of the roles within R5A, in particular how non-R5A respondents perceived the core tasks of PCs, geometric assurance and weight calculation. In addition, misalignments in the understanding of the role of COIN coordinators are also presented. The core subthemes were thus as follows:

- Empirically recorded perceptions of R5A - from the POV of non-R5A respondents
- Implications of perception-based challenges
- Role of COIN coordinator

Empirically Recorded Perceptions of R5A

Evident by the PCs', R5A5's and managers' combined experiences, there was a feeling that few people were aware of what R5A's core tasks were and the part they played in the ECO value chain. This perception was highlighted very early on in the study, being mentioned as early as in some of the preparatory observations. Hence, every interview with non-PC respondents would end with a question about the role of PCs and R5A5. What became apparent was that very few could describe the core responsibilities of PCs, often reflecting the skewed perception that some PCs had mentioned in the observation phase. However, the ones that gave an accurate description of the product coordinators' responsibilities were the respondents that had closely collaborated with them.

The less accurate descriptions came from respondents that had limited collaborational experience with PCs and ongoing distant partnerships. In fact, one of the project managers admitted that their idea of the product coordinators' role completely changed after organizing the

ECO workshops, stating that their view on the needs of product coordinators was previously unrecognized. Yet, much like a lot of other respondents, the project manager viewed PCs as a "quality net" in the ECO flow, stating that their main responsibility was to go through ECOs and "make sure that everything is correct". The quality net description was commonly mentioned by non-R5A respondents, where a notable amount did not acknowledge the structural responsibilities and ownership. Hence, the PC-given description of their responsibilities was, for the most part, not fully reflected by the non-R5A respondents (see survey results below for further comparisons). The same was recorded for the geometric assurance and weight calculation groups respectively.

Overall, a strong majority of the non-R5A respondents claimed that PCs were highly knowledgeable about the product structure as well as other aspects of the development process. Some also regarded the R5A5 group as a valuable source of constructive feedback that would provide improvement suggestions upon detecting an error. The COIN coordinator, who is also a project manager, noted that they highly regarded the expertise of the R5A groups, claiming that they were resourceful in more aspects than just the product structure. The test vehicle coordinator also gave multiple examples of scenarios where they would contact geometric assurance and PCs for a range of different types of questions.

More specifically, the R5A1 PC highlighted that they had played an instrumental role in the moving of projects across COINs, having been consulted by the project office about the ECO-related consequences since certain ECOs were dependent on each other. In that case, the R5A1 PC provided information about which ECOs needed to be implemented first and thus which ECOs to move and projects to reschedule since the project office's understanding of ECO-to-project dependencies was not sufficient to conclusively assess the viability of the move without consulting more knowledgeable parties. In general, consulting PCs was regarded as a common occurrence by both non-R5A respondents and confirmed by the PCs themselves as being a significant part of their daily work, taking up notable chunks of their time.

Implications of Perception-Based Challenges

Noteworthy was also the criticality and frequency of the role awareness-related challenges in the R5A groups, where the problem stood out as being most frequently occurring in the geometric assurance group. The R5A5 manager claimed that the absence of any mention of geometric assurance in the PD process made it time-consuming for their group to complete their work. Often, upon contacting DEs to ask for parts to be GEO-published, the DEs would not be aware of the importance of publishing their models, nor would they acknowledge the reason for R5A5 contacting them in the first place. According to the R5A5 engineer, reaching out to the DEs was a common occurrence because their parts (CAD) were not made available in the system in time for the ECO deadlines. As a result, taking time out to "ping" DEs was affecting R5A5's lead time. As such, R5A5 often establishes an unsystematic network of back-and-forth communications with DEs who have not published their parts in time for the geometric assurance.

Similarly, the R5A5 manager mentioned that a lacking view of what help R5A can offer may have been the underlying reason for why few DE groups would participate in the "quick meetings" that PCs and R5A5 periodically organize. In those meetings, common geometric deviations and ECO issues would be highlighted and openly discussed, utilizing the meeting as a way to solve problems in an integrated fashion. Much like the other cross-functional initiatives, the "quick meetings" were needs-based and not officially part of the standard PD process. The R5A5 manager noted that the DEs that had attended the meetings recognized their value and would use it as a forum when addressing future deviations.

The product coordinators also explained that random inquiries from other functions would take up a significant part of their daily work hours. In fact, most PCs viewed these inquiries to be misdirected and that in most cases they were not, theoretically, the appropriate persons to contact but that some functions insisted on doing it because of their multifaceted knowledge. The other R5A groups also made similar remarks, with the R5A5 respondents stating that they were mostly test vehicle-related. Hence, the opinion on the value of addressing outside of the group's core tasks was generally negative (see survey results below for more details).

Role of COIN Coordinator

Differences were also recorded in the R5A and P0 views of the COIN coordinator's role. Whilst one of the PC managers expressed the need for COIN-level coordination of deliverables to aid their ECO planning needs, the interviewed COIN coordinator clarified that their responsibilities were holistic in nature. Rather, they stated that the project managers of the COINs were ideally supposed to facilitate the coordination of project deliverables and make sure that projects are completed in a timely manner. Also, they further noted that their core responsibilities were centered around coordinating COIN milestones and, together with each respective project manager, determining the projects that should have common milestone integrations.

Limitations pertaining to general cross-functional role awareness were also mentioned by the non-PC and non-DE respondents, particularly those from the test vehicle and weight calculation groups respectively. The issues stemmed from difficulties in finding the individuals that could answer specific questions in the internal social network. The weight calculation engineer explained that there were no standard role descriptions or functional domain breakdowns that made it clear whether or not a person possessed the qualifications to answer queries related to their domain.

Moreover, the test vehicle coordinator along with the project manager and others underlined the difficulty in getting information out to the R&D organization and making sure that the relevant people stay informed. Being centrally involved in the Scania pulse meetings, the project manager spoke about the normality of functions not being aware of critical progression updates of contiguous departments and groups.

5.2.5 DE-Induced Delays and Effects

The DEs and object leaders clarified the different causes of ECO delays that stemmed from their activities but collectively noted that they frequently originated from different sources. Some of the reasons included:

- Delayed feedback from stakeholders
- Uncertainties in design plan
- Time constraints and ECO prioritization

Delayed Feedback From Stakeholders

Mentioned by all was the inheritance of delays from other functions that they depended on such as purchasing, suppliers and production. A common scenario was that suppliers would be late with providing part-essential information that would induce unforseen layers of complexity. The R3D1 object leader spoke of one instance where a supplier provided feedback on a part which required rework to be done to the design. After instituting the necessary changes per the feedback of the supplier, they had to wait for the revised quotation which was dragging and, as a result, causing them to stand still in the process. In general, back-and-forth communications with suppliers and purchasing were regarded as commonplace and time-consuming. Similar communications with production also stood out as detrimental from a delivery time point of view.

In another case, highlighted by the R3A1 object leader, a supplier could not provide an essential part in the specified time which was projected to be elemental in a large number of variants. The R3A1 object leader explained that they had to temporarily define another part that was going to be used in the meantime until the desired one was going to be delivered by the supplier. Because of this unforeseen change, a PC from R5A2 was consulted to assist with formulating the conditions in the ECO and structure to reflect the changes. Consequently, the R3A1 design group's capacity was held up to deal with the design implications of the temporary change, effectively delaying other deliveries.

Uncertainties in Design Plan

In addition, according to the interviewed object leaders and design engineers, general uncertainties in the design work also played a part in revising their initially set delivery plans. Partially related to the dependencies on the information-providing stakeholders, the uncertainties also pertained to the challenges associated with daily design work. Examples included unexpected feedback from stakeholders, test results and technical problems in the CAD software suite. Most object leaders noted that unexpected feedback in, for instance, the testing phase would sometimes require major redesigns to be done. Relatedly, as emphasized by most object leaders, the ECO-related work and notifying PCs about the revised plans would in most cases become a second thought in those cases.

Time Constraints and ECO Prioritization

Rushed ECOs resulting from project time constraints were also brought up as recognized problems that primarily affected PCs. The R3D2 object leader stated that they sometimes had to send incomplete ECOs to meet deadlines, even if test results were not factored into the design and that certain information was deliberately left missing. In one particular case, they explained that they were not able to wait for test results since they had exhausted their ability to push local deadlines and were “forced” to deliver the ECO with missing information. Also, they noted that projects with shorter-than-usual deadlines had become more common and that they often lead to an inability to fully complete their assigned work.

Moreover, the DEs and object leaders alluded to product-strategic prioritizations of projects as underlying reasons for not actively working on or informing about certain ECOs. More specifically, the DEs and object leaders explained that in a situation where multiple projects are being worked on, focus and resources are directed to the projects of the most strategic and financial value. Thus, ECOs connected to other projects become a second thought and thus are not attended to as diligently. As a result, the time plan accuracy and ECO quality of low-priority projects both go down in favor of the other projects. Relatedly, the implications of this include not actively addressing geometric clashes of low-priority ECOs, especially those that affect a relatively low number of module variants.

5.2.6 Project Structure and Management

Certain issues were attributed to the way projects were structured and managed, with respondents both directly and indirectly associating ECO-related problems with project-related aspects. Table 10 further down shows an overview of the projects that are referred to in this section. The most common project-related issues were:

- Project time plan (time to market)
- Project delays
- Project newness
- Project management and organization

Project Time Plan

Several respondents highlighted the implications of the way projects were organized and managed where they mentioned how certain projects would purposely be initiated with a tighter time plan and using an abridged version of the development process in order to minimize the time to market. Interestingly, the PCs were working on a couple of those projects and explained how the routines differed from “regular” assignments. Firstly, in project E, more emphasis was put on cross-functional coordination, calling for DEs to meet with PCs and other functions on a regular basis. The R5A1 process developer added that they were also taking part in the early discussions about the technical specifications, something they would usually do much later in the process. Likewise, the R5A1 PC said that they were closely collaborating with the DEs and object leaders of their domain and having daily meetings to continuously assess the structural progression. According to the R5A1 manager, they were using those experiences to explore ways of improving future collaboration strategies, potentially for project C.

The COIN coordinator mentioned that the company is considering a revision of their currently employed project portfolio approach where they ideally would like to work on less projects simultaneously in an attempt to achieve shorter lead times.

Project Delays

However, as noted by several PCs, project delays would also function as drivers for cross-functional initiatives, incentivizing functions to integrate and work more closely together to get the projects back on track. For instance, in project A, extensive issues in the early and mid stages led to an overabundance of ECOs being sent in to PCs around the same time frame. Therefore, the PCs were excessively backlogged and could not complete the ECO in allotted time of 14 days. The R4D1 object leader similarly highlighted one of those instances from the perspective of their previous role as product preparator. Much like ICD and weight calculation, the product preparators worked on the ECOs when in status 3:4 which made them susceptible to heavy ECO workloads. The object leader added that in one particular project that was heavily delayed, measures were taken to ease the concentrated ECO pressure by assigning a person from their group who would be in contact with the DEs to disperse the flow of ECOs.

Project Newness

Many interviewees correlated the newness of the projects with structural issues and overall problems with ECOs and the processing of them. Emphasis was also put on the understanding of the product as it was deemed to play a major role in formulation of the structural conditions (KS/TCR/VCR). The R5A2 PC explained that they were experiencing major delays in project D both due to inherited delays but also internally because of added complexity in their work. They clarified that project D introduced a completely new type of truck that was both incompatible with many existing parts but also introduced exclusive components. As such, efforts had to be dedicated to solving problems related to structurally describing those new components in the midst of regular deliveries from other ongoing projects. Hence, the situation spawned backlogs and forced the group to prioritize ECOs in order of most critical deadlines, an approach reportedly employed by DEs when faced with similar situations.

These scenarios were frequently brought up as hindrances by PCs and object leaders alike for actively attending cross-functional meetings. At the time of the study, the R5A3 group was facing a comparable situation in project B which was bus-exclusive. The R5A3 respondent claimed that they were backlogged with ECOs that had been submitted months prior and thus facing issues with DEs not remembering details about ECOs that required additional information. As a result, it was taking longer than usual to address individual ECOs due to the DEs having to refamiliarize themselves with the ECO upon consultation by the R5A3 PCs. Furthermore, adding on to the project newness implications, the R5A5 manager added that they needed more input data and collaboration with DEs when working on projects that made drastic changes to the modular “bygglåda” as opposed to projects that instituted modest changes. In addition to exchanging knowledge about the product, the R5A5 required contextual information about the parts included in the ECOs to more accurately deem the validity of clashes.

Project Management and Organization

In the opinion of the project manager, coordination efforts should ideally stem from the line organization, referring to the functional divisions of the R&D department. They went on to further assert that although the project office functioned as a “thermometer” that was tasked to make sure that the projects were on track, they also acted as a support function to members of the project. The project manager added that they only stepped in to remind and spread awareness of issues that they either detected or were brought to their attention. At the same time, they maintained that coordination efforts should preferably be built into the line organization and they did not want them to fully rely on the project management to fill the void.

Still, contrasting views were expressed by the PC respondents who were for the idea of systemizating ECO follow-up forums. Most notably, the R5A2 manager suggested that they would benefit from enforcing ECO follow-up meetings in the project as it would prevent issues from happening and, at the same, inform project stakeholders about their role and needs. The scarcity of any cross-functional forums involving the R5A groups was also a persistent theme brought up by all the R5A respondents. Some correlated the underlying reasons for this with the organizational structure. Non-PC respondents such as the ICD engineer specifically stated that they felt like the organizational setup organically encouraged individuals to focus on their assigned task and that few incentives existed for crossing the group boundaries, referring to each function as being "another brick in the wall". Similar sentiments were expressed by the R5A2 PC who alluded to the systematic encouragement to exclusively focus on one's own domain which, as previously mentioned, was historically the case within the PC groups.

Table 11. Overview of a few problematic projects that were mentioned by the interviewees where active projects (at the time of the study) are highlighted by an asterix

Project Name	Project Lead Time	Product Newness	Project Readiness
Project A	Normal	Very high	Heavily delayed
Project B	Normal	Very high	Delayed
Project C	Normal	High	-
Project D	Shorter than normal	Very high	Delayed
Project E	Shorter than normal	Very high	Delayed

5.3 Quantitative Study

This section contains the most topic-relevant results from the conducted survey.

5.3.1 DE and OL Survey

Below are the results of the survey that was tailored to DEs and OLs. Each item is presented and dissected individually where the leftmost bar in the chart shows the total distribution of answers of all the DEs, while the other bars showcase the results for each individual design department (2-letter acronym level).

Statement 2: I have a good grasp of how to properly write ECOs.

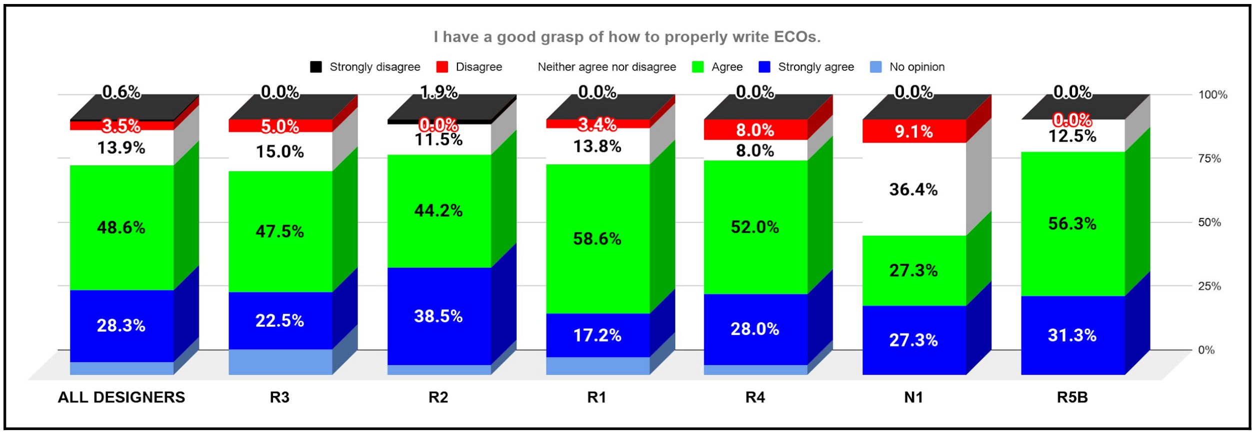


Figure 22. Responses by DEs for statement 2.

The DE's regarded their ECO writing knowledge to be high, evident by the majority of respondents agreeing or strongly agreeing with the statement. As illustrated in figure 22 above, ~77% of DEs concurred with the notion of them having a good grasp of how to properly write ECOs. The distribution of answers shown in the total summary for all DEs ("ALL DESIGNERS" bar) was reflected in all individual groups except for N1 where the percentage of neutral and disagreeing responses were almost tied with the concurring answers.

Statement 3: I have a good understanding of why I am writing an ECO and who the recipients are.

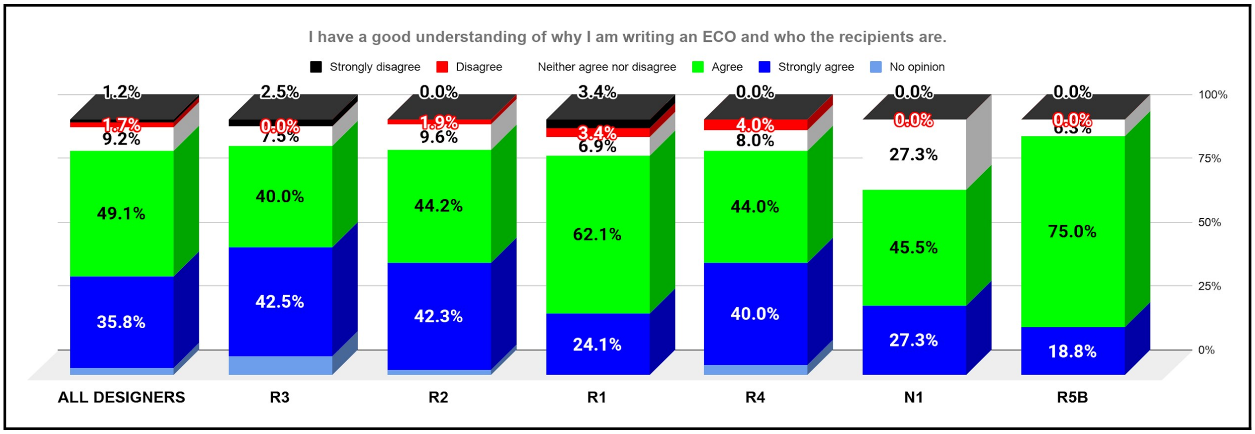


Figure 23. Responses by DEs for statement 3.

The DEs returned similar responses to the notion about their understanding of the reasons for writing ECOs and the recipients of them. Similar to the previous statement, the results were consistent across all design engineer groups. According to figure 23, N1 was the only group with a relatively high percentage of neutral answers (~27%) and R5B was the group with the most concurring views with 94% of responses being “agree” or “strongly agree”. Overall, the results suggest that DEs claim that they have a good understanding of why they are writing ECOs and who the recipients are.

Statement 4: I have a good understanding of the product coordinator’s role in the product development process.

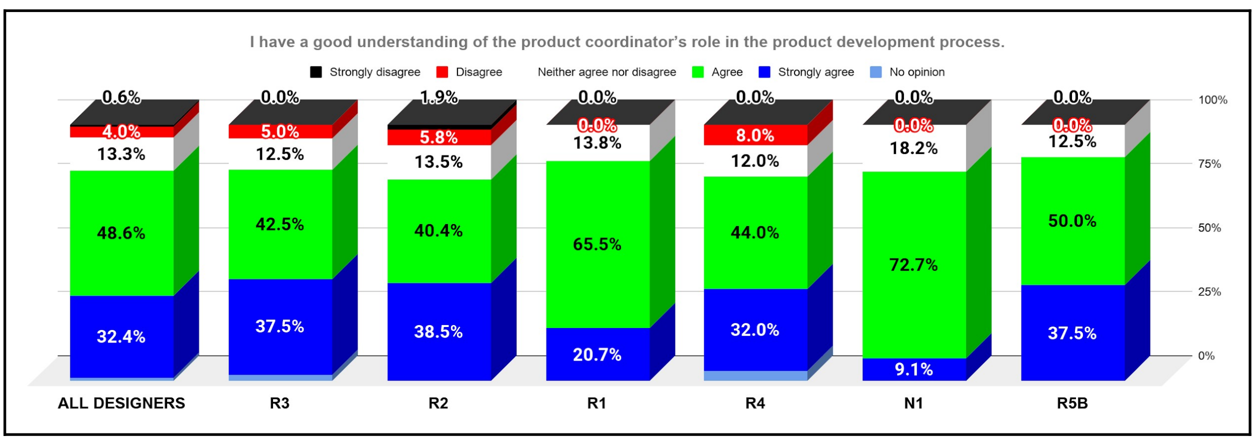


Figure 24. Responses by DEs for statement 4.

The design engineers concurringly viewed their understanding of the product coordinators role as good, with all design engineer groups having at least 76% of their answers being “agree” or “strongly agree” - see figure 24. Around 81% of the DEs feel that they have a good understanding of PCs' roles. No significant differences between the groups were observed.

Thus, the results of this Statement suggest that most design engineer groups claim to have an adequate understanding of the role of a product coordinator.

Statement 5: When my deliverables are delayed, I notify the affected parties that rely on them accordingly.

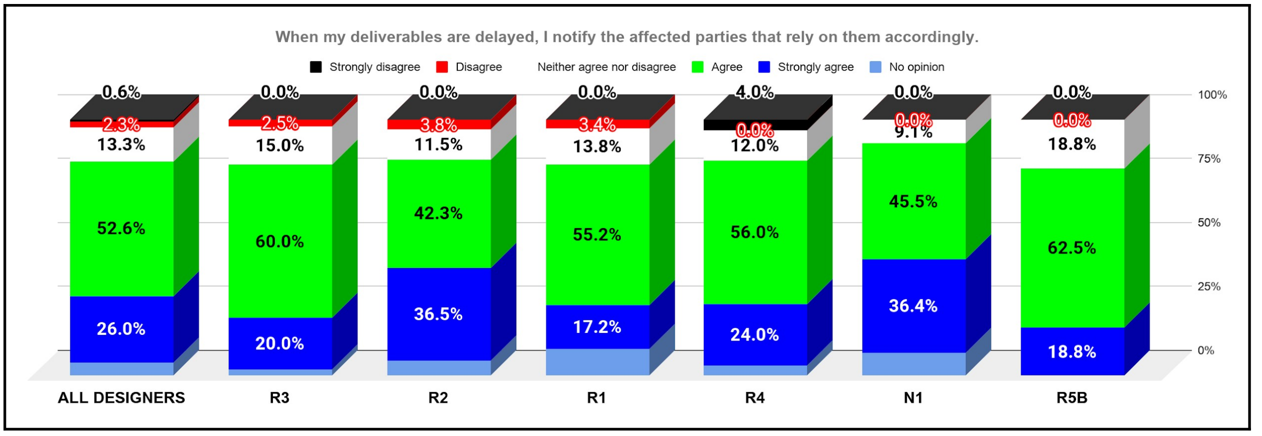


Fig 25. Responses by DEs for statement 5.

Routine-wise, the chart in figure 25 above suggests that a strong majority of inquired DEs (~79%) actively notify the relevant parties when their deliverables are delayed. With an identical distribution of answers across all groups, it can be concluded that all DE groups are in agreement regarding this Statement. The department which has more responses in this section is N1 with ~82% and very closely followed by R5B ~81%. But the responses from other teams were also in the range of 78-80%.

Statement 6: When I plan ECOs, I account for the product coordinators' workload.

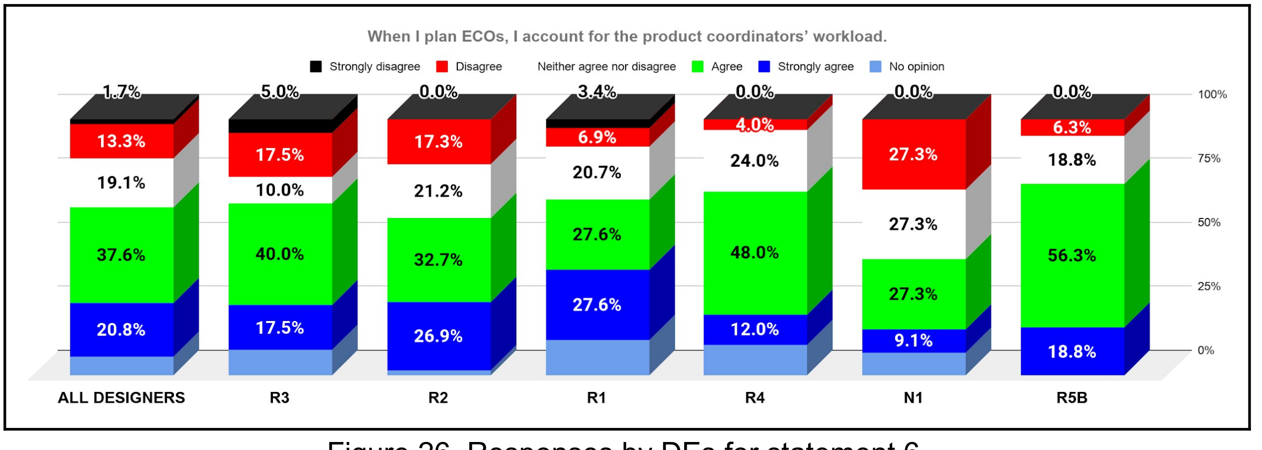


Figure 26. Responses by DEs for statement 6.

This chart shows the first signs of polarization with considerably more neutral and negative answers compared to the previous 5 Statements. Although the overall picture suggests that a majority of DEs account for the PC's workload whilst planning ECOs, the cross-group comparisons show more results of disagreement. In particular, the majority of respondents from the N1 group were either neutral or disagreed, accounting for ~55% of answers compared to the ~36% of agreeing or strongly agreeing answers. Significant percentages of disagreement can also be seen in R3 and R2.

Statement 7: When I plan ECOs, I account for the geo. assurance group's workload.

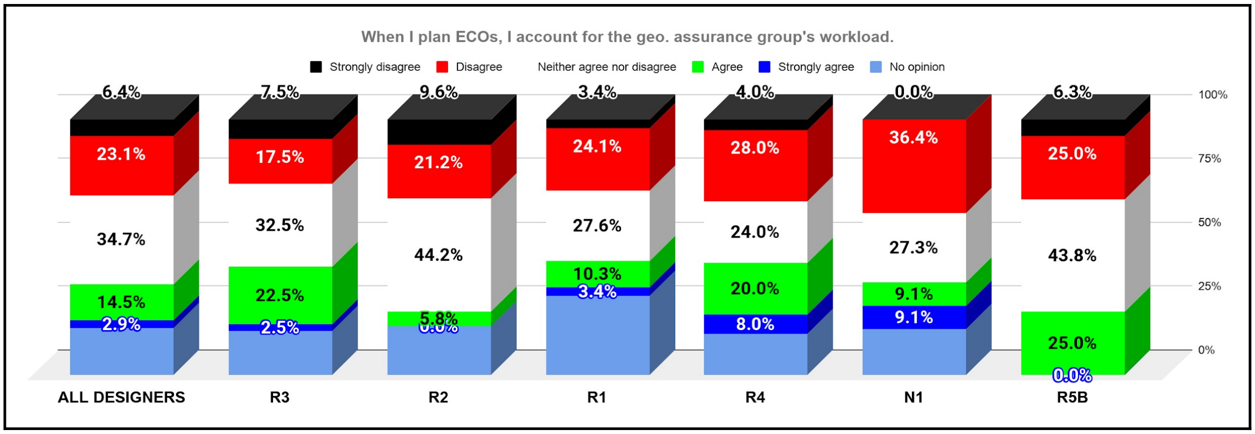


Figure 27. Responses by DEs for statement 7.

In regards to planning ECOs with the geometric assurance group's workload in mind (R5A5), a strong majority of DEs responded that they were either neutral, disagreed, strongly disagreed or had no opinion. This pattern was observed in all groups as shown in figure 27 above with few to no noteworthy differences. R3, R4 and R5B were the only groups with agreeing answers (agree and strongly agree) surpassing 20%. The percentage of neutral and non-opinionated answers was high across all groups indicating a high level of uncertainty regarding this topic.

Statement 11: Projects that introduce something new in the vehicle require more ECOs.

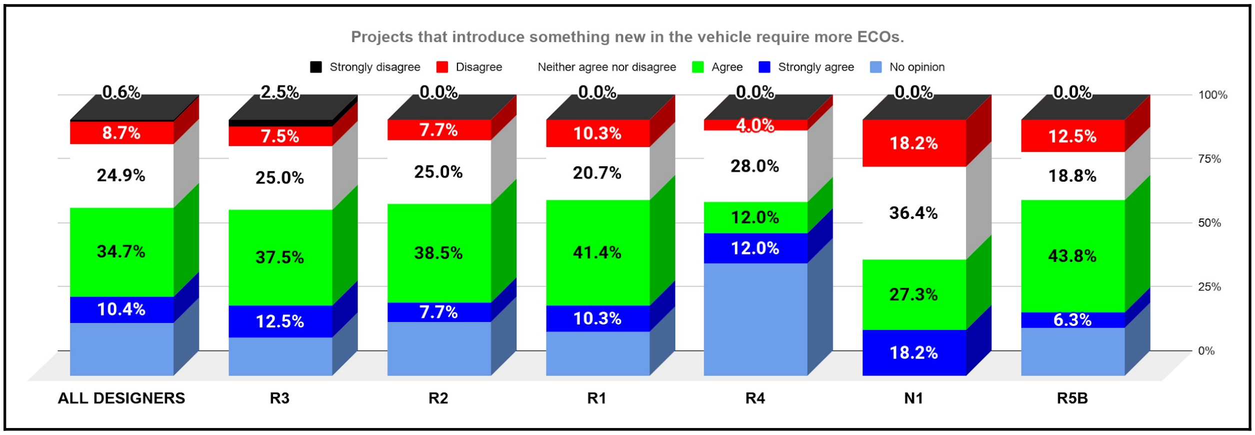


Figure 28. Responses by DEs for statement 11.

The Statement about the implications of project newness on ECO volume was generally met with uncertainty, yielding ~46% neutral and non-opinionated answers. However, notable numbers of agreeing answers were recorded in R3, R2, R1 and R5B, as shown in figure 28 above. R4 stood out as the biggest source of “no opinion” answers.

Reasons for ECO Delays

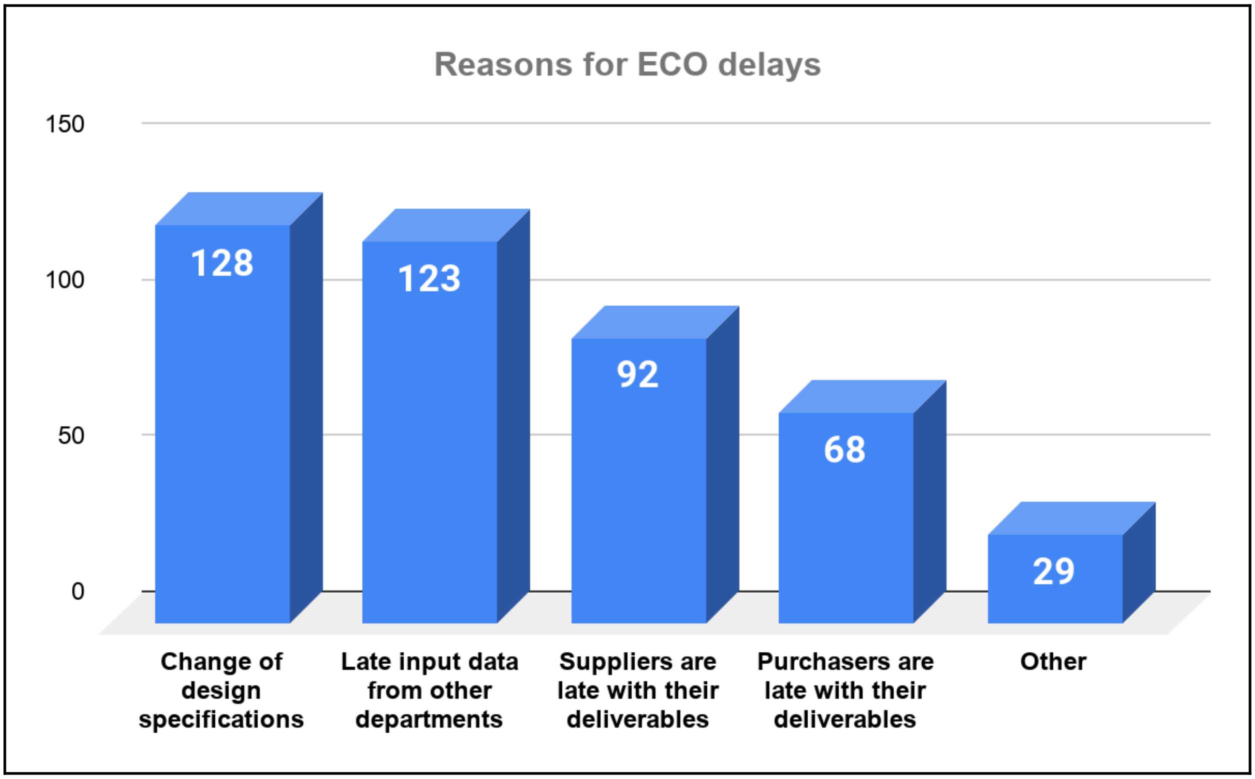


Figure 29. Chart visualizing most commonly stated reasons for ECO delays according to the (predominantly) DE respondents.

Figure 29 shows responses to the question about causes for delays in DEs work. Worth noting is that this was a multiple choice question with given alternatives. Both “change of design of specifications” and “late input data from other departments” were noticeably more common than other alternatives. Though, the other alternatives also pertain to the theme of late deliveries, with the exception of “others” which included open answers.

5.3.2 R5A Survey

Below are the results of the survey that was specifically tailored to R5A. Each item is presented and dissected individually where the leftmost bar in the chart shows the total distribution of answers of all the R5A groups, while the other bars showcase the results for each individual group (4-letter acronym level).

Statement D: I am backlogged with ECOs at the moment.

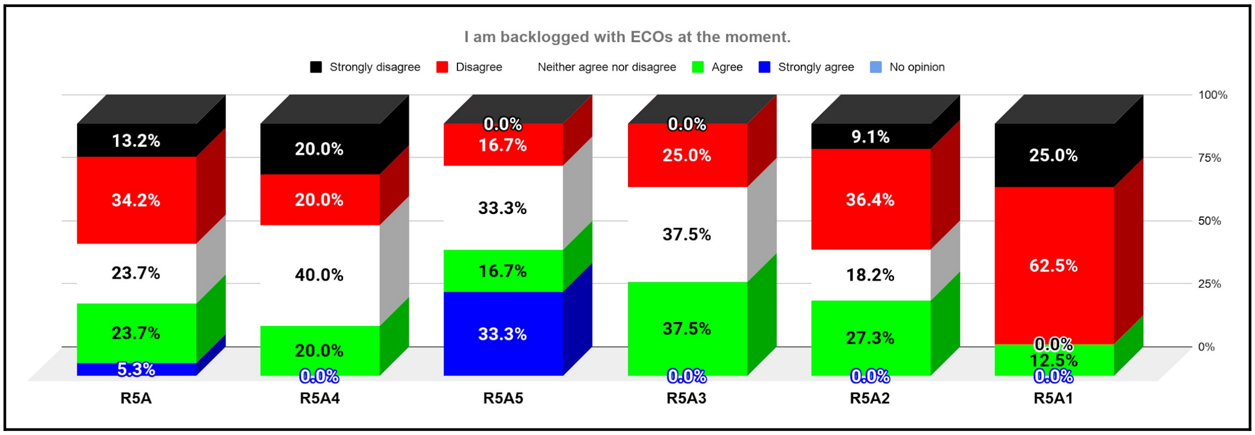


Figure 30. Responses by R5A for statement D.

Related to the ECO and ECM Challenges theme, this statement sought to gauge the current state of the PC’s ECO work. Figure 30 shows that R5A5, R5A3 and R5A2 had the highest percentages of agreeing answers with R5A5 standing out as the only group with a majority of “strongly agree” responses. Strong disagreements primarily stemmed from R5A1, with R5A2 and R5A4 also showing significant percentages of disagreeing responses. However, neutral answers were also common, being especially apparent in R5A4, R5A5 and R5A3.

Statement F: I know when I will recieve my ECOs and thus can plan my work accordingly

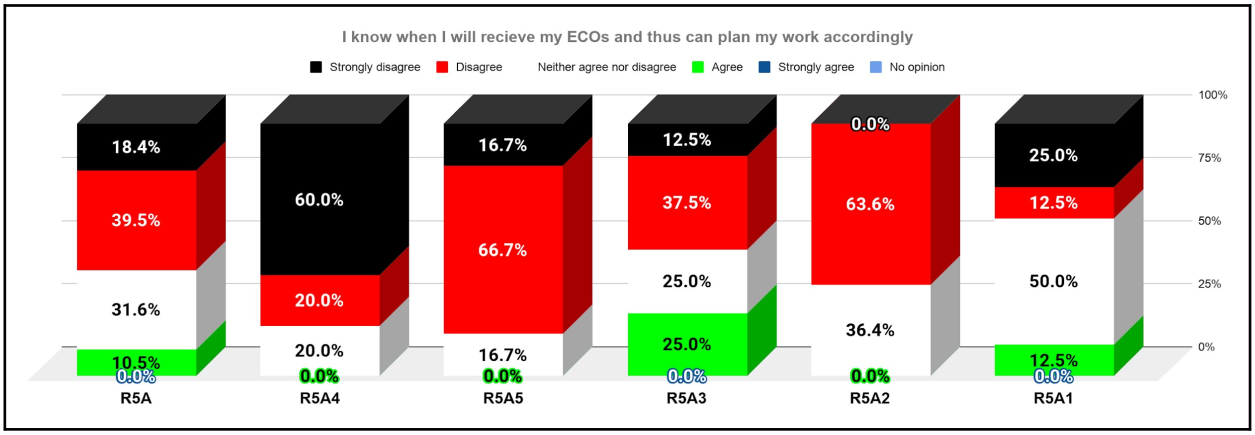


Figure 31. Responses by R5A for statement F.

The uncertainty regarding reception of ECO deliveries is clearly shown in figure 31 above, indicating that a strong majority of R5A do not know when ECOs will be received. Here, R5A4, R5A5 and R5A2 sport the biggest amount of disagreeing answers where R5A4 yielded the biggest percentage of strong disagreements making up 60% of their responses. There was also a significant amount of neutral responses from all groups.

Statement G: I have enough time to complete the work that is assigned to me.

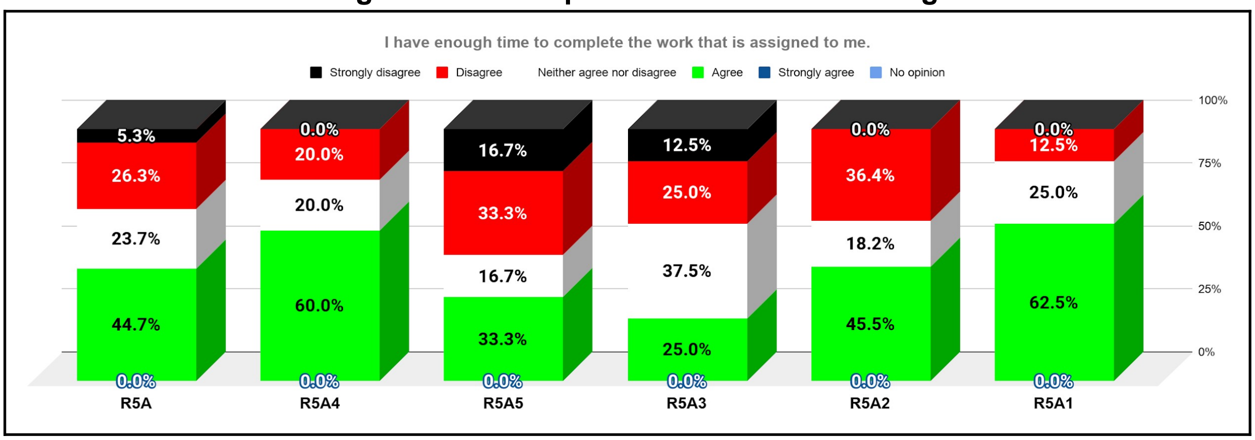


Figure 32. Responses by R5A for statement G.

Relatively dichotomic, the results in figure 32 show different views on the time required to complete assigned work. Whilst the general view suggests that most R5A respondents agree that the allocated time is sufficient, a closer inspection reveals that R5A3 and R5A5 sport a majority of combined neutral and disagreeing answers. Significant disagreements can also be found in R5A2 though, at the same time, R5A2, R5A4 and R5A1 make up the groups with a majority of positive responses.

Statement H: Being able to know when ECOs will be delivered is important to me.

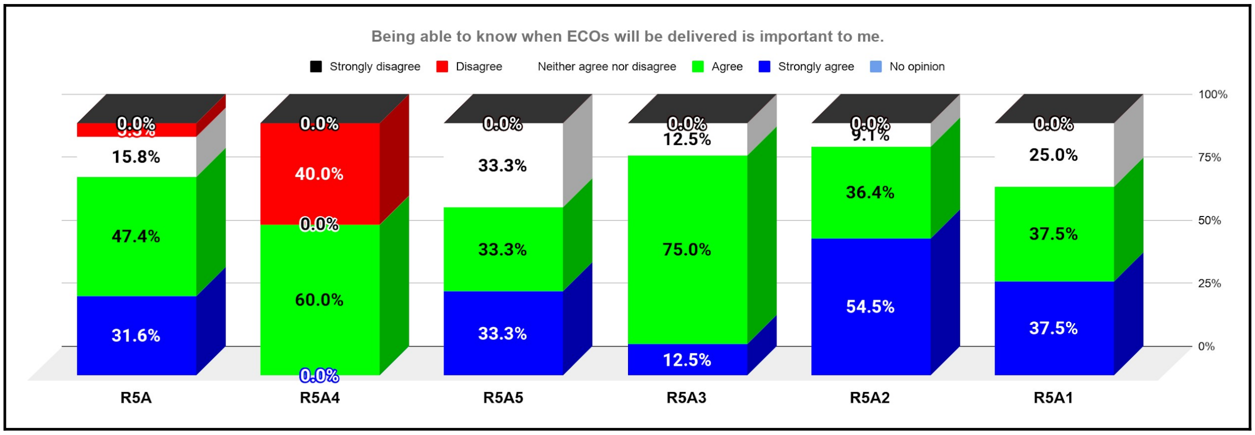


Figure 33. Responses by R5A for statement H.

Overall, the importance of knowledge about ECO delivery dates was regarded highly in all R5A groups, as illustrated in figure 33. However, negative views were expressed in R5A4 making up 40% of the answers. In addition, a notable amount of neutral responses were given in R5A5 and R5A1 indicating a certain level of reluctance. At the same time, however, the strongest agreements were recorded in R5A1, R5A2 and R5A5 showing that there exist different views within those groups.

Statement I: Being able to plan my work is important to me.

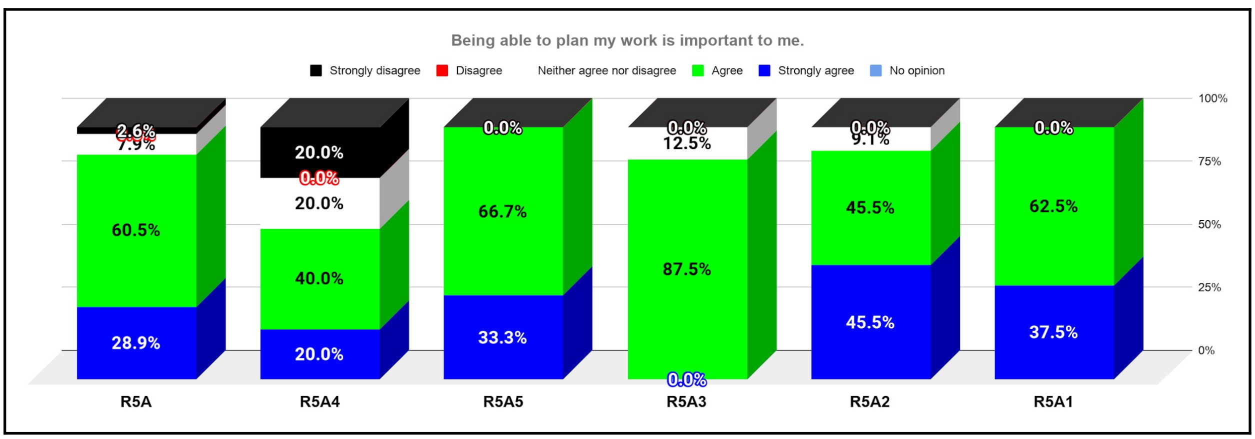


Figure 34. Responses by R5A for statement I.

Related to the previous statement, the importance of planning one's work was also held in high regard, receiving responses of higher certainty according to figure 34 above. In other words, the percentages of both neutral and negative answers were lower compared to the aspect of being able to know when ECOs will be delivered, while the amount of positive responses was considerably higher. Thus, the ability of planning one's work was regarded as an important aspect.

Statement K: Projects that introduce something completely new in the vehicle entail more work than other types of projects

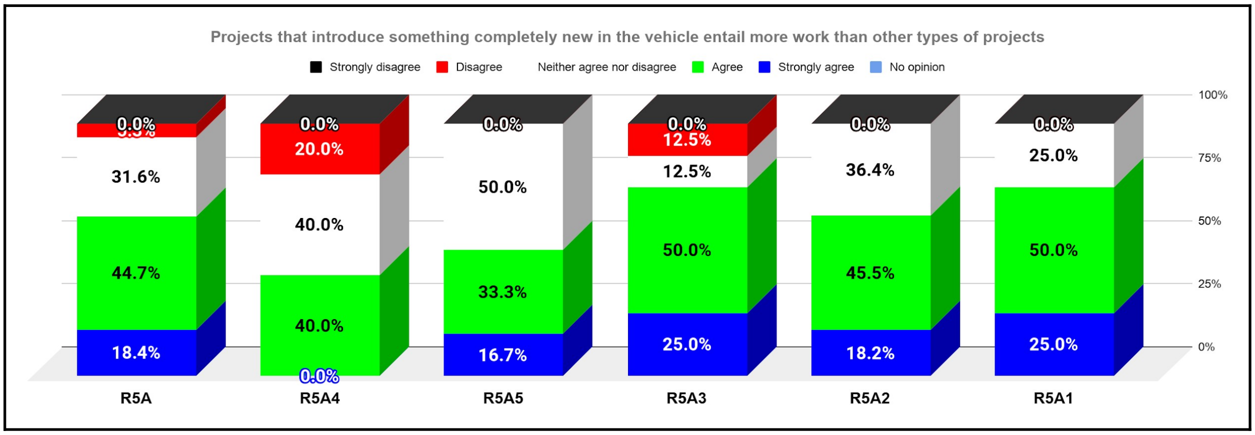


Figure 35. Responses by R5A for statement K.

Some uncertainties were also observed regarding the relation between project newness and workload. Similar to the results of the statement about ECO volume and project newness in the design engineer survey, a neutral response was common in almost all R5A groups. According to the charts in figure 35, R5A1, R5A2 and R5A3 had a clear majority of agreeing answers whilst R5A5 and R5A4 had closer results between neutral and concurring views. Negative views were minor in comparison and only recorded in R5A3 and R5A4. Overall, ~63% of R5A respondents concurred while ~37% were either neutral or disagreed.

Statement M: I often have to contact the CO responsible because their ECOs have incomplete or missing information.

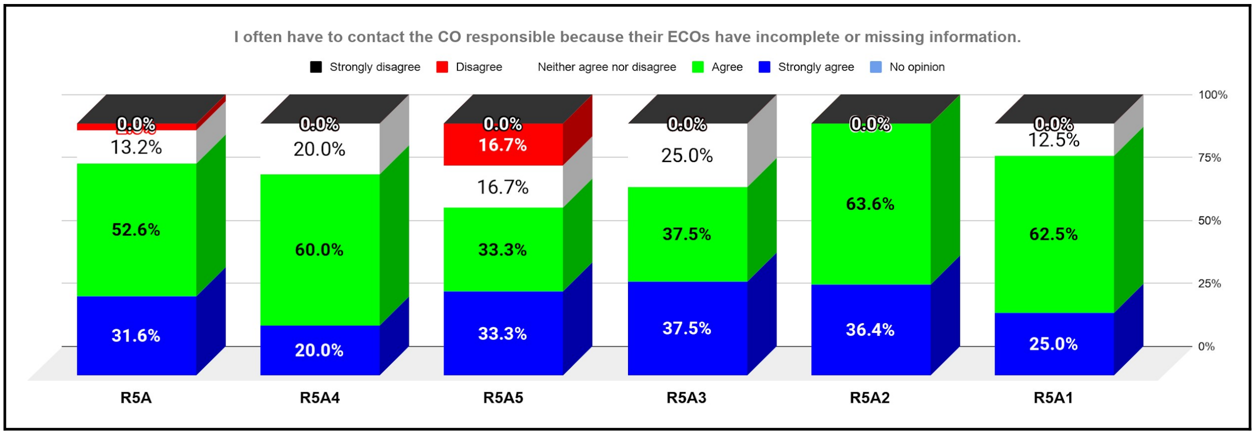


Figure 36. Responses by R5A for statement M.

A strong majority of PCs concurred with the statement about having to contact their CO responsible due to missing ECO information. This pattern was observed in all groups as shown in figure 36 above.

Statement N: When there are changes made to an ECO that I have already processed, I am notified accordingly.

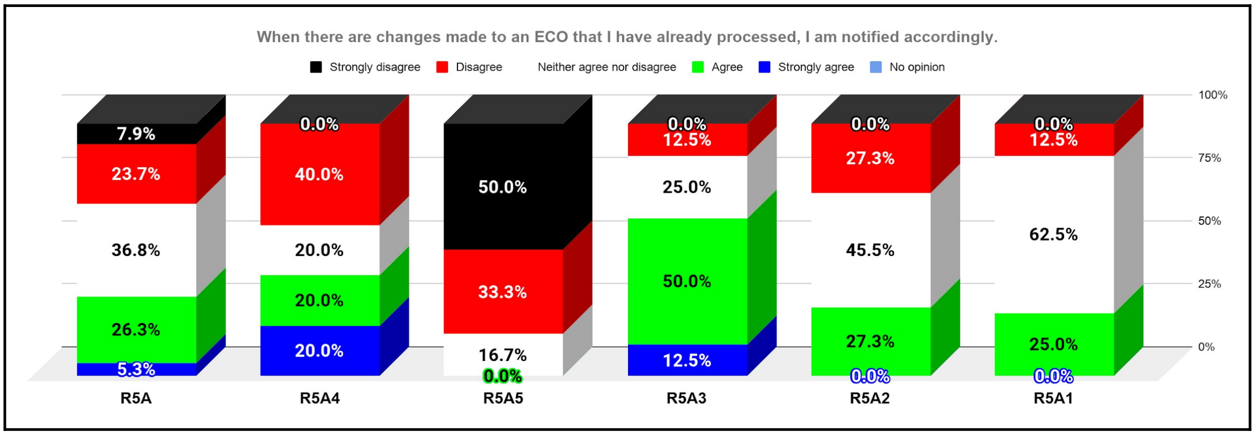


Figure 37. Responses by R5A for statement N.

The statement about updates being informed when changes are done to an already processed ECO yielded more dichotomic results (figure 37). R5A4, R5A5 and R5A2 stood out as the groups with the largest percentages of disagreeing answers, with R5A5 being the only group with exclusively neutral and negative responses. Whilst R5A1 had a significant number of neutral answers, R5A3 was the only group that returned a notable amount of agreeing responses.

Statement P: I feel like the design engineers have a good understanding of what information to put in the ECO.

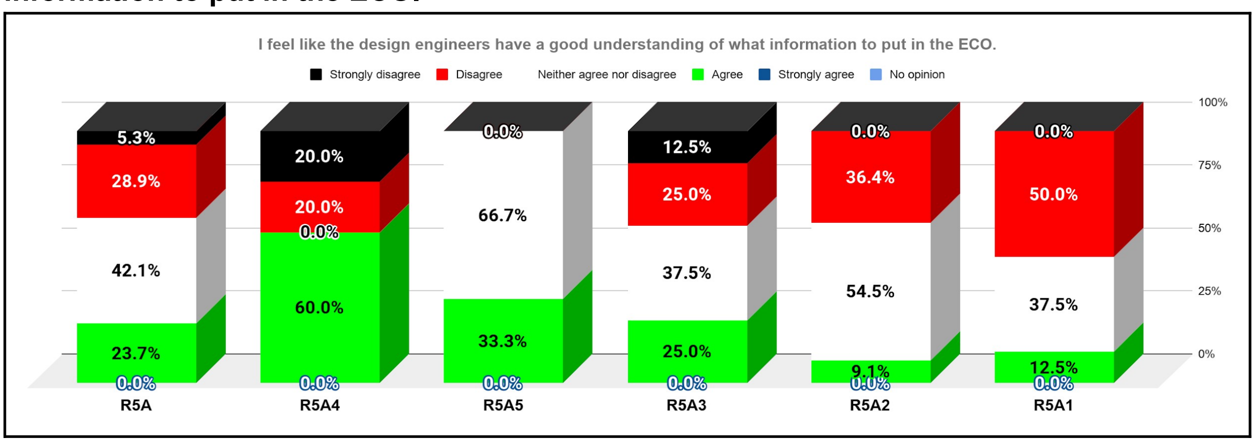


Figure 38. Responses by R5A for statement P.

The DEs understanding of ECO writing was viewed as poor evident by the large volume of negative reactions visualized in figure 38. R5A4 stood out as the only group with a majority responding positively. However, worth noting is that the neutral response was the most common answer.

Statement Q: I feel like design engineers know what my role is and what deliverables I need.

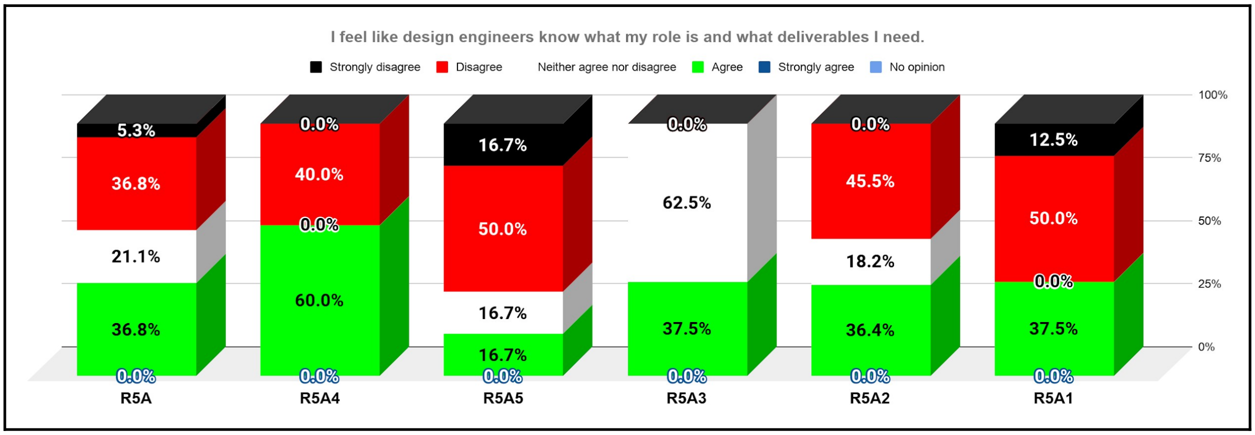


Figure 39. Responses by R5A for statement Q.

This statement stemmed from the PC's perception of how well the DE's knew the PCs role. A strong majority of PCs responded that they were either neutral, disagreed or strongly disagreed, indicating that they felt like the DEs did not fully know their role and desired deliverables. This pattern was observed in almost all groups as shown in figure 39 above. The top responses were neutral or negative in all groups except for R5A4 where the majority of answers were positive.

Statement R: I feel like other functions in Scania know what my role is and what my main responsibilities are.

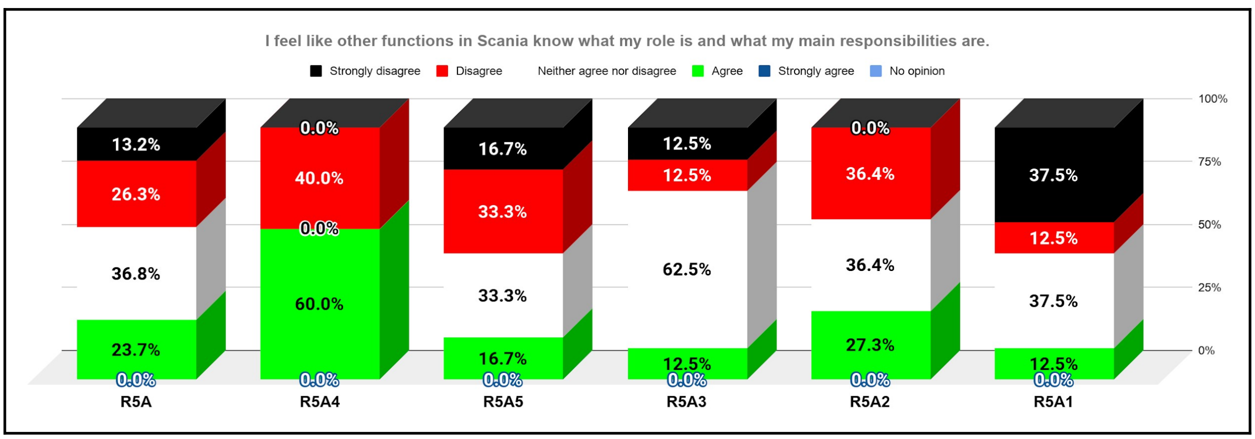


Figure 40. Responses by R5A for statement R.

In regards to other functions knowing PC role and responsibilities a strong majority of PCs responded that they were either neutral, disagreed and strongly disagreed. This pattern was observed in almost all groups as shown in figure 40 above. But in R5A4, the percentage of agreement (60%) is more compared to other groups. R5A2, R5A1, R5A5 and R5A4 were the groups with neutral and disagreeing answers (agree and strongly agree) surpassing more than 75%. We can also note that the percentage of strongly disagreed answers was high in R5A1 (i.e 37.5%).

Statement X: I can easily estimate how much time it is going to take to complete an ECO before I receive it.

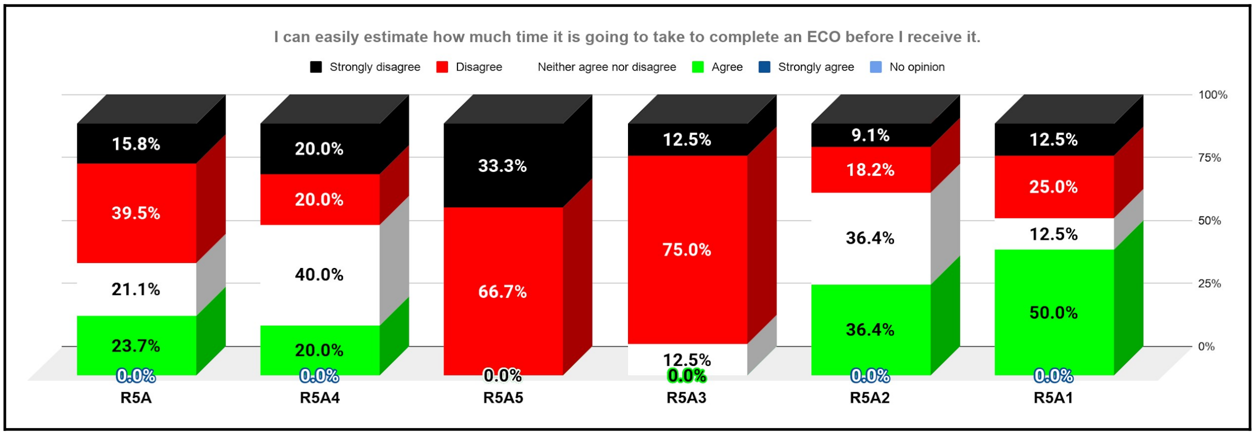


Figure 41. Responses by R5A for statement X.

In regards to estimation of how much time it is going to take to complete an ECO before the PC receives it - a strong majority of PCs responded that they were either neutral, disagreed and strongly disagreed. This pattern was observed in all groups as shown in figure 41 above. However, R5A2, R5A1 and R5A4 were the only groups with agreeing answers (“agree”). The percentage of disagreeing answers (“disagree” and “strongly disagree”) was high in both R5A5 and R5A3 groups, indicating how unsure PCs within those departments are in estimating how much time it will take to complete an ECO. Neutral responses were recorded in all the groups but in R5A4 it corresponded to 40%. In summary, all R5A groups indicated, to different extents, that estimation of the time required for completing an ECO was not viewed as easy.

Statement Y: I have a good understanding of the product and project that I am working on.

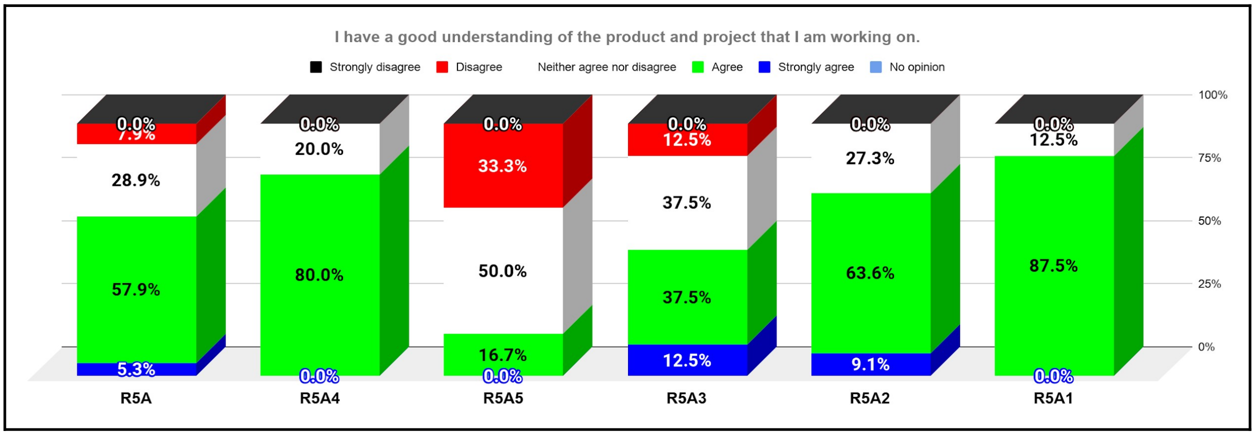


Figure 42. Responses by R5A for statement Y.

Figure 42 above suggests that PCs (~63%) generally have a good understanding of the product and project which they are working on. But there were differences in responses within the groups. There is an identical distribution of positive answers across R5A1 (~88%), R5A4 (80%) and R5A2 (~73%) where responses were more in agreement with the statement. Another notable thing to be seen in this graph is that disagreements were only recorded in R5A5 and R5A3. In R5A5, neutral and disagreeing answers corresponded to ~83%, clearly overshadowing the concurring responses.

Statement Z: Knowing the product I am working on is important to me.

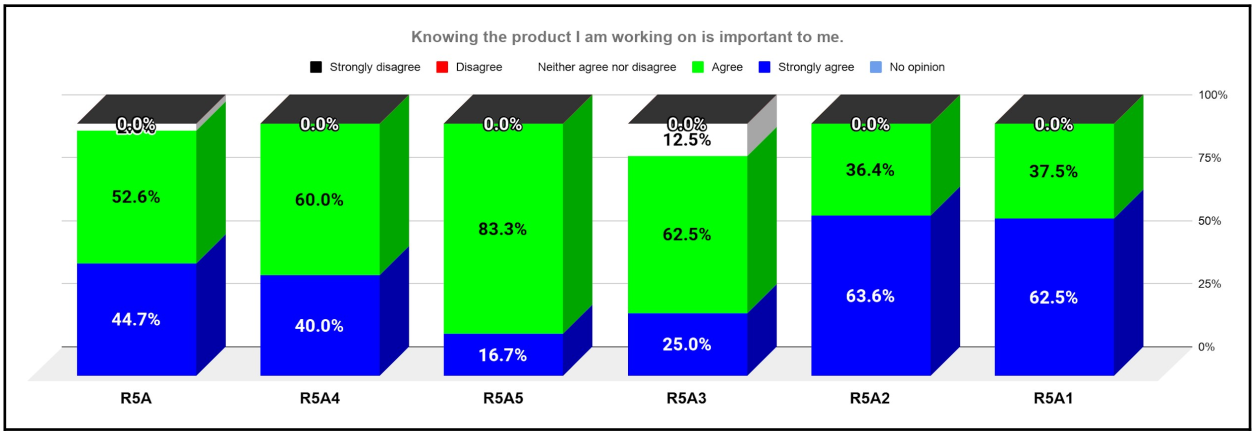


Figure 43. Responses by R5A for statement Z.

Being knowledgeable about the product that is being worked on was highly regarded in all R5A groups as illustrated in figure 43, with a very clear majority of respondents (~97%) agreeing with the statement. However, no negative views (“disagree” and “strongly disagree”) were expressed in the responses from the groups. Yet, there is some variation in responses within one group. In R5A3, neutral responses were recorded which only accounted for 13%. From this graph it is evident that having knowledge about the product is an important factor for the R5A groups.

Statement AD: Please rank the following in the order of importance

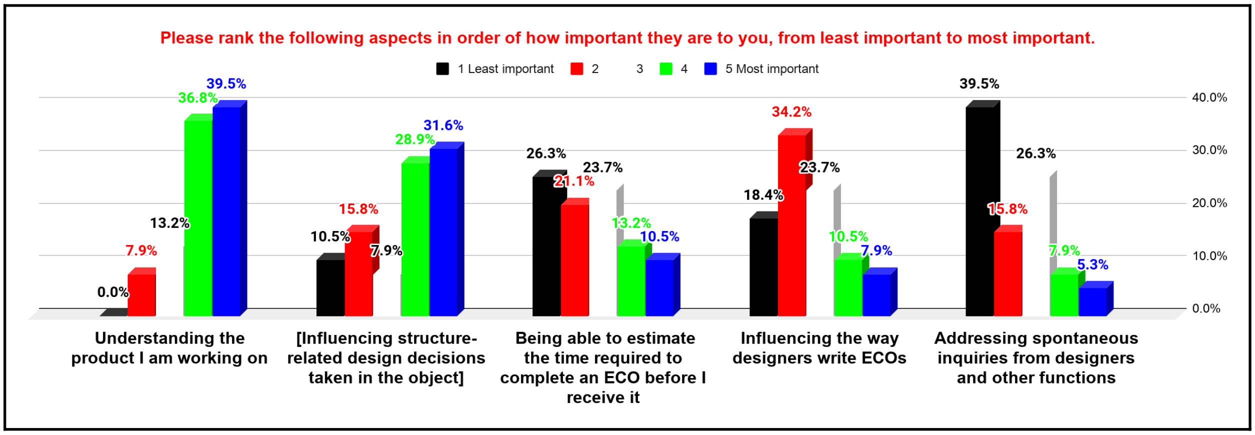


Figure 44. Responses recorded by PCs among the five factors which they perceive that are important to them.

Figure 44 shows responses recorded by PCs among the five factors which they perceive that are important to them. We can see from the chart that, *understanding the product* is the most important aspect and has ~77% of votes from the PC. No response has been registered for least important in this section. The next important work that PC’s feel is *influencing structure related design decisions taken in the object* which received around 60% of the votes. 45% of PC’s either feel neutral and less important for the option *estimation of time required to complete an ECO* because PC’s currently have no measures to estimate how much time an ECO would require to be worked upon. Around 35% of PC's feel that *influencing the way designers write the ECOs is less important.* The least important work which PCs feel is *addressing spontaneous inquiries which corresponds to ~40% of the votes*, and the reason is because PCs feel such activities take up more time during their work.

Statement: List of methods tried to communicate or coordinate deliveries with DEs

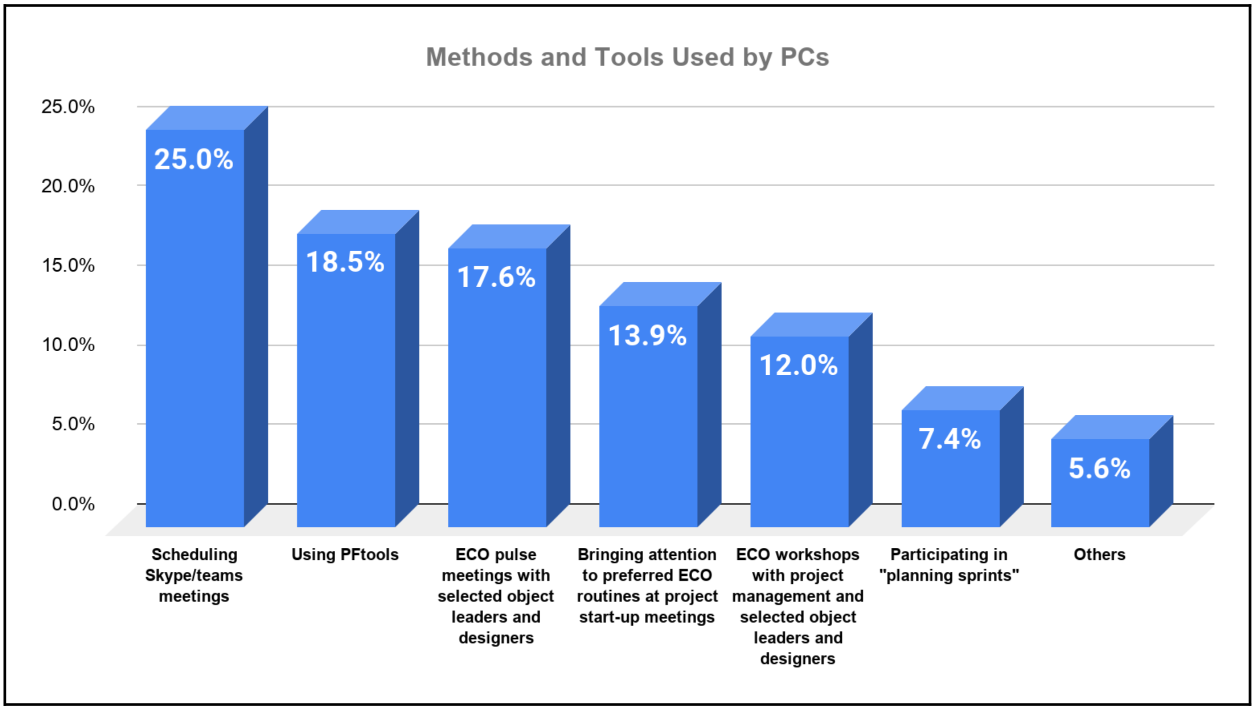


Figure 45. Responses by PCs regarding attempted coordination methods.

Figure 45 shows the coordination methods that the PCs have tried with DEs. Worth noting is that this was a multiple choice question with given alternatives. Direct communication via Skype or Teams yielded the most amount of responses followed by utilization of PFtools and ECO pulse meetings.

5.4 Intra-group Analysis

Product knowledge was considered a highly important aspect as made apparent by the charts for statements Z and AD, with the latter showing that it was the highest valued out of the 5 given aspects. The results solidify the weight of product knowledge for the R5A groups, something that was highly touted in the interviews. The correlation between an increased product knowledge and cross-functional integration can be seen as positive evident by the experience of the PC respondents that had been involved in project and object meetings with DEs and object leaders. For example, the R5A1 PC's close collaboration with their DEs on early concepts of the object had definitively resulted in a better understanding of the product. In general, better familiarization with the product generally resulted in less questions being asked therefore requiring less time to process the ECO compared to the scenario where the PC had no prior recollection of the ECO-encompassed parts.

The results for statement G (time to complete assigned work) showed that R5A3 and R5A5 stood out as the groups with the highest combined total of neutral and negative responses which can be attributed to their situational workload at the time of the study. As highlighted in the interview data, the R5A3 respondent claimed that they were inundated with work that had been caused by a string of delays that they had inherited in the form of undispersed deliveries.

Also, the R5A5 group had a recognized manpower issue which rendered them unable to work at full capacity. The symptoms of this issue were further accentuated by the identified ECO problems (ECO and ECM Challenges limitation sub themes) that were brought up by the other R5A respondents. As a result, they were prioritizing their tasks and skipping the geometric assurance of non-critical domains. Moreover, the extent of R5A3 and R5A5's backlogs are clearly shown in the bar charts of statement D. Thus, the deviation of those two groups in particular as shown in the bar charts were expected.

However, the polarized views represented in the R5A2 charts of the same statements show a stark difference of opinion within R5A2 regarding the situation about having enough time to complete assigned work. Similarly, the statement about current backlogs also show deviating responses of noticeable proportions within the group. As covered in the qualitative data, some R5A interviewees noted that certain domains may at times be more backlogged than others due to, for instance, their inherent complexity. This was also hinted at by the respondents who had pushed for better ingroup collaboration and more unified ways of working. Therefore, the differences within one group, R5A2 in this case, may be a reflection of domain-dependent workloads in the group.

Certain findings from the interviews were confirmed by the survey results. Particularly, the issue pertaining to unpredictable ECO deliveries (ECO planning and undispersed ECO deliveries), which was frequently mentioned in the interviews with the PC respondents, was reflected in the chart for statement F where a clear majority disagreed with the notion that they were able to predict incoming ECO deliveries and plain their work accordingly. The staunch disagreement coupled with uncertainty represented by a substantial amount of neutral responses shows that the issue is prevalent in all R5A groups. In addition, the results of statement H, which was based on statement F, further solidify the importance of the awareness of ECO deliveries, with a clear majority emphasizing their agreement with the given statement regarding the importance of accurate forecasting of ECOs. Furthermore, the value of being able to plan one's work, represented by the chart for statement I, was also viewed as an important aspect evident by the high number of concurring responses. Therefore, it can be concluded that accurate information about ECO deliveries is something that all R5A groups agree is not being consistently supplied but should, ideally, be provided as it is considered to be valuable information for them.

Interestingly, the results of statement 7 echo what was insinuated by the R5A5 respondents regarding the ECO deliveries being optimized for their capacity. The high level of uncertainty illustrated by the large amount of neutral and non-opinionated responses suggests that DEs currently do not account for the R5A5 group's workload when planning ECOs. Relatedly, the bar chart for statement N clearly shows the criticality of this issue with an alarmingly high number of R5A5 respondents strongly disagreeing with the notion that they are notified when changes are done to an already processed ECO. This indicates that the issue is group-wide and strongly detrimental, further amplified by the absence of any concurring responses for that particular statement. In fact, the results for statement 5 indicate that the DEs generally do not recognize R5A5 as main stakeholders of their deliverables. This can be directly related to one object leader's remarks about how they considered PCs and R5A5 to be "gatekeepers" as opposed to functions involved in ongoing DE work, a theme that was commonly brought up by DEs and object leaders.

Constrastingly, the DEs appeared to be remarkably more certain about accounting for the PCs' workload as illustrated in the bar chart for statement 6, highlighting another point of contention between DEs and PCs. As mentioned in the interviews, undispersed ECO deliveries made up one of the most central challenges which were said to stem from the DE's not spreading out their ECO deliveries. Although no such statement was included in the R5A version of the survey, yielding no quantifiable results for that topic, the challenge was considered so central and commonly mentioned by all PCs that it was not included in order to make room for more uncertain themes. Thus, these findings imply that there is a major difference in opinion on how well ECOs are planned and optimized for PCs. In addition, there is a strong indication that R5A5 is not considered to be an essential stakeholder by the DE departments.

5.5 DE-PC Comparative Analysis

Some contrasting differences in opinions were recorded from PCs and DEs. Figures 80, 81 and 82 (Appendix B) visualize some of these differences, in this case for DEs and PCs within the same domain and that interact with each other (R5A1 and R3D). Since the R3D department was chassis component-based, they were closely linked with R5A1, the product coordinator group responsible for structural description of chassis components. Table 13 (Appendix B) summarizes some of the major differences, one being the polarized view of the ECO writing knowledge. Although a clear majority of R3D members felt that their knowledge of ECO writing was sufficient with an overwhelming percentage of concurring responses, the R5A1 respondents, on the other hand, clearly disagreed as 50% of responses were of the option "disagree". With the neutral option being a close second in terms of vote percentage, the indiciation is that the R5A1 group clearly has a less favorable view on the ECO writing skills of their design engineer counterparts. The same pattern can be observed when comparing the complete set of results. Hence, it can be concluded that there is a misalignment in ECO writing standards between DE and PC groups.

Also related to perception-based challenges was the difference in how the two roles perceived each other's core tasks and main areas of responsibility. Again, the DEs regarded their knowledge of the PCs' role in the product development process to be adequate with a sizable number of concurring views on that statement (statement 4). The R5A groups' opinions, in contrast, were telling a different story, clearly showing that they did not believe that the DEs had a good grasp of what the PCs' roles were (statement Q). Interestingly, this was also shown to be that case when it came to their views on other functions and roles' understanding of their job (statement R). This topic also emerged in the interviews where the PCs frequently highlighted the case of ECOs missing crucial information or being lacking in several fundamental aspects. The bar charts of statement M, which is directly based on this theme, clearly show that a large majority of R5A groups consider the back-and-forth communication with DEs for acquisition of missing ECO information to be a common occurrence. Furthermore, specific examples regarding issues about the DEs' often flawed understanding of ECO writing given by the PCs of R5A3, R5A4 and R5A1 also illustrate the frequency of these types of issues (subtheme incomplete or missing ECO information). It is thus apparent that fundamental and practical aspects of ECO writing are sources of contention that need more focus.

The differences between statements 11 and K show that the R5A groups were more assured about the ECO workload-related effects of projects that introduced new components (project newness). As highlighted, the DE groups reflected a high level of uncertainty with a large amount of non-opinionated and neutral responses regarding the implications of project newness on ECO volume. One plausible reason is that the R5A groups have more hands-on experience with ECOs, working on defining the structural conditions and combinatory validity (PCs), as well as accessing geometric parts for clash assurance, weight calculation or creation of bodybuilder drawings (R5A5, weight calculation, ICD). Thus, in the case of PCs, unfamiliar additions to the structure may entail more uncertainty and require more effort to define and describe, hence requiring more work.

However, worth noting is that the DE statement (statement 11) referred to the relationship between ECO volume and project newness whilst the R5A statement (statement K) specifically associated workload with project newness. Due to the variance in ECO writing and the technical specifics of how big an ECO is, typically measured by the number of parts that are introduced, the DEs may not necessarily regard ECO volume as a direct measurement of workload. Hence, the two statements, although partially related, were intrinsically different. Interestingly, ECO size approximation was one of the most frequently mentioned topics in the interviews, being cited by many respondents as essential for their ability to plan. In fact, some R5A groups had purposely abandoned existing ECO coordination tools (PFtools) partially because of the absence of any ECO size approximation, further highlighting this as a core issue.

The ECO size-related difficulties were further highlighted by the charts for statement X, which clearly show that a majority of R5A respondents can not easily approximate ECO workloads before receiving them. Coupled with the results that indicated that the R5A groups generally viewed planning and knowledge of incoming ECO deliveries as important (statements H and I), it can be concluded that ECO size is to be regarded over ECO volume as a more accurate measurement of workload.

5.6 Proposed Solutions

This chapter introduces the conceptual framework of solutions that was created to address the identified empirical challenges.

5.6.1 Conceptual Framework of Proposed Solutions

Based on the analysis of the recorded results from both the study of Scania's tools and processes, interviews and survey, a 3-tier modular framework of solutions was proposed. The solutions are divided into tiers (tier 1, 2 and 3 respectively) on the basis of factors such as employee involvement, ease of implementation of the solution, and how much effort is required to change from the existing way of working (organization restructure). Figure 46 below summarizes all individual concepts in the framework and illustrates the modular link between some of the concepts.

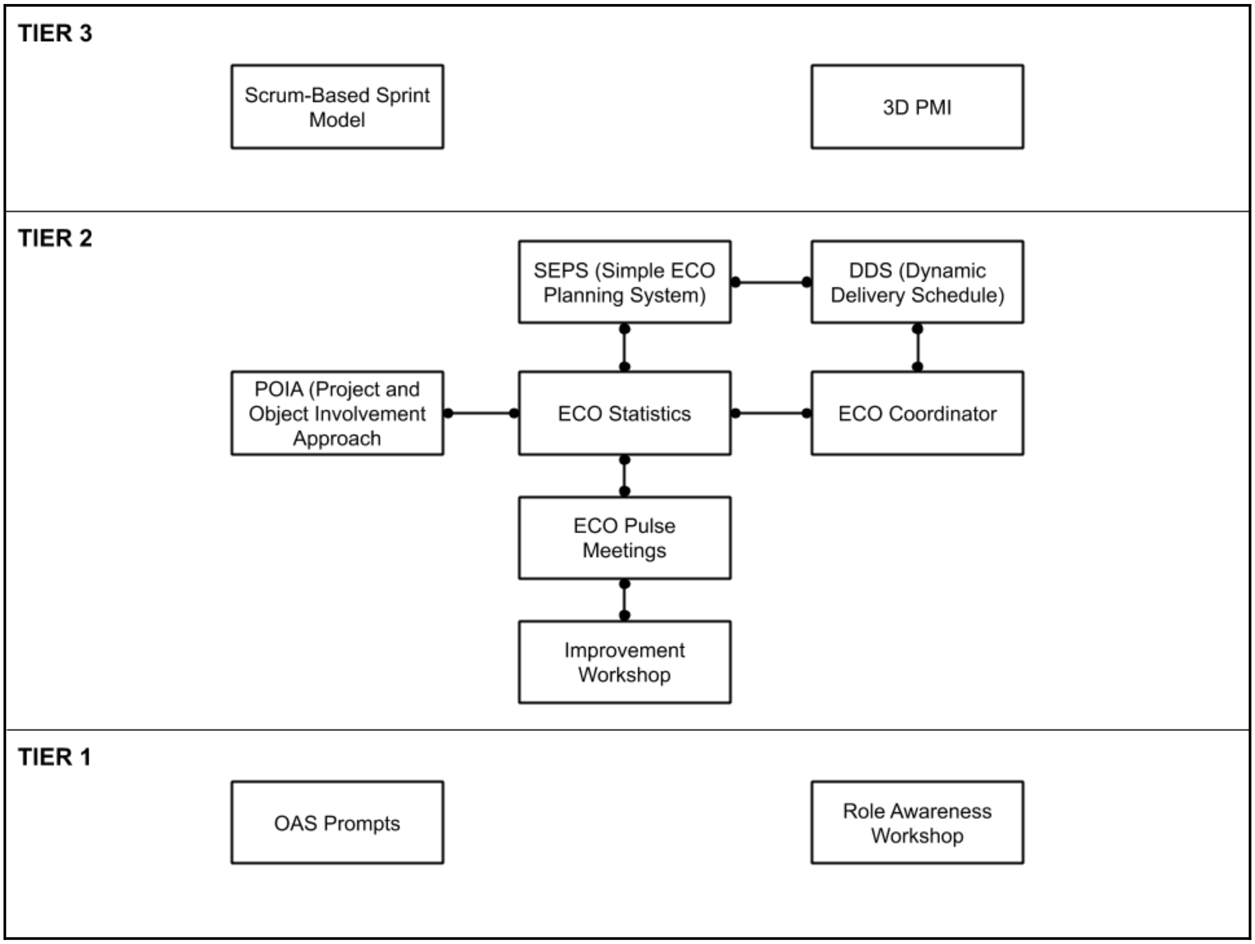


Figure 46. Illustration of tier-based framework that showcases the modularity and compatibility of the tier 2 solutions.

Tier 1

The tier 1 concepts are short-term-based and easy to implement and do not require a lot of time and effort to implement. In this case for example the “Role Awareness Workshop” is similar to other workshops which are currently implemented in their existing way of working. So to implement this solution will not be difficult as it does not require a lot of changes needed.

Tier 2

Most developed solutions were made with cross-compatibility and expansion in mind. Hence, as shown in the illustration (figure 46), tier 2 solutions feature linkages that indicate which concepts that constructively build on each other. For example, the “ECO statistics” solution is modular and can be used with other solutions such as SEPS, ECO coordinator, ECO pulse meetings and POIA. “ECO statistics” can be used as a supporting tool with other solutions. One scenario is the reports of statistics help PC groups to conduct workshops and training for design teams that face problems with issues regarding ECOs.

Tier 3
The tier 3 concepts are focused on long term solutions and thus require considerably more time, effort and change in way of working compared to the previous tiers. For example, the proposed scrum-based sprint model entails adopting a completely new way of working in the R5A groups and requires systematic integration with other functions (DE stakeholders) in the form of schedule synchronization (see Appendix C).

In this chapter, 4 tier 2 concepts will be presented. The selection of concepts is based on feedback from the company, being viewed as the most attractive solutions. Hence, the remaining concepts are appended and can be seen in Appendix C.

Every concept is presented with a brief description, projected benefits, schematic overview and implementation strategy. Furthermore, a justification for the need of the concept is also presented, listing aspects recorded in both the survey and interviews (qualitative framework) that the concepts directly address. Lastly, the concept expansive potential is presented with respect to the modular connection with other tier 2 concepts.

5.6.2 SEPS - Simple ECO Planning System

Brief Description
SEPS is an ECO planning and forecasting tool that aims to visualize ECO deliveries on a week-by-week basis and thus aid proactive planning activities.

Why SEPS?
Below the recorded themes from the interviews that SEPS addresses are presented (figure 47). Also, key survey results that support the implementation of SEPS are summarized.

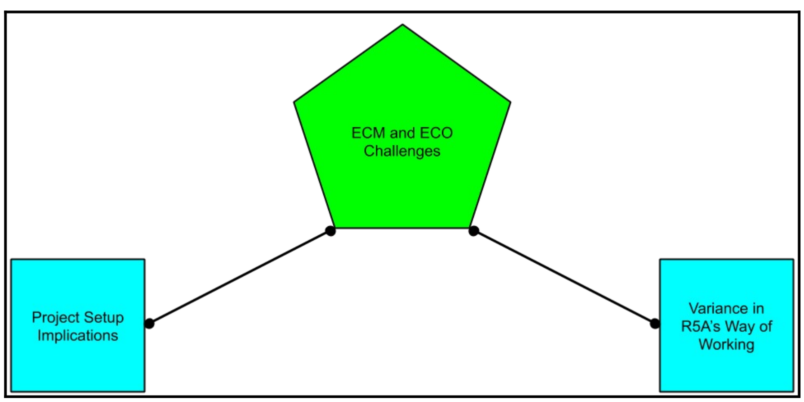


Figure 47. Overview of the themes that SEPS addresses.

- Enables planning of work
- Allows R5A groups to anticipate ECO deliveries
- Allows estimation of ECO work

On the basis of data recorded from the survey, from the graphs it is evident that there is a need among the PCs if there is a tool that gives PCs an indication about when ECOs would be delivered to them, being able to plan their work, time estimation to complete an ECO, etc. Hence the solution SEPS (Simple ECO Planning System) provides the PC with all the necessary information regarding ECO planning and ECO forecasting.

How the Concept Works - Schematic Overview

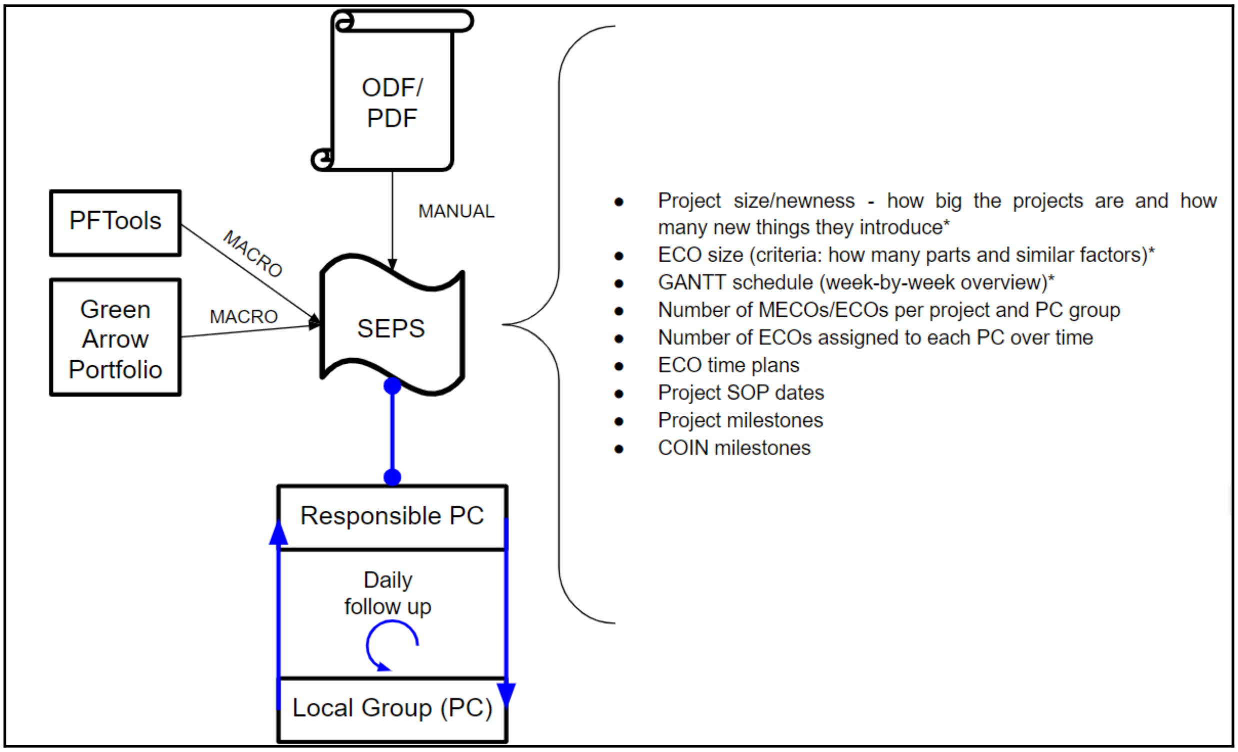


Figure 48. Basic overview of the input data and resulting information that is visualized in SEPS. Unique information that is exclusively provided in SEPS is marked with an asterix.

SEPS concept has 2 main functions, one is to show an overview of all ongoing projects and another to visualize the amount ECOs delegated to each PC over time in a week-by-week GANTT chart. The GANTT-based view can be displayed as a group-based breakdown (4-letter acronym) or department-based (3-letter acronym, all R5A groups). SEPS pulls its core data from PF tools and Green Arrow Portfolio using an automated macro function. From there, all published ECO and project information is extracted.

The project overview can be seen in figure 49 below. Cyan-colored cells (project newness) indicate that they are reserved for manual input whilst green and yellow cells pull data from the *Green Arrow Portfolio* and *PF tools* respectively with the help of a macro. In this case

Project Name	Project Newness/Scale	COIN/SOP	Domain/Groups	Total No. of ECOs	RVDC	No. of MECOs	R&D10	D10
Project 1	Big	2023.03.21	B	211		5	2020.03.21	2020.05.21
Project 2	Medium	2024.03.22	B	133		3	2020.03.29	2020.05.30
Project 3	Big	2020.06.04	C/S/P	398		6	2020.04.30	2020.06.30
Project 4	Small	2022.09.01	C/S/P	109		2	2020.05.01	2020.07.15
Project 5	Medium	2023.03.30	C/S/P	135		3	2020.05.30	2020.09.30
Project 6	Big	2023.09.01	C/S/P	190		4		

Figure 49. Project overview sheet showing all ongoing projects and their connected milestones.

The ODF and the PDF are manually read and used to estimate the newness and scale of the project, more specifically to gauge the workload of the ECOs that are attached to the objects and projects. This check is done by the SEPS-responsible PC as shown in figure 49 above.

Moreover, one SEPS-responsible PC per group is tasked with maintaining the sheet and ensuring the accuracy of the information. Also, a daily follow-up routine is done at each PC group to collectively assess the ECO landscape. The idea is that SEPS will become a central planning aid in daily steerings. Figure 50 below shows the input, output and role delegation. The inclusion of SEPS in the daily meetings also serves as a validation mechanism, allowing the local group to collectively evaluate the ECO work estimations.

The GANTT chart-based ECO overview is visualized in figure 50 below. Using the planned ECO delivery dates as input (planned status raises), the document automatically highlights and assigns the two week lead times for each planned status raise in a GANTT chart. This is done for all PCs in the group, giving a complete overview of all planned deliveries over the span of several weeks.

As previously mentioned, estimated ECO size is determined by reading through PDF/ODF documents and early ECO descriptions to see how many parts will be introduced and how new they are. In addition, other estimation techniques such as number of rows can preferably be considered and discussed in the local groups. This allows the PC groups to better prepare for ECO deliveries and gives managers the tools to more accurately estimate future resource allocations. As presented in figure 50 below, ECO sizes are estimated using a 3-grade scale according to table 12 below.

ECO Number	ECO Title	ECO Description	Estimated ECO Size	Product Coordinator	CO Responsible	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27
9837595	Bracket for wheel ASSY	new bracket for attachment of wheel ASSY	Medium	John D	James R	3:4	3:4						
7439587	ECO TITLE	ECO DESCRIPTION	Small	John D	Edna K		3:3	3:3					
99733245	ECO TITLE	ECO DESCRIPTION	Large	John D	Edna K		3:4	3:4					
66729337	ECO TITLE	ECO DESCRIPTION	Large	John D	Paul T		3:4	3:4					
343254543	ECO TITLE	ECO DESCRIPTION	Medium	John D	Edna K		2:3	2:3					
23424235	ECO TITLE	ECO DESCRIPTION	Large	John D	Edna K		3:4	3:4					
5654843	ECO TITLE	ECO DESCRIPTION	Medium	John D	Paul T			2:3	2:3				
9937221	ECO TITLE	ECO DESCRIPTION	Small	John D	Edna K				3:3	3:3			
1948222	ECO TITLE	ECO DESCRIPTION	Small	John D	Edna K				2:3	2:3			
131986084	ECO TITLE	ECO DESCRIPTION	Medium	John D	Paul T				3:4	3:4			
262023946	ECO TITLE	ECO DESCRIPTION	Large	John D	Edna K				3:4	3:4			
392061808	ECO TITLE	ECO DESCRIPTION	Medium	John D	Edna K					3:3	3:3		
522099670	ECO TITLE	ECO DESCRIPTION	Small	John D	Paul T					3:4	3:4		
652137532	ECO TITLE	ECO DESCRIPTION	Small	John D	Edna K					3:4	3:4		
782175394	ECO TITLE	ECO DESCRIPTION	Medium	John D	Edna K					2:3	2:3		
912213256	ECO TITLE	ECO DESCRIPTION	Large	John D	Paul T					3:4	3:4		
1042251118	ECO TITLE	ECO DESCRIPTION	Medium	John D	Edna K						2:3	2:3	
1172288980	ECO TITLE	ECO DESCRIPTION	Small	John D	Edna K							3:3	3:3
1302326842	ECO TITLE	ECO DESCRIPTION	Small	John D	Paul T							2:3	2:3
1432364704	ECO TITLE	ECO DESCRIPTION	Medium	Jane D	Edna K							3:4	3:4

Figure 50. GANTT chart of ECOs delegated to each member of the PC group over the course of a couple of weeks. Note that the GANTT chart forecasts all published ECO time plans and can thus be used to determine the outlook beyond just a couple of weeks.

Table 12. Proposed ECO size estimation system based on the standard ECO lead time of 80 hours.

ECO Size Measure	Projected Time Required (hours)
Small	0-16 h
Medium	16-32 h
Large	32-80 h

Implementation strategies and enforcement

One assigned PC per group is responsible for maintaining the sheet and ensuring the accuracy of the information. Overall, there are few to no dependencies on adjacent functions.

Projected Benefits

- Improves outlook and enables ECO forecasting.
- Allows detection of concentrated ECO deliveries.
- Improves the ability to plan work.
- Functions as an ECO follow-up tool.
- Visualizes all published ECO time plans.
- Integratable with daily steerings.

Expansion - Modular Compatibility With Other Concepts

SEPS can preferably be combined with ECO statistics to get a better overview of the number of ECOs in the project of different types. For instance, ECOs of a certain type e.g. introduction of mounting brackets may be deemed problematic and thus beneficial to track and tag in the SEPS sheet. Also, additional measures such as the number of certain ECO types may aid in better estimating ECO size. Combination with DDS, which is a derivative of SEPS, may also aid in introducing an integration mechanism between PCs and DEs which can be used to further validate the data in SEPS.

5.6.3 DDS - Dynamic Delivery Schedule

Brief Description
A GANTT chart that shows how many ECOs a PC has been delegated over the course of several weeks (months). Projected to be used by DEs to determine the best possible time to deliver ECOs to avoid undispersed ECO deliveries. One important thing to note here is that DDS is the lite version of the above-explained concept SEPS.

Why DDS?
Below the recorded themes from the interviews that DDS addresses are presented (figure 51). Also, key survey results that support the implementation of DDS are summarized.

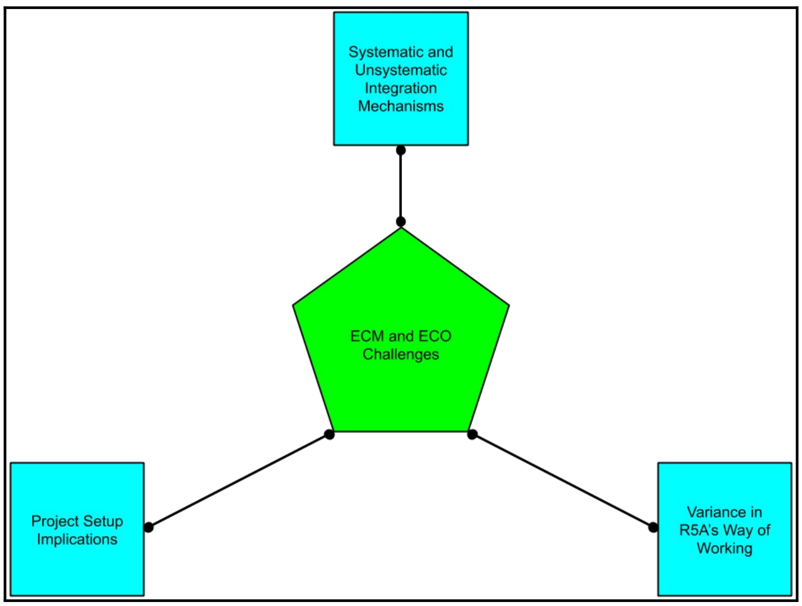


Figure 51. Overview of the themes that SEPS addresses.

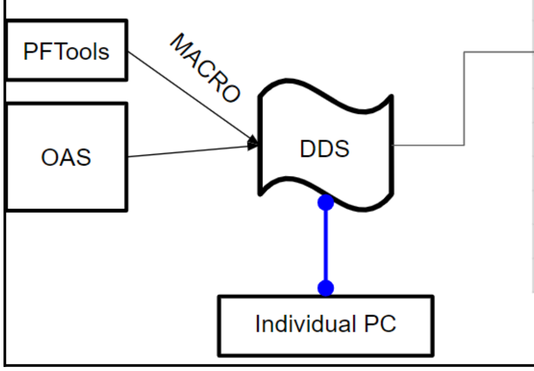
- Enables planning of work
- Allows R5A groups to anticipate ECO deliveries
- Allows estimation of ECO work
- Allows updates to be communicated from DE to PC

On the basis of data recorded in the survey, from the graphs it is evident that there is a need among the PCs if there is a tool that gives PCs an indication about when ECOs would be delivered to them, being able to plan their work, time estimation to complete an ECO, etc. Hence the solution DDS (Dynamic Delivery Schedule) helps the managers to see how many ECO a PC has been delegated over the course of several weeks (months) and by the DE when they plan an ECO to avoid undispersed ECO.

How the Concept Works - Schematic Overview

Input Sources

The DDS will grab its core data from both OAS and PFtools, extracting ECO-related information and project-related data for one individual PC. Figure 52 shows the input sources and resulting GANTT chart that the proposed tool produces from this data (output).



ECO Number	Estimated ECO Size	Week 5	Week 6	Week 7	Week 8	Week 9
343254543	Medium	2:3	2:3			
23424235	Large	3:3	3:3			
5654843	Medium		2:3	2:3		
9937221	Small		2:3	2:3		
1948222	Small		3:4	3:4		
131986084	Medium		3:4	3:4		
262023946	Large			2:3	2:3	
392061808	Medium				3:4	3:4
522099670	Small				4:4	4:4
652137532	Small				3:3	3:3
782175394	Medium				2:3	2:3

Figure 52. Schematic overview showing input data from OAS and PFtools and the resulting GANTT chart for one individual PC.

Output

Through a script, the DDS will automatically reserve 2-week time slots of planned ECOs (published) in the GANTT chart. This chart is then intended to be used by DEs when planning their ECOs to avoid undispersed ECO deliveries. Each individual PC is responsible for regularly checking and maintaining the charts.

Expandability

Can be linked and combined with SEPS to give individual and group-based overviews of ECO deliveries over the course of several months. Since both tools grab their core data from the same sources, integration is deemed to be seamless.

Implementation strategies and enforcement

One assigned PC per group is responsible for maintaining the sheet and ensuring the accuracy of the information. Daily checks are thus required to assure that the information is up-to-date. Much like SEPS, discussions surrounding DDS should preferably be integrated in the R5A groups daily meetings to allow for work balancing.

Projected Benefits

- Encourages dispersed ECO deliveries.
- Improves the ability to plan work.
- DDS document is readily available and easy to access for DEs to visualize PC workload at any point of time.

Expansion - Modular Compatibility With Other Concepts

If combined with the ECO coordinator concept, DDS can be used as a reference and visualization of the PC's workload for both the object and project. The ECO coordinator can thus use DDS as part of their assertion strategy and inform stakeholders of the PCs' capacity.

5.6.4 ECO Pulse Meetings

Brief Description

Routinely occurring ECO pulse meetings that each individual PC holds with the DEs that they receive ECOs from to discuss common practices and collaboration routines.

Why ECO Pulse Meetings?

Below, the recorded themes from the interviews that ECO pulse meetings address are presented (figure 53). Also, key survey results that support the implementation of ECO pulse meetings are summarized.

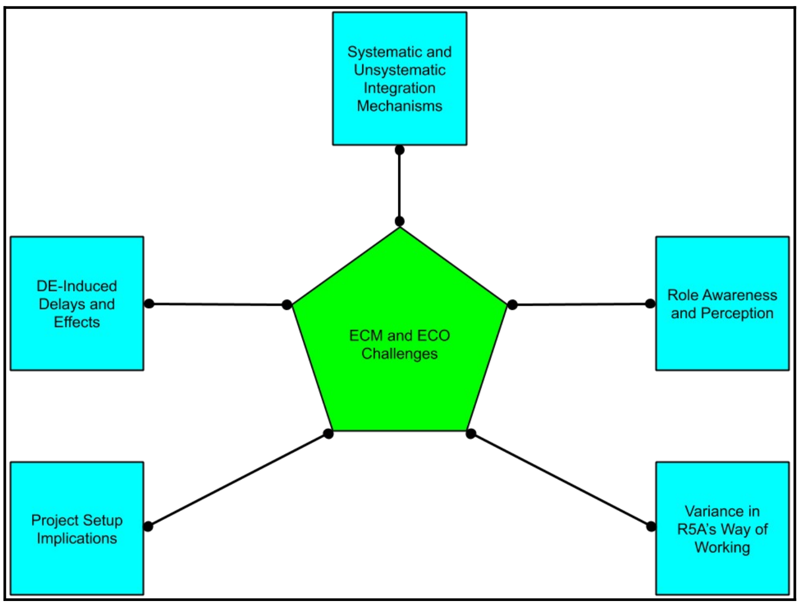


Figure 53. Overview of the themes that SEPS addresses.

- Allows R5A groups to anticipate ECO deliveries
- Enables early project involvement
- Reduces need to contact DEs for additional ECO information
- Allows direct updates from DEs regarding ECOs

On the basis of data recorded in the survey, from the graphs it is evident that PC would like to be involved early in the project and discuss

How the concept works - Schematic Overview

Input

The meetings are owned by each individual PC and follow a prepared agenda that is standardized. Before the first pulse meeting, each PC compiles a list of all DEs that they receive ECOs from and divides them into separable groups based on common domain. These groups are then equally allocated time slots in the meeting. An example is given below in figure 54.

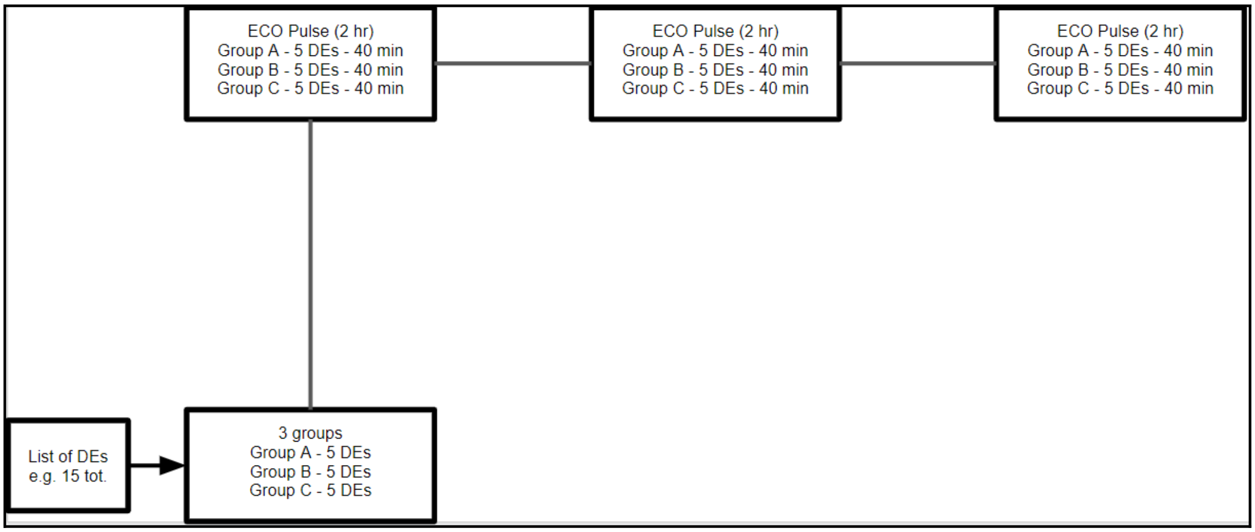


Figure 54. Process for determining pulse meeting groups and time slots

The pulse meetings occur every 3 weeks with the first one standing out as unique because it includes a segment where the PCs establish their roles and key responsibilities to ensure that the participants are aware of their part in the ECO value chain, thus preventing future misunderstandings. The succeeding meetings mostly follow the same agenda and setup which the main difference being that they include follow-up questions and are intended for assessment of ECO planning and agreed PC-DE collaboration routines. Figure 59 illustrates the framework of the meetings.

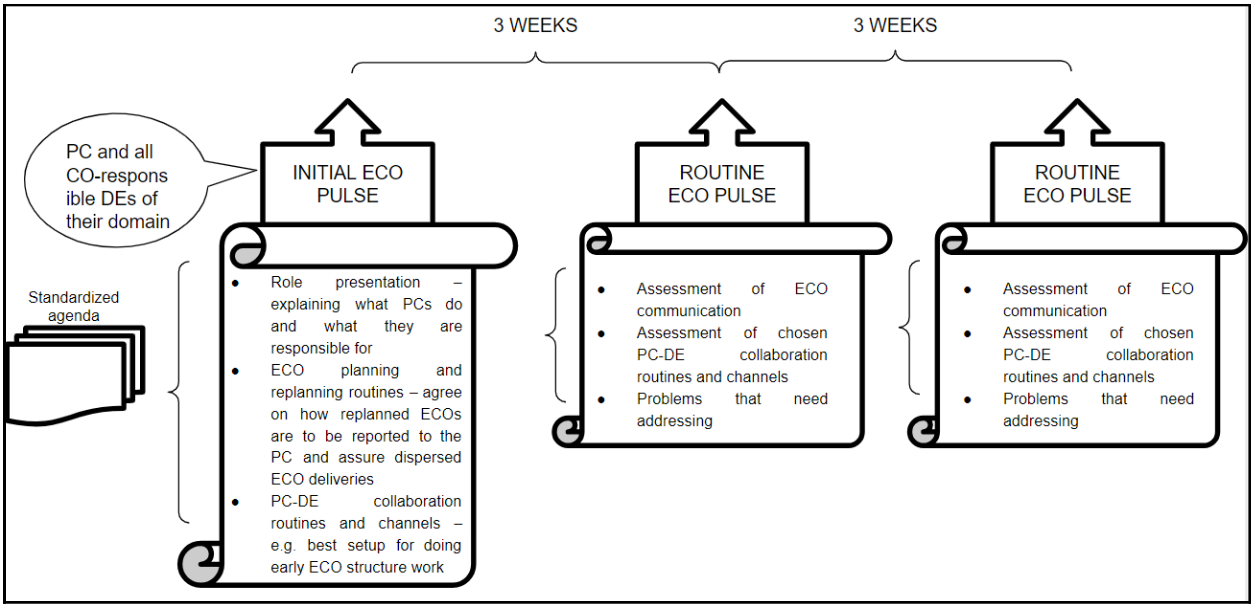


Figure 55. Timeline showing the initial pulse meeting and the routinely occurring ECO pulse meetings.

Moreover, the agenda that is used in the initial ECO pulse meeting is in the form of a presentation with common key points [*ECO Pulse Meeting [INITIAL + ROUTINE].pptx*].

Then, as previously stated, the follow-up meetings function as assessments and time slots to solve specific problems. Hence, the follow-up meetings' agenda will look like what is shown in [*ECO Pulse Meeting [INITIAL + ROUTINE].pptx*].

Implementation Strategies and Enforcement

The concept can be implemented in two ways:

1. Enforce pulse meetings by making them an official part (activity) of the PD process that is the PC equivalent of "design reviews". Also, instruct all project managers and object leaders to remind DEs to attend them when instructed by the PCs.

2. The PCs organize and schedule the ECO pulse meetings every three weeks by themselves (own initiative). They individually contact and invite the parties that they wish to have discussions with. The goal is for it to gradually become a formal routine over time. R5A managers assist by telling project leaders and design managers to spread the word about the pulse meetings.

Projected Benefits

- Improves and increases awareness of DE-induced delays
- Simplifies estimation of ECO size (required work)
- Becomes part of a common integration approach within R5A
- Systematic integration mechanism between DEs and PCs
- Functions as an ECO follow-up system
- Facilitates better understanding of PCs' role.

Expansion - Modular Compatibility With Other Concepts

ECO pulse meetings can be used together with ECO statistics to better understand integration needs. For instance, if the recorded statistics show that a certain design group has had a large portion of their ECOs returned or stalled, the PCs may schedule stand-alone pulse meetings with those specific groups to address specific issues pertaining to the problems reflected in the statistics. Thus, the ECO statistics may function as problem detectors. In addition, insights from the local improvement workshops done in R5A may be implemented in ECO pulse meetings to continuously improve the setup and quality of the meetings.

5.6.5 Global-Level ECO Statistics

Brief Description

System in the form of a sheet that continuously pulls data from OAS and visualizes global-level ECO statistics, covering a range of different aspects of the ECO process flow.

Why Global-Level ECO Statistics?

Below, the recorded themes from the interviews that ECO pulse meetings address are presented (figure 56). In this case, the concept solely focuses on the core ECM and ECO issues. Also, figure 57 highlights the cruciality of global-level ECO analytics with relation to the company's value chain.

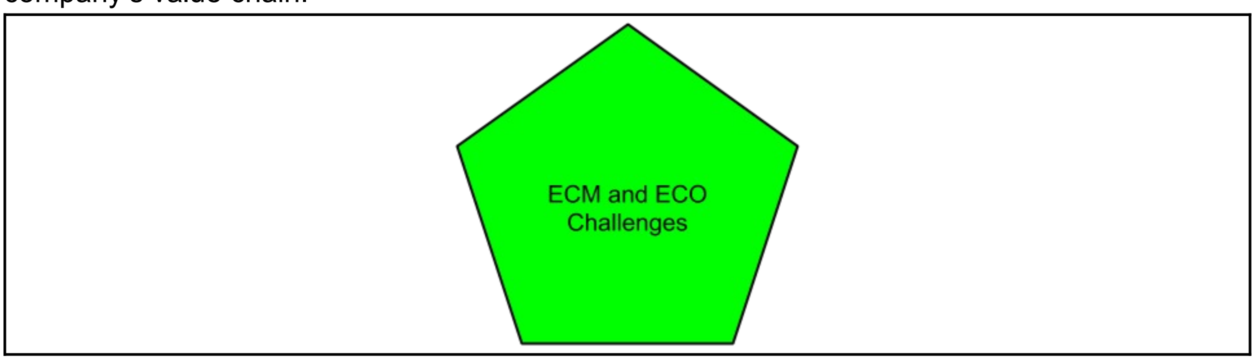


Figure 56. Overview of the themes that the global-level ECO statistics address.

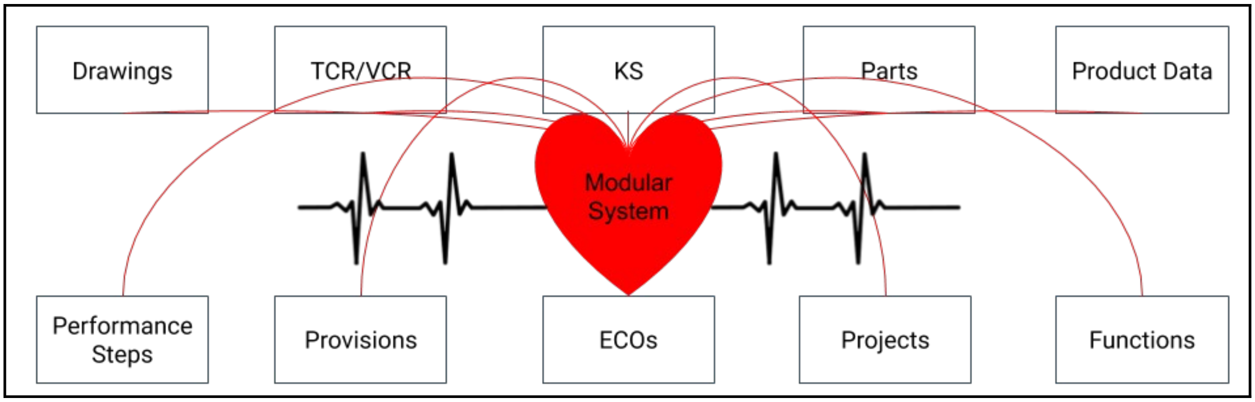


Figure 57. Illustration of the theoretical relationship between the company's modular system and parts of its value chain.

How the Concept Works - Schematic Overview

Input
Figure 58 below showcases the basic flow of the input and output.

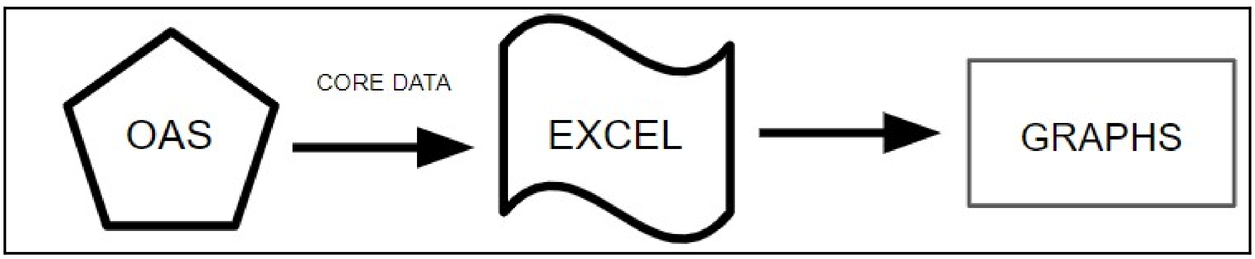


Figure 58. Simplified flow chart of how ECO statistics are captured and compiled

Most notably, the system relies on core data being accessible and taken directly (continuously) from OAS.

Output
After processing the captured data, the tool will give an overview of ECO statistics, on a *4-, 3- and 2-letter acronym level*, showing (but not limited to):

- Number of times ECOs have been rescheduled
- Number of issues created per ECO (to measure how often they have been changed or sent back)
- Number/percentage of ECOs overdue or on time
- Number of ECOs with published time plans
- Number of GEO ECOs

Figure 59. shows an example of how a break-down of ECOs with missing time plans can look.

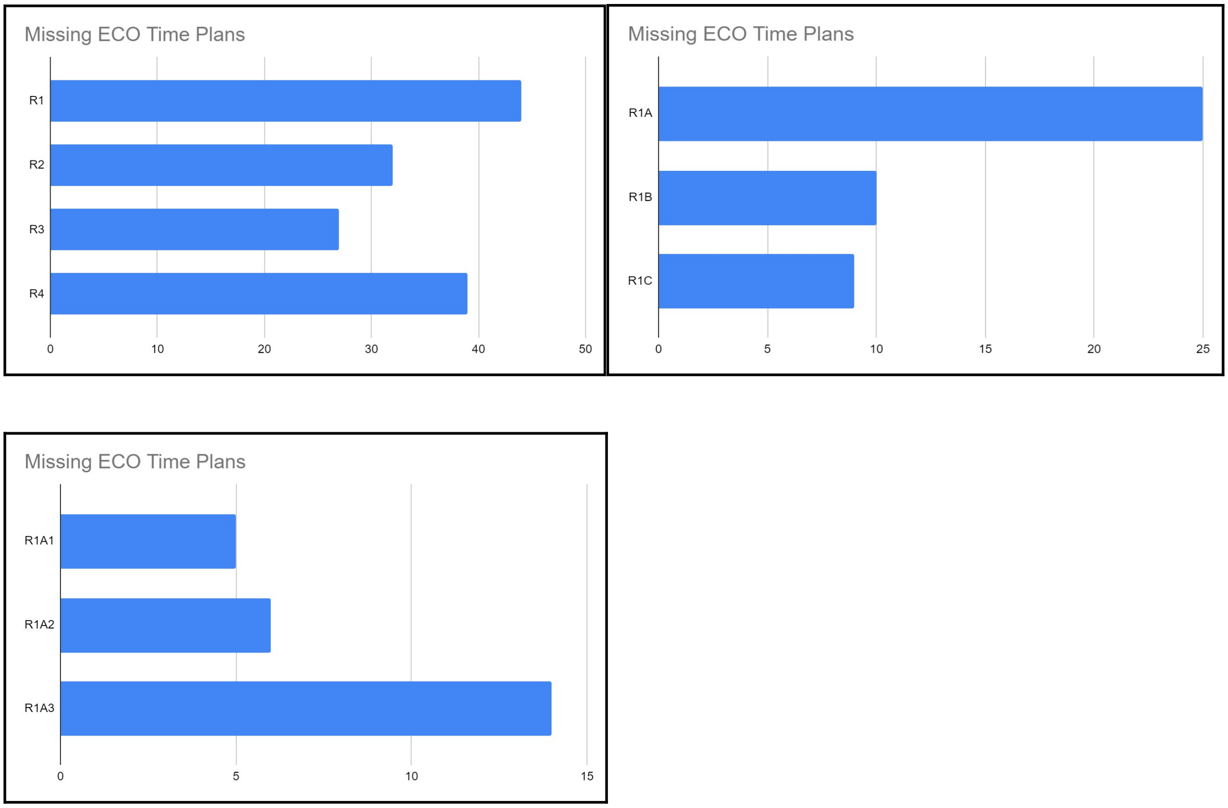


Figure 59. Charts showing missing ECO time plans on a 2-, 3- and 4-letter acronym level.

Projected Benefits

- Allows identification of source of problems
- Can be used as an ECO follow-up tool
- Compatible with all ECO-related concepts - can be used as a support tool for determining integration needs - reports of statistics help PC groups to conduct workshops and training for Design teams which face problems with issues regarding ECOs.

Expansion - Modular Compatibility With Other Concepts

ECO pulse meetings can be used together with ECO statistics to better understand integration needs. For instance, if the recorded statistics show that a certain design group has had a lrge portion of their ECOs returned or stalled, the PCs may schedule stand-alone pulse meetings with those specific groups to address specific issues pertaining to the problems reflected in the statistics. Thus, the ECO statistics may function as problem detectors. In addition, insights from the local improvement workshops done in R5A may be implemented in ECO pulse meetings to continuously improve the setup and quality of the meetings.

6. Discussion

In this section, the yielded results are compared with the presented literature where synergies and differences are highlighted and discussed in detail.

6.1 Modularization

In regards to the modularization aspect of the firm's core product strategy, some of the identified challenges could be associated with the architectural modularity of the product system. Maintaining a large amount of product variants and possible combinations meant that the frequency of compatibility errors was high since a new component had to be compatible with a large selection of existing components. The clash analysis done by the geometric assurance group functioned as an error check to see if the components introduced by the change order were incompatible with the existing catalog of items in the catalog (bygglåda). However, due to the sheer amount of clashes that would often be produced in the geometric test environment (R5A5), the DEs would often choose to only prioritize the most critical errors. Coupled with the frequently cited pressure of fast-approaching deadlines, the interviewed DEs and object leaders stated that the prioritization of errors was based on the number of clashes produced by possible combinations.

Many of the existing studies on the topic of modularization regard the combinatory opportunities brought forth by module segmentation as the characteristic benefits of product modularization. For instance, Miller and Elgard view the main principle of modularization as the combination of a large number of segmented modules to create different products, emphasizing the volume of parts that are available to combine [1]. Schuh et al. similarly mention the modules' interchangeability aspect but also underline the desired outcome of being able to reach many customer profiles with different needs [9]. Worth noting is that the module-based view on value discipline is internally regarded as "*performance levels*" in the firm's ECM and module syntax. Thus, although commonly touted as a major benefit of modularization, the ability to combine a large number of modules also introduces complexities in practically managing the number of valid combinations, especially when new components are introduced in the architecture. Correspondingly, the volume of variant compatibility errors resulting from engineering changes introduce difficulties in maintaining a functional modular structure, making quality assurance an imperative tool. Hence, some ECO challenges were directly related to the essence of modular systems which induced challenges through the relation and maintenance of many components that new items have to adhere to.

Moving projects was also made more complex because of the structural interdependencies that determined the sequential order of ECOs as some components were purposely laid out to be introduced later than others. As a result, those components depended on certain parts being introduced prior to their implementation, highlighting the part dependencies in a product strategic context (umbrella projects). Stark similarities can be found in the results of both Bonvoisin et al. and Tee et al. who stress that the challenge lies in the retention of synergy between modules when a project evolves [10] [11].

6.2 Organizing Principles - Organizational Structure

By scrutinizing the organizational map of the firm, one may find that it closely resembles that of a vertical organization as explained by Daft, Mintzberg among others [29] [30] [33] [31]. On closer inspection, the cross-functional challenges that were identified shared many similarities with the issues highlighted in literature. For instance, coordination across specialized departments was a common point of tension which originated from each function's inability to foresee problems from the perspective of other functional units that depended on their deliverables [37]. In this case, the PCs cited a list of issues that stemmed from DEs which, in some cases, were not directly reciprocated by them. The misaligned views on ECO writing and undispersed ECO deliveries highlighted in the comparative analysis above serve as examples of this. Although certain issues were acknowledged, such as the ECOs being rushed or DEs not updating PCs about changes in ECO prioritizations, the implications of said issues which affected the R5A groups were not completely recognized by the DEs.

In addition, the studied company's delivery flow also shows textbook characteristics of an over-the-wall approach, which was not exclusively limited to DE-to-PC deliveries. A running theme throughout the study was the prevalence of inherited delays, a phenomenon commonly associated with the over-the-wall-based makeup of traditional engineering-based processes [38]. Results of the statement pertaining to sources of delays (figure 30) show that as being one of the most common reasons for ECO delays from the DE's point of view. Despite the company-adopted PD process prescribing cross-functional links at certain points in the process, the main flow followed a sequential layout with functions handing over deliverables to other functions. Moreover, the PD process-prescribed cross-functional links were essentially decision points that functioned as checkups to ensure that the planned deliveries were done at the specified time as opposed to scheduled integration mechanisms.

The over-the-wall process trait was also made apparent by the DE's impersonal handover of ECOs to PCs commonly resulting in the PCs not having sufficient knowledge of the product due to limited cross-functional involvement in project activities. Nonetheless, product knowledge was a highly regarded aspect by the product coordinators, as shown in figures 42, 43 and 44, and was considered to be vital for ECO processing. Furthermore, similar examples from the interviews show that there is a direct correlation between ECO processing time and product knowledge, implying that sufficient knowledge about the product that is being worked on mitigates uncertainty associated with the ECO work. As pointed out by Allen, ensuring that a common understanding of the product is shared by all units is a challenging aspect which can be attributed to the narrow focus of each functional unit. In addition, physically separating units was cited as a driver for functions to inadvertently lean toward the use of impersonal communication channels [37]. This can be directly associated with most PC and DE interviewees favoring in-person interaction but having to rely on less personal alternatives such as Emailing or voice calls. The physical distance between their functions was further widened after the organizational restructure of September 2019.

Highlighted by Starbuck, the theoretical premise in vertical organizations is that the managerial functions supply and facilitate coordination needs to units within their span of control via a systematic delivery system [39]. Many other authors agree with this concept that emphasizes the organization's role in enabling cross-functional integration mechanisms, in particular that they are facilitated by both management and the organizational structure [40] [28] [30] [32] [29]. The lack of any persistent cross-functional links between R5A groups and remaining object stakeholders (primarily DEs and object leaders) despite the expressed need for them indicates that management is not actively facilitating the coordination needs of R5A groups. Thus, the addition of formal integration mechanisms would mitigate this issue and allow the capitalization of the R5A groups' full potential. Being regarded as highly knowledgeable and sources of insightful and sometimes essential feedback, the systematic inclusion of R5A groups in (early) project and object activities would most likely yield a string of benefits, something further supported by many examples of positive outcomes of PCs' involvement in object or DE activites.

Ultimately, hand-in-hand with the ideal achievement of high differentiation and high integration, ensuring that organizational units with codependencies are integrated is seen as an equally important aspect, especially when the firm produces a complex product. As asserted by Lawrence and Lorsch, integration has to be balanced with the use of specialized functions in order to achieve the best of both worlds [47]. With Scania being one of the biggest truck manufacturers in the world and arguably the most known users of modular product systems in the automotive industry, more emphasis has to be put on providing links between the specialized functions. Therefore, the tier 2 solutions of the proposed framework seek to do just that, establishing cross-functional links in a systematic way that is structurally harmonious with the organizational makeup.

6.2.1 Organizing Principles - Cross-Functional Links

The importance of cross-functional links in modularization firms was a strongly emphasized theme in literature, being highlighted by a multitude of authors as a crucial success factor. Therefore, the absence of such links between the R5A groups and their stakeholders (not exclusively limited to PCs) was a noteworthily fundamental challenge. As shown by Schuh et al., the aspect concerning the need for coordination is considered especially important for modularization firms employing a vertical structure to make sure that functions are aware of each other's progression and enable close collaboration [44]. Though, slightly paradoxical is that most modularization firms have been found to organize their company after the division of the product's subsystems, something that often results in the formation of functional branches with narrow scopes [46]. Furthermore, the issues related to cross-functional coordination and communication can be associated with the firm's organizational structure as it has been shown to be a determinant for the applicability of cross-functional integration [35]. Thus, the inclusion of organic cross-functional coordination mechanisms can be seen as an imperative prerequisite for success, since it involves bridging the communication and direct coordination gaps introduced by rigid organizational boundaries.

However, the case study showed that very few cross-functional links existed for the R5A groups. Despite the majority of the R5A groups being tasked with maintaining the product structure (KS) and defining the combinatory conditions (TCR/VCR), which collectively make out the core of the company’s modularization system (bygglåda), there were very few instances where they were cross-functionally involved in other value-creating activities. Though some respondents highlighted a few scenarios where PCs had positively contributed with valuable insights, the general consensus suggested that they were not actively or routinely involved. Despite the recognized benefits and projected advantages of involving PCs in the work of DEs and the object in general, no formal forums existed for PCs in the same way as other object-bound functions such as production, purchasing etc.

Still, some object leaders who were aware of the value of the PCs’ insights would occasionally invite them to select meetings where their feedback was desired. One of the R5A4 PCs specifically noted this as being far from all object leaders, which can be related to the flexibility of the routines employed by each object leader since they were given freedom to choose object attendees. Nevertheless, a detail of note here is that time and capacity were cited as the most common reasons for efforts not materializing. Practically, almost all interviewed object leaders claimed that PCs would state that they did not have sufficient time to attend the object meeting because of ongoing ECO work taking up their capacity, something affirmed by the PC respondents. This is most likely a symptom of the unavailability of any formal integration mechanisms that would include the PCs (and other R5A functions) in the project since they would otherwise have to take time out from their regular work hours where they are expected to work on delegated ECOs to participate in non-PC work.

Moreover, the absence of any formal coordination mechanisms, which were emphasized by Olson et al. as being crucial success factors, were said to have negatively impacted the projects leading to recognition of errors at a relatively late stage - inevitably causing delays [45]. The example of how a PC and a member of the geometric assurance team successfully identified a potentially costly error during an object meeting illustrates the usefulness of involving them in object meetings. Nonetheless, the issue of time which was said to hinder R5A groups from attending object meetings (in the case they were invited to them) was made more complicated by the number of ongoing projects. Attending all object meetings was deemed to be difficult due to the required time and resulting impact on the ECO work capacity.

Challenges stemming from a lack of cross-functional collaboration were also further complexed by the organization’s project structure. Hierarchically higher up in the organizational chain, the project manager stated they ideally wanted the line organization to autonomously collaborate and coordinate deliverables, without the direct interference of the project office function. Although underlining their role as facilitators of cross-functional collaboration, the project manager stated that there were few clear-cut examples of systematic collaboration forums. The COIN coordinator, also a project manager, clarified that coordination efforts were mainly determined by the individual projects, led by the assigned project manager. As projects individually followed the PD process up until their integration at the so-called V-gen phase (granted that they are part of the same COIN), the cross-functional routines were said to be based on the needs of the individual projects. Hence, the difference between Allen’s theory and Scania is that Scania facilitates cross-functional collaboration via a project-based approach where the responsibility rests on the shoulders of the project manager [37].

An example of this was the organization of ECO workshops to highlight unplanned ECOs, planned and led by the project manager. In that case, the workshops were put together as a reaction to an overabundance of unplanned ECOs that were brought to the project management's attention. The workshops did not function as an ongoing forum, but rather utilized as a one-time meeting to address encountered issues in one particular project. Similarly, the PC-organized ECO pulse meetings also functioned as reactive measures only implemented when problems had already occurred in the individual project. Thus, measures to bridge communication gaps were only organized in individual projects to address issues within them and were often reactive. To summarize, there was an absence of systematic coordination and integration methods employed across all ongoing projects. This confirmed the project-exclusive nature of cross-functional collaboration initiatives.

Involvement in multiple projects has been shown to be a challenge in existing case study-based literature, hindering functional units from being engaged in individual projects. Hence, the Texas instruments case presented by Bernasco et al. indicates that factors outside of the structure-to-process alignment may play a role in stopping functions from being engaged in the project [36]. In the case of Scania, the sheer volume of projects, propagated by the strategy of continuous introductions, may prevent cross-functional links from being established with all functions even if the proposed framework (figure 46) is to be adopted. Acknowledged by one of the project managers to be a probable strategic shift, maintaining a smaller project portfolio with shorter time-to-market per project would theoretically mitigate this challenge by having less projects running at the same time. Thus, the PCs' ECO work would be more streamlined with less risk of projects being neglected as a result of internal delays and market-strategic factors favoring some projects over others (see *Time Constraints and ECO Prioritization* in chapter *5.2.5*).

Despite the scarceness of formal integration mechanisms, informal structures and routines were frequently cited as go-to approaches for cross-functional integration. According to Sosa, informal structures make up the communication links between individuals that are outside of the formal structures that are outlined by the organizational boundaries and practically represented by the division of teams, functions etc [41]. In that regard, the rapports between individual PCs and DEs served as examples of such structures. Regardless of their involvement (or lack thereof) in formal meetings and activities, all interviewed PCs were said to have collaborational links with a number of their assigned DEs. Some groups such as R5A4 were fully relying on these informal interactions as part of their ECO work, having DEs stop by their desk to collaborate or ask questions. Other R5A groups similarly relied on these types of interactions. For instance, individual PCs in the R5A2 and R5A1 groups would periodically organize ECO pulse meetings where they would invite selected DEs to discuss missing ECO time plans and request progress reports on stalling ECOs. Informal routines were thus commonly used and regarded as essential coordination tools outside of the formal organizational boundaries, confirming the prevalence of both types of boundaries, as described by Sosa, and underlining their empirical application [41][42].

6.3 Core ECM and ECO Challenges

Unlike the case study presented by Jokinen et al, there were no official ECO statistics being recorded in the ECM of Scania at the time of the study. Although the project manager claimed that they were manually creating ECO statistics for one particular project which were based on "public" data from PFtools and OAS, performance analytics linked to the core data of the ECM were not being utilized. Also, the statistics were, again, a reactive measure done to combat an escalated issue related to following up ECOs. In other words, no global statistics were being recorded and maintained to monitor the ECO-related performance of all ongoing projects. Jokinen et al.'s study illustrates the importance of utilizing ECO statistics as it can be used to identify insufficiencies in the ECO value chain and trace them back to specific stakeholders [52]. In addition, given that most managers were uncertain about how to inject themselves in the project, the use of statistics would theoretically provide them with a starting point to base their integration efforts on as it would inform them about which units that they require better communication with to effectively combat delays.

Delays were also said to be the cause for other challenges related to the DE's retention of tacit knowledge exclusive to a particular ECO. Several PCs had encountered scenarios where DEs would have difficulties recalling specifics of an ECO when consulted for additional information about it. Hence, similar to the findings by Jokinen et al., tacit knowledge played a part in causing ECO delays which can be viewed as a byproduct of lingering ECO backlogs [52]. This issue was most commonly mentioned by the R5A5 and R5A3 respondents who, at the time of study, were faced with massive ECO backlogs as visualized in figure 30. The risk of this issue occurring increased the more time that passed after receiving the ECO.

Furthermore, ECO batching was found to be a direct consequence of backlogs that were caused by a multitude of factors, most often a result of inherited delays. The issue of undispersed ECOs was rooted in the inability to process a large number of ECOs at the same time and simultaneously honor the 14-day lead time for each received ECO. Therefore, the results in this study support the findings of both Terwiesch and, to some extent, even Bhuyian et al. since batching of related ECOs was done by some PCs when they received a manageable amount of ECOs [51] [53]. As part of their approach, most PCs would sort their ECOs to identify dependencies and base their work on those sortings. The difference between the two studies' findings can be ascribed to the intricate differences between the nature of the two papers as one was a case study investigation of a department within an automotive company whilst the other was a simulation based on a paradigmatic model of an NPD process. Nonetheless, these differences are expected since ECM implementations have been shown to be heavily dependent on intricate details of an organization's operational structure, those being its processes, divisions etc. [54].

Lastly, as ECO and ECM practices fluctuate and are mostly non-standardized, general processing time and related data is difficult to generalize. Therefore, relative measures in the form of case-recorded verifications and quantified improvements serve as the primary sources of insight. Hence, improvements recorded in empirical studies are to be taken with a grain of salt. Nevertheless, a common theme in most literature about the subject is the lack of direct parallels to modularization principles and the empirical adoption of said principles, despite the fact that a majority of the studies revolve around modular systems.

6.4 Proposed Framework

The developed solutions, illustrated in chapter 5.6.1 Conceptual Framework of Proposed Solutions, were directly optimized and tailored to Scania using the qualitative data as the primary theoretical base. Rather than proposing an all-encompassing ECM framework like most existing studies on the topic, this study proposes constructive additions to an already existing ECM system that aim to solve coordination challenges that affect the ECO lead time. Evident by the empirical findings, most of the ECO-related challenges were found to be symptomatic and stem from cross-functional insufficiencies, in line with the characteristic tensions found in functional organizations with a modularization-based focus. Thus, the value of the concepts does not exclusively stem from the projected benefits. Instead, the full context of the study which primarily centers around the challenges associated with practical implementations of ECM at a functionally structured modularization firm are to be viewed as the primary points of focus. Also, much like the case with implementing new ECM systems, future practitioners may still have to make elaborate modifications to better suit their unique cases resulting in customization costs if they are to attempt to implement the suggested solutions [65].

As a result, the concepts (tier 1 and 2) require less resource commitment than overhauls of ECMs that are commonly produced by ECO-centered empirical studies. As such, the challenges linked to optimization of ECM frameworks to companies' local routines, processes etc. are partially avoided by the solutions being constructive. Moreover, associated switching costs are projected to be significantly less dramatic since the ECM system is retained in favor of tighter integration mechanisms. In the case of Scania which, as illustrated in figure 34, had an organizational structure of the functional type, resource commitment is measured by how high up in the structure a decision is required to institute a change. The tier 2 solutions are lightweight in that regard since they only require cross-functional collaboration between local stakeholders in the bottom tiers of the organization..

Lakymenko et al. presented a few barriers that may deter firms from adopting literature-prescribed ECM tools which they linked to intricate details in the way organizations have set up their processes, routines etc [54]. However, a framework that is independent of root processes circumvents some of those highlighted challenges by instead addressing surrounding factors. Since an ECM system is considered a core component in the management of modular systems, a modification of such a synthesized organ would thus jeopardize the stability of the company's value chain. Hence, the developed concepts sought to primarily be synergic coordination tools in a mechanistic organizational environment.

7. Conclusion

Below are the summarized key findings of this study.

The company utilizes an in-house developed ECM system called OAS to manage and implement ECOs. The modular architecture of the truck is primarily made up of a product structure that maps out parts, components, subsystems etc. of the truck and variant codes that describe permissible module combinations, which are all contained in OAS. A dedicated function is responsible for maintaining and implementing all design changes in the product structure and updating the permissible variant combinations (see *5.1 ECM Implementation and Cross-Functional Collaboration in Modularization-Based Firms*).

The most central ECO-related issues were identified as:

- ECO planning - limited insight on when ECOs will be delivered (including forecasting beyond 14 days)
- Undispersed ECO deliveries - too many ECOs being delivered at once leading to massive backlogs and resulting in delays
- ECO criticality and priority - information about how critical an ECO is and the priority relative to to other ECOs
- ECO delays - insufficient communication of changes made to the delivery date of a planned ECO as a result of delays from the ECO responsible
- Incomplete or missing ECO information - ECOs being sent in with fundamental errors or missing crucial information
- Estimated ECO size - no clear indication of how much work and time that is required for an individual ECO
- GEO ECO - no clear indication in the system if an ECO requires geometric assurance
- ECO updates - no clear indication if an already processed ECO changes after an issue update
- ECO transparency - difficult to obtain information about when an ECO is being worked on by PC or DE (vice versa)
- ECO follow-up responsibility - unclear what party is responsible for following up lagging ECOs
- Product knowledge - acquiring sufficient knowledge about the product in order to accurately relay it structural description

Furthermore, there was a cause-and-effect relationship between ECO-related challenges and cross-functional links. Whilst some ECO challenges stemmed from inherent issues in the ECM system, other problems could be regarded as symptomatic of the lacking cross-functional linkages between functional groups. Especially, collaboration ties to the function primarily responsible for the modular architecture and structural change order implementation were found to be inadequate and thus a root cause for a multitude of ECO-related issues that affected their lead time. Moreover, some problems could also be attributed to the functional structure of the organization and the structure-to-process alignment which implicitly promoted specialization over collaboration.

Implementation of a 3-tier framework that was developed and tailored to the already existing practices of Scania (see Conceptual Framework of Proposed Solutions). In particular, the tier 2 solutions, which serve to bridge informational gaps in the ECM system and coordination gaps between functions, can be regarded as the mitigation tool for the core ECO-related challenges.

8. Future Work

The addition of local sprint-based methods in select design engineer groups (as mentioned in 4.2.3) indicate that the organization is aware of some of the limitations and challenges that they are currently facing and are constantly experimenting. Thus, future studies should also be dedicated to studying the symbiosis between different product development processes and ECM implementations in modularization firms. Particularly, the effects of having different development processes in a product based on a system-dependent architecture. Building on the findings of this thesis, additional research should also aim to study the relationship between organizational structures and modularization-based architectural systems to identify empirical challenges associated with each structure-to-process setup. Furthermore, future research efforts should preferably be dedicated to conducting more empirical studies to highlight practical applications of ECM systems to further enrich the knowledge of how they are used in real-life firms as research on practical ECO implementations and their associated challenges in modularization firms is very thin.

Lastly, due to the COVID-19 pandemic of 2020, the ability to test the concepts was severely hampered. Therefore, it behooves the company to test the concepts, preferably in a focus group environment to identify the compatibility-based issues and eliminate major optimization costs when adopting company-wide tests.

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Appendix A: Rest of the graphs

DE-OL SURVEY

Statement 1:

When I design my parts/components, I actively think about Scania's modularization principles.

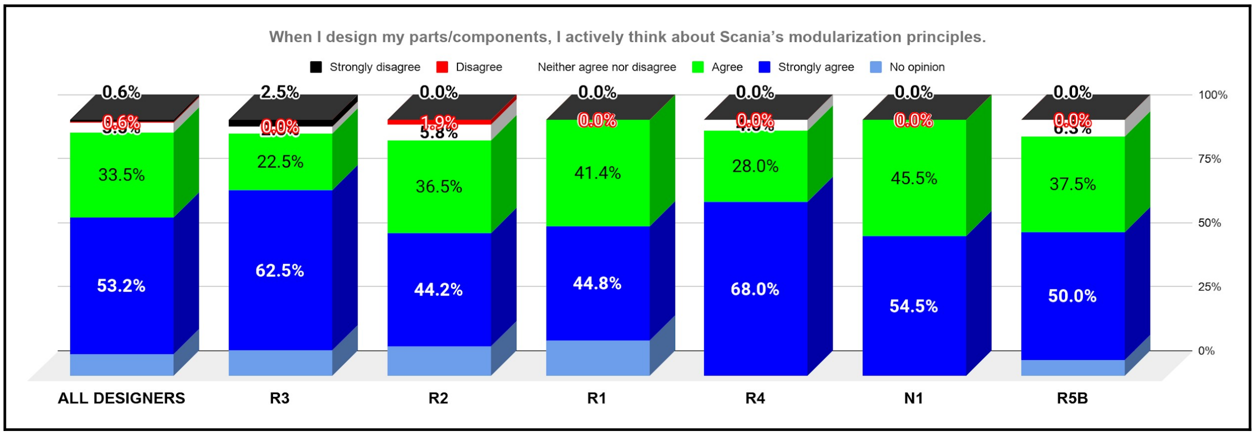

Figure 60. Responses by DEs for statement 1.

Being exclusive to the design engineer survey, the statement regarding how well the company's modularization principles are followed returned a strong majority of concurring responses, amounting to ~87% of the answers. As seen in figure 60 above, The distribution of answers was similar across all groups. However, worth noting is that a number of respondents gave neutral and non-opinionated answers, with the non-opinionated answers most likely originating from non-DE respondents.

Statement 8

I reach out to R5A (product coordination and geo. assurance) when I need assistance with issues that are not structure-related.

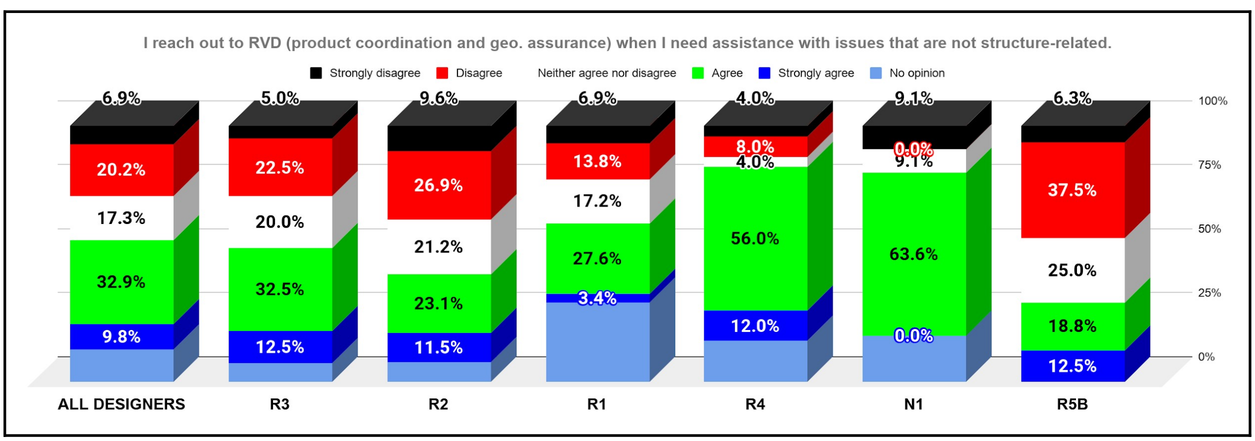

Figure 61. Responses by DEs for statement 8.

Although 43% of DEs “Agree and Strongly agree” to this statement, the responses within groups were varying. R5B in particular had appx. 57.5% of answers which were either neutral nor disagreed. This similar trend can be seen in R2 also where appx 48% of the responses which were either neutral nor disagreed. But there were contrasting responses in R4 and N1 where the responses were either “Strongly Agree or Agree” for appx 60%.

Statement 9

The product coordinators are actively trying to involve themselves in project discussions from an early phase.

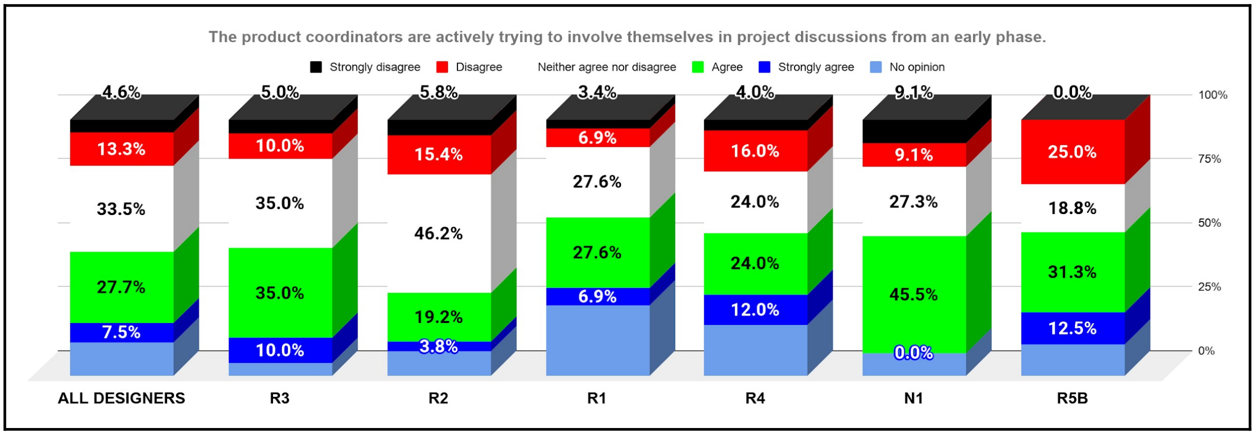

Figure 62. Responses by DEs for statement 9.

Inspired by the common theme identified in the qualitative interviews, the Statement was asked to gauge the DE perspective on PC’s current project involvement initiatives as the interviews indicated that PCs were heavily interested in closer project involvement. However, results shown in figure 62 above illustrate that the majority of groups were either neutral or disagreed with the notion about PCs actively trying to involve themselves in projects. R3, N1 and R5B stood out as the only groups that had noteworthy numbers of agreeing answers. Overall, most groups had a neutral stance on the topic.

Statement 10

I feel like I have a good rapport/partnership with the product coordinators that I interact with.

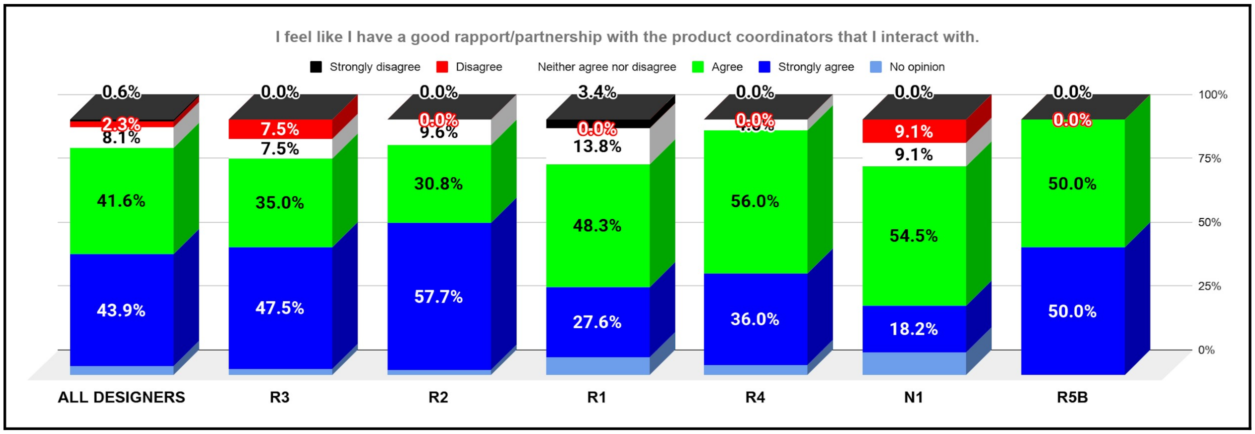

Figure 63. Responses by DEs for statement 10

Figure 63 shows that all design engineer groups agree that they have a good rapport and partnership with their product coordinators, with a majority of DEs strongly agreeing with this statement. The Statement was derived from the qualitative findings where most PCs, likewise, stated that they had good rapports with their assigned DEs. More specifically, ~86% of DEs “Strongly agree and agree” to this statement. The maximum responses recorded in this section is R5B with 100% and followed by R3 and R2 with 92.5% and 88.5% respectively. However the lowest response in this stage was by the N1 team with 72.7%.

Statement E:If I feel overloaded with work, I can rely on my colleagues for assistance.

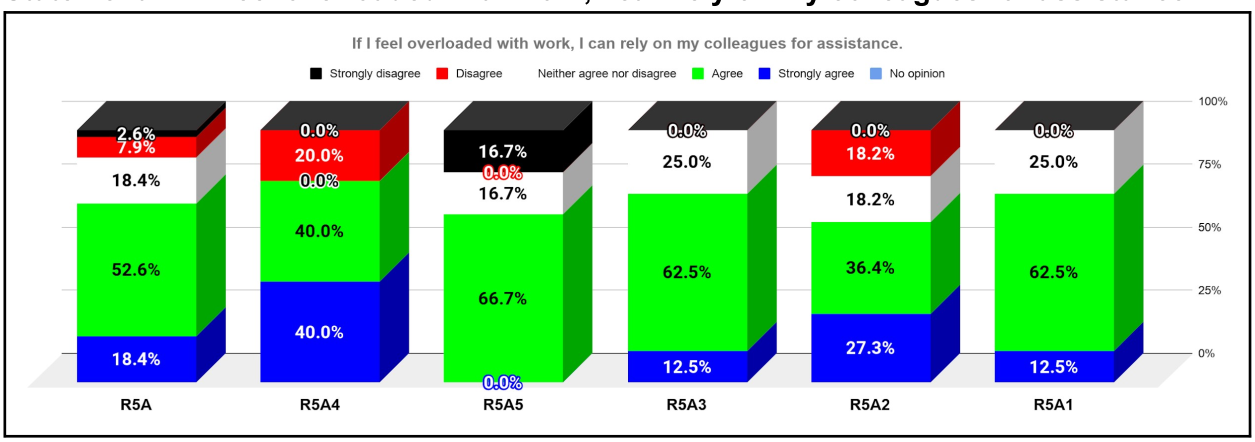

Figure 64. Responses by R5A for statement E.

Collaboration-wise, most groups claimed that they could rely on colleagues for assistance when being inundated with work, yielding 71% of agreeing responses in total according to figure 64. Note that the statement referred to intra-group collaboration as opposed to cross-group collaboration which was further dissected in the interviews. Though, some disagreements were recorded in R5A4, R5A5 and R5A2 accounting for less than 20% in all groups respectively with R5A5 standing out as the only group with strong disagreements. Also, R5A1 and R5A3 had no negative responses.

Statement J: I actively involve myself in the project by attending meetings with e.g. object leaders and design engineers.

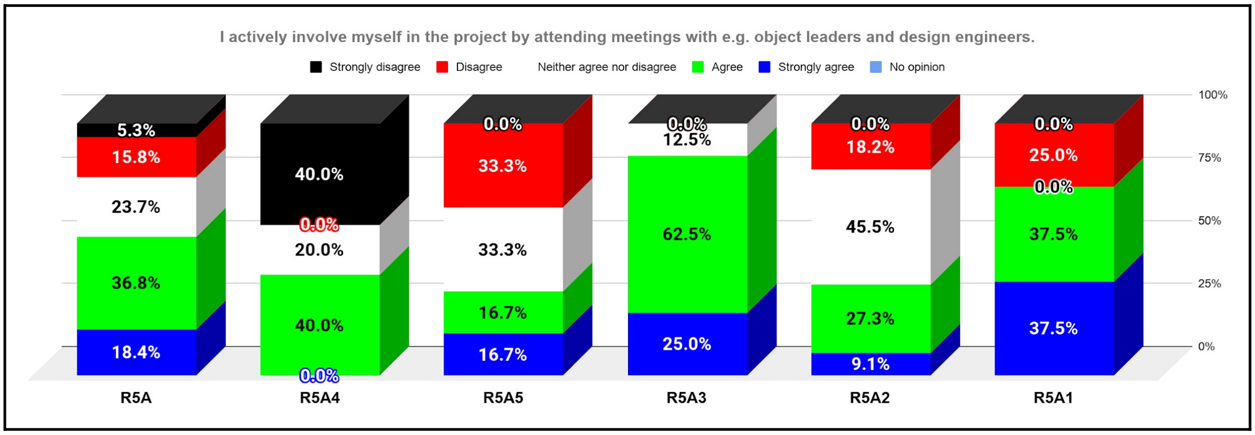

Figure 65. Responses by R5A for statement J.

Different views were recorded regarding cross-functional involvement in projects, yielding a mixed distribution of answers, illustrated in figure 65. Negative views were noted in all groups but R5A3 where the general view was positive with ~88% of respondents agreeing and strongly agreeing with the given statement. However, R5A1 also had a big portion of agreeing responses, totaling to 75%. In addition, R5A4 and R5A5 had a noteworthy amount of negative responses. Furthermore, both R5A2 and R5A5 had a high percentage of neutral answers, implying that there exists some uncertainty regarding this topic.

Statement L: Object leaders and design engineers actively want to involve me in their work by inviting me to their meetings.

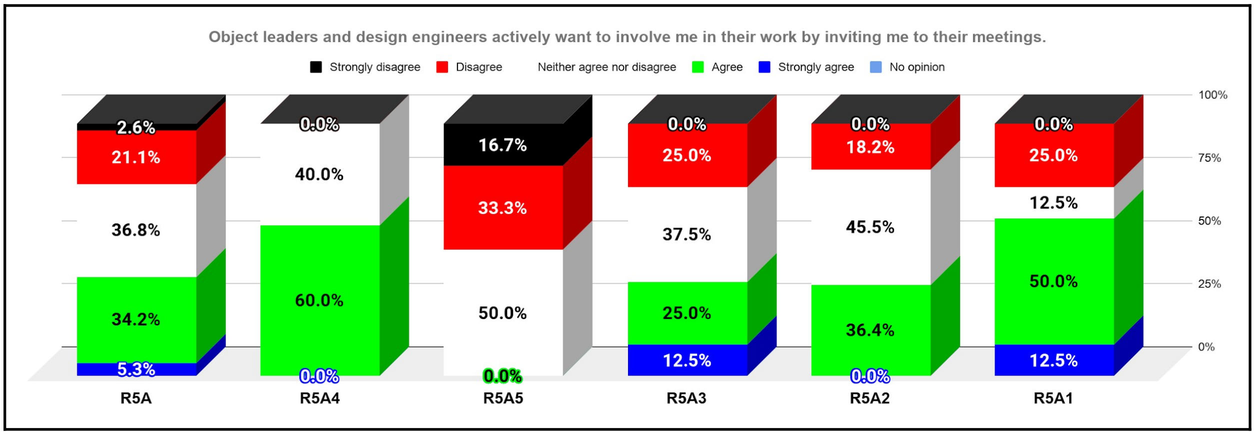

Figure 66. Responses by R5A for statement L.

Much like previous statements about cross-functional involvement, contrasting views were recorded about the degree of involvement in object and design engineer activities as well as their willingness to involve R5A groups. Whilst concurrings responses were common in R5A1 and R5A4, neutral and disapproving views were more prominent in R5A5, R5A3 and R5A2 (figure 66). Noteworthy is that R5A5's responses only consisted of neutral, disagreeing and strongly disagreeing answers compared to the others that had at least ~36% of agreeing responses.

Statement O: I consider that it is important to be involved early in the project.

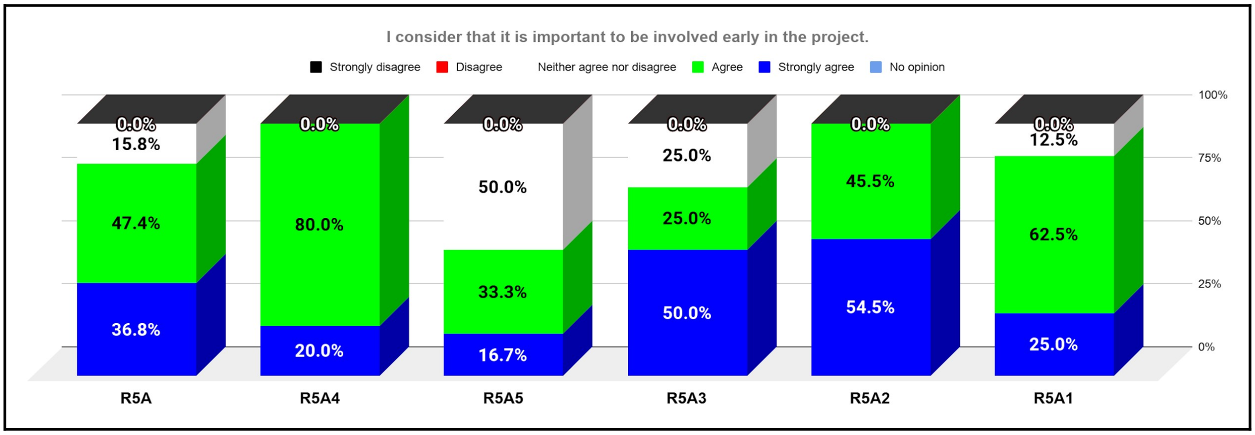

Figure 67. Responses by R5A for statement O.

All groups regarded project involvement as an important aspect, returning a notable amount of strongly agreeing responses as shown in figure 67 above. R5A5 was the only group that had a neutral reaction with half of the respondents neither agreeing nor disagreeing.

Statement S: I organize meetings with design engineers and object leaders when I feel like it is needed.

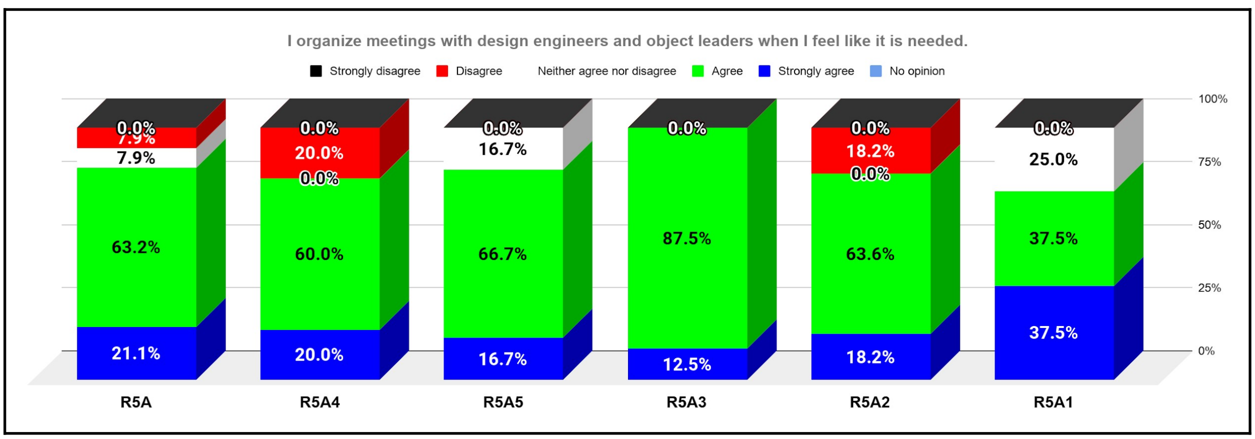

Figure 68. Responses by R5A for statement S.

84% of PCs “agree” and “strongly agree” that they organize meetings with design engineers and object leaders when needed. Although some minor differences were observed, most groups reflected the distribution illustrated in the left-most bar chart. Worth noting is that R5A3 stood out as the only group with strictly concurring views on the statement.

Statement T: I want to involve myself more in projects but I do not have enough time to do so.

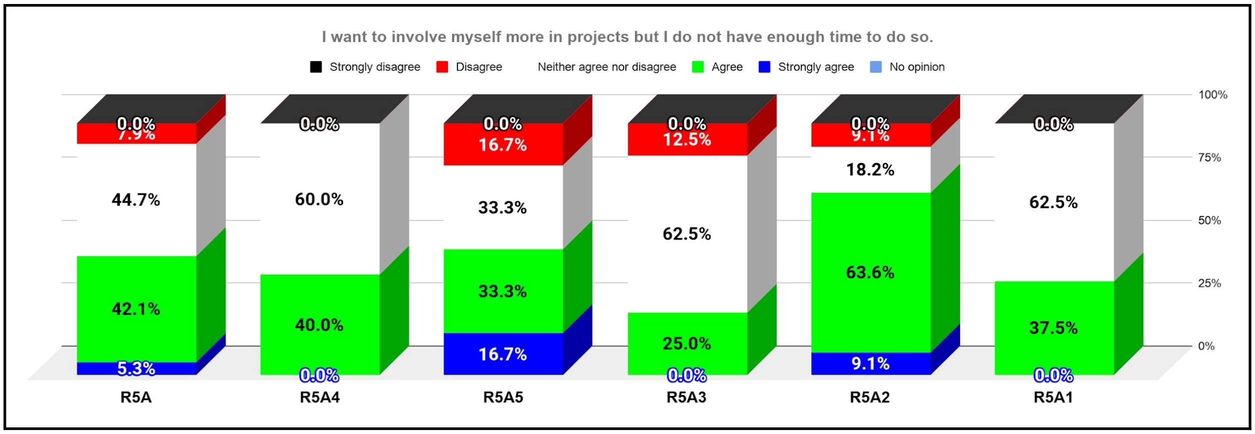

Figure 69. Responses by R5A for statement T.

Close to ~47% of PCs agree that they want to involve themselves more in projects but they do not have the time to do so. However, a significant amount of uncertainty was also observed in all groups, with neutral answers making up ~45% of all responses. The highest percentage of agreement was found in R5A2 at ~73%. In the case of R5A1 and R5A4 there were no responses in which the respondents were neutral or disagreed. In R5A3, the percentage of agreeing answers was 25% and was the lowest in comparison with other groups. Disagreement was recorded in three groups R5A5, R5A3 and R5A2, but the maximum was found in R5A5 with 17% of respondents who chose “disagree”.

Statement U: I often get distracted by other inquiries that take up a large chunk of my time.

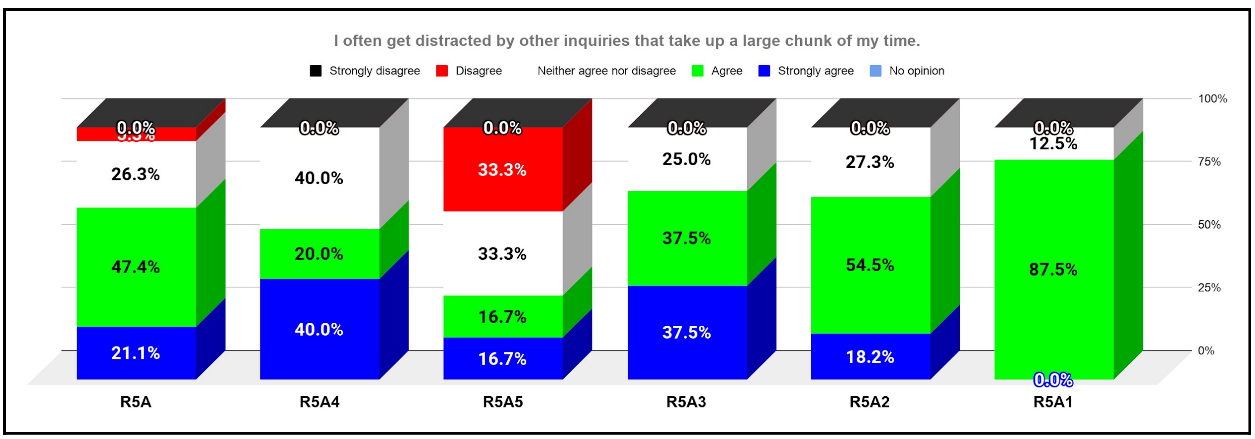

Figure 70. Responses by R5A for statement U.

In regards to getting distracted by other inquiries, a majority of R5A respondents agreed with the statement. This pattern was observed in all groups but R5A5 where the percentage of neutral and strongly disagreed answers was around 67%. In addition, R5A5 was the only group that gave disagreeing responses. R5A4 had the maximum percentage of neutral responses compared to other groups closely followed by R5A5 at ~33%. These results indicate that distraction by non-ECO inquiries are frequently occurring and constitute a big chunk of the PC respondents’ time.

Statement V: If I have a suggestion for improvement, I know what forums to use to escalate it.

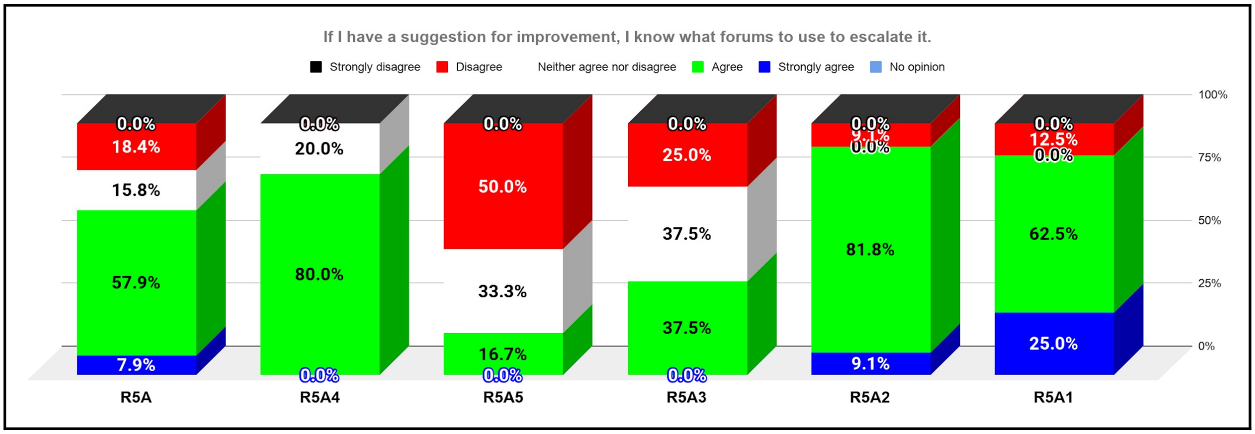

Figure 71. Responses by R5A for statement V.

According to figure 71, around ~66% of R5A respondents concurred with the statement about them having forums for escalating improvement suggestions. But the responses varied between the groups. In the case of R5A5 and R5A3 there were more responses in which the respondents were neutral and disagreed compared to the other three. The major percentage of disagreement can be seen in R5A5 where 50% of respondents disagreed. R5A4, R5A2 and R5A1 had responses which were more in agreement with the statement (at least 80%).

Statement W: I have enough time to work on process improvements.

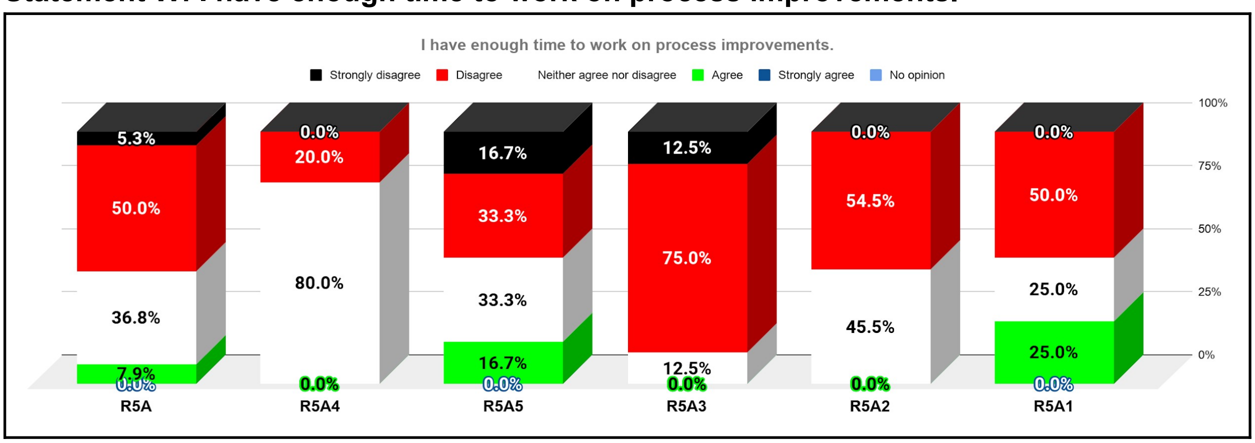

Figure 72. Responses by R5A for statement W.

As shown in figure 72 above, a strong majority of PCs responded that they were either neutral, disagreed or strongly disagreed regarding time allocated to work on process improvements. We can see that this pattern was observed in all R5A groups. R5A2, R5A3 and R5A4 were the groups that only had neutral and disagreeing answers. The only groups that had agreeing answers were R5A1 and R5A5 even though it was 25% and 17% respectively. Moreover, R5A4 had the highest percentage of neutral answers at 80%. The results suggest that little-to-no time is practically allocated to process improvement work.

Statement AA: If any of my colleagues are absent, I can jump in and cover their domain.

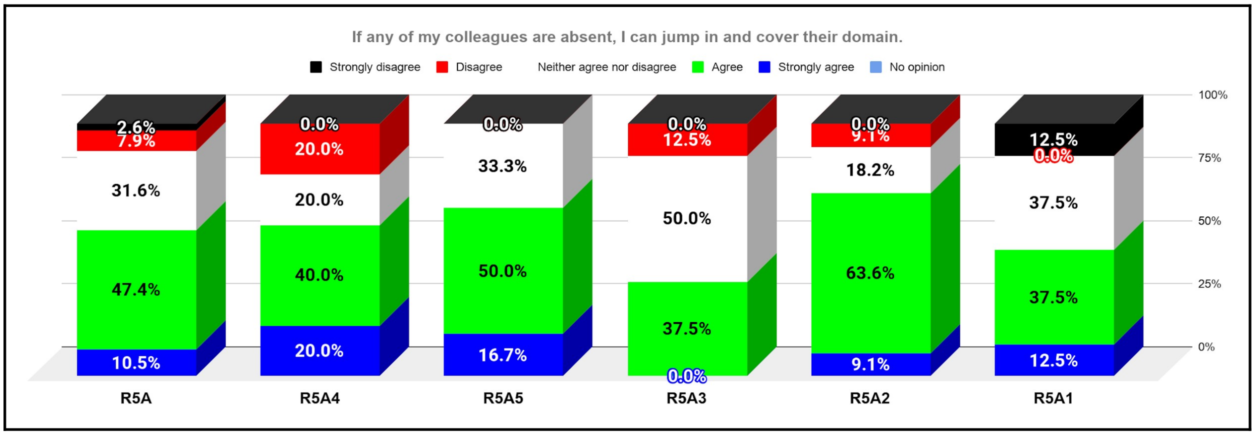

Figure 73. Responses by R5A for statement AA.

Figure 73 shows responses recorded by PCs with considerably more neutral and positive answers when asked about if they can jump in and work in other domains when their colleagues are absent. Within the cross-group comparisons, however, there are more stark patterns of disagreement. In particular, the majority of respondents from the R5A3 group were either neutral or disagreed, accounting for ~73% of answers compared to the ~38% of agreeing or strongly agreeing answers. In R5A1 there were equal responses of both agreement and disagreement with ~13% of people strongly disagreeing. Also, another thing to be noted is that R5A4, R5A5 and R5A2 had more neutral and positive answers compared to other two groups.

Statement AB: My colleagues and I follow an agreed standard when we work with the design structure.

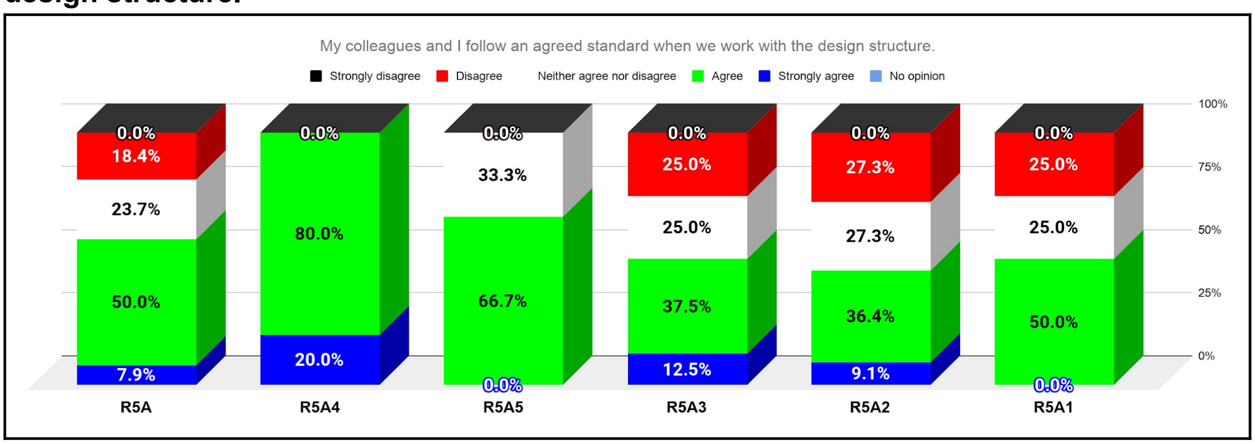

Figure 74. Responses by R5A for statement AB.

According to the charts visualized in figure 74 above, around ~57% of DEs "Agree and Strongly agree" to this statement but the responses varied between individual groups. In the case of R5A4 there were no responses in which the respondents disagreed. But in R5A1 and R5A3 agreeing views ("agree" and "strongly disagree") equaled the total percentage of neutral and disagreeing responses ("neither agree nor disagree", "disagree" and "strongly disagree"). A similar trend can also be seen in R5A2 also where approximately 55% of the responses were either neutral or disagreeing.

Statement AC: Please grade the following ECO status raises in order of time investment required

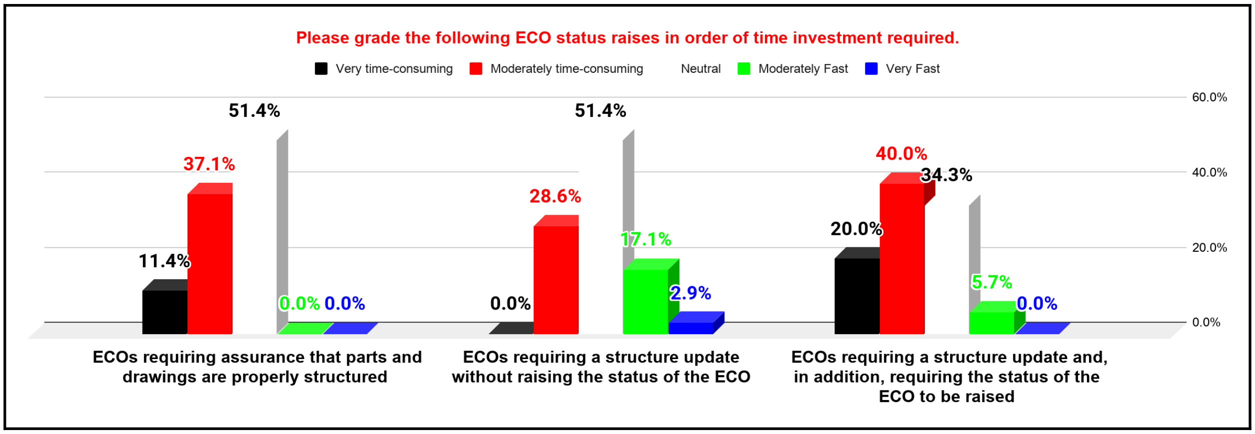

Figure 75. Responses recorded by PC's for which factor is time consuming.

Figure 75 shows responses recorded by PCs among the three status raise factors which they feel is more time consuming. One common trend among the three factors is that they have a considerable amount of neutral responses. We can see from the chart *that "ECO requiring a structure update and requiring the status of ECO to be raised"* requires the most time investment as 60% PC's either feel it as moderately time consuming and very time consuming. The second selected option is "*ECO requiring assurance that parts and drawings are properly structured"* as 48.5% of PC's either feel it as moderately time consuming and very time consuming. 20% PCs responded *"ECOs requiring a structure update without raising status"* as less time consuming and this status raise can be done in a fast way compared to the other two sceanrios.

Appendix B: Comparative Charts

Here, results of related PC and DE groups of the same domain are shown in a side-by-side comparison.

R3D and R5A1

Figure 76 below shows the comparison between the answers given by the associated R5A and design groups. In this scenario the design group is R3D and the R5A group is R5A1. The reason for selecting R3D and R5A1 is because the ECOs which are sent by R3D are worked and approved by R5A1. The comparison is to find synergies between the associated PC and DE group over certain themes such as ECO awareness, project setup and implications etc. Table 13 below shows the differences in responses for related statements in figure 80.

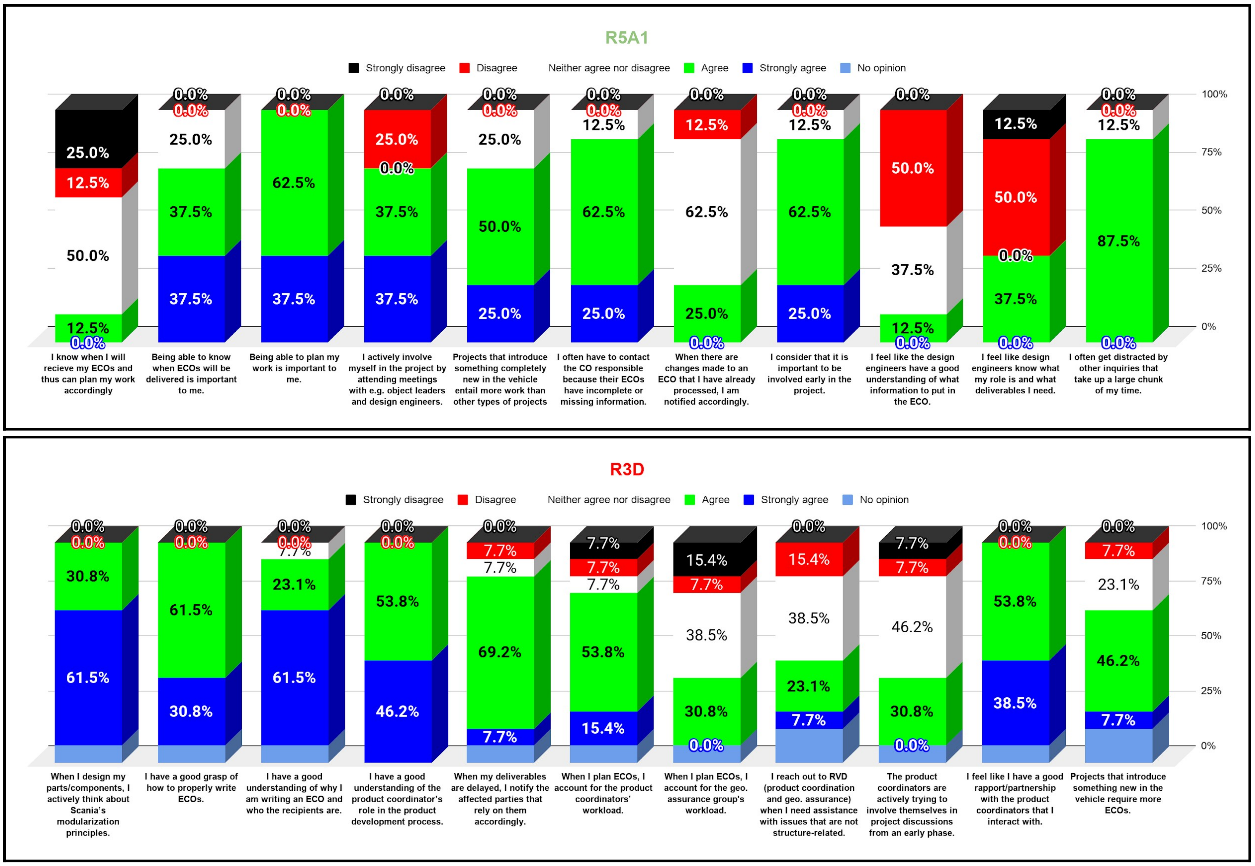

Figure 76. Comparison between R5A1 (top chart) and R3D (bottom chart).

Table 13. Summary of differences between related statements in both surveys (R3D and R5A1)

Statement code (DE)	Concurring responses (%)	Neutral	Disagreeing responses (%)	Statement code (R5A)	Concurring responses (%)	Neutral	Disagreeing responses (%)
2	92.3	7.7	-	**P**	12.5	37.5	50

3	84.6	15.4	-				
5	76.9	15.4	7.7	**N**	25	62.5	12.5
8	30.8	53.9	15.4	**U**	87.5	12.5	-
9	30.8	53.9	15.4	**O**	87.5	12.5	-
11	53.9	38.5	7.7	**K**	75	25	-

R5A2 and N1B

A similar comparison can also be made for the base chassis domain. Figure 77 shows the results of R5A2 and N1B for related statements. Table 14 below shows the differences in responses for related statements in figure 77.

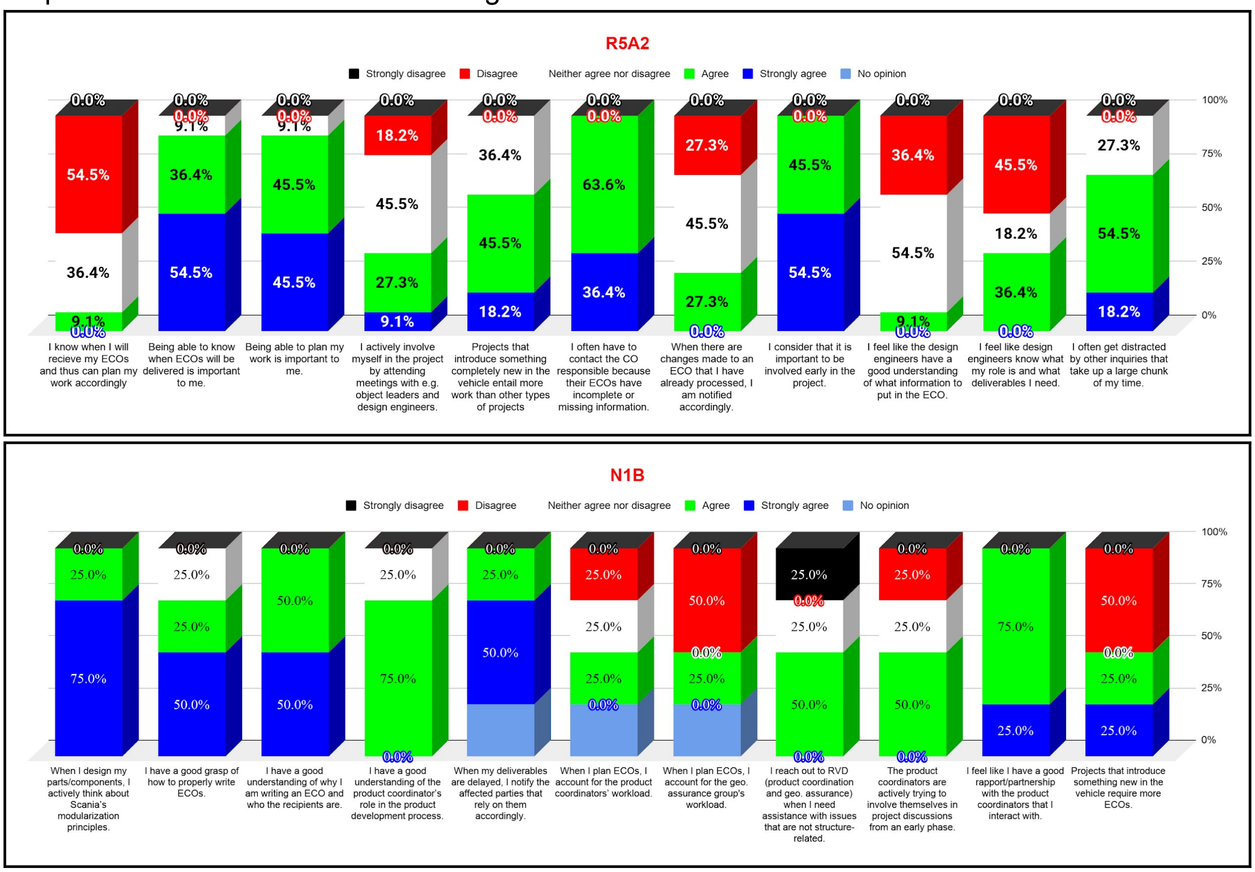

Figure 77. Comparison between R5A2 (top chart) and N1B (bottom chart).

Table 14. Summary of differences between related statements in both surveys (R5A2 and N1B)

Statement code (DE)	Concurring responses (%)	Neutral	Disagreeing responses (%)	Statement code (R5A)	Concurring responses (%)	Neutral	Disagreeing responses (%)
2	75	25	-	**P**	9	54.5	36.4

3	100	-	-				
5	75	25	-	**N**	27.3	45.5	27.3
8	50	25	25	**U**	72.7	27.3	-
9	50	25	25	**O**	100	-	-
11	50	-	50	**K**	63.7	36.3	-

R5A3 and R1D

Figure 78 shows the results of R5A3 and R1D for related statements. Table 15 below shows the differences in responses for related statements in figure 78.

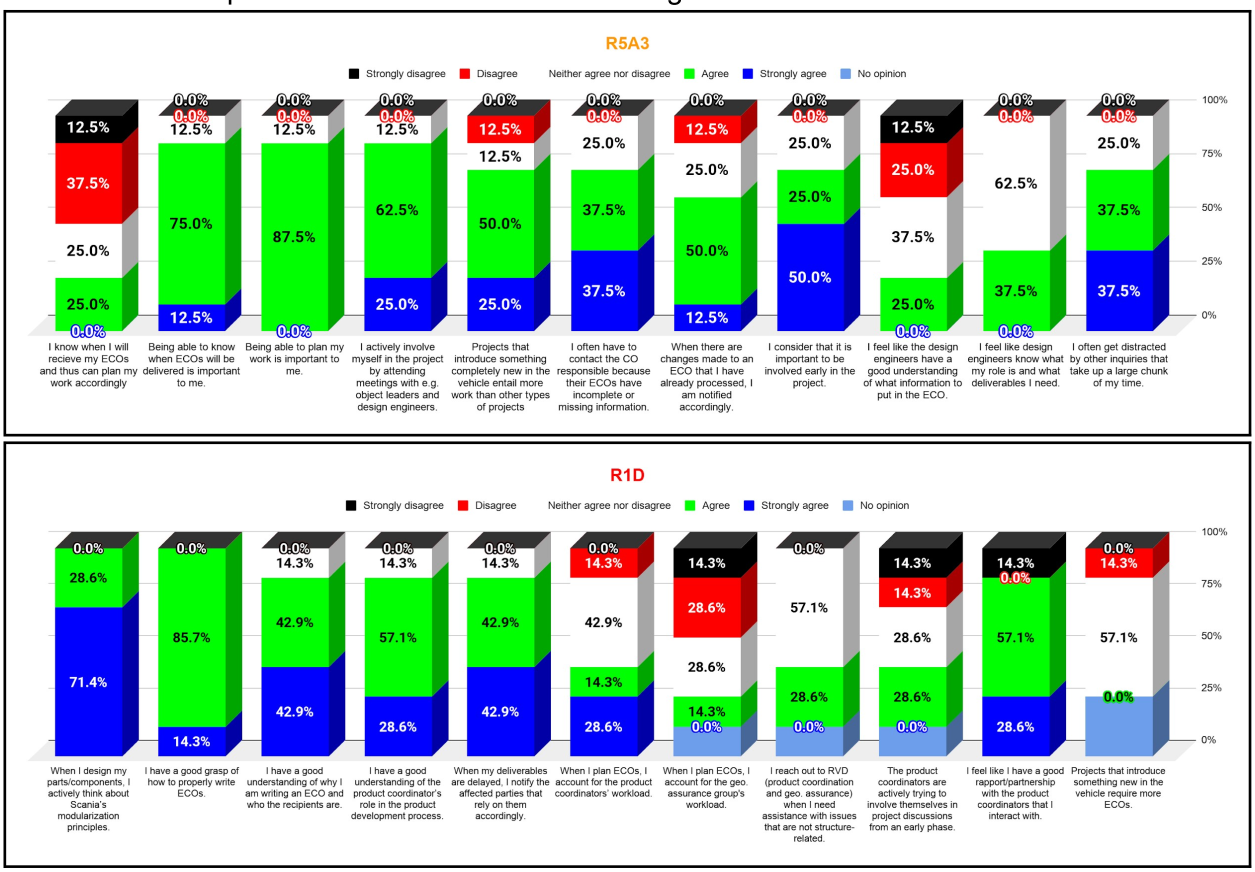

Figure 78. Comparison between R5A3 (top chart) and R1D (bottom chart).

Table 15. Summary of differences between related statements in both surveys (R5A3 and R1D)

Statement code (DE)	**Concurring responses (%)**	**Neutral**	**Disagreeing responses (%)**	**Statement code (R5A)**	**Concurring responses (%)**	**Neutral**	**Disagreeing responses (%)**
2	100	-	-	**P**	25	37.5	37.5

3	85.8	14.2	-				
5	85.8	14.2	-	**N**	62.5	25	12.5
8	28.6	71.4	-	**U**	75	25	-
9	28.6	42.8	28.6	**O**	75	25	-
11	85.7	14.3	-	**K**	75	12.5	12.5

Below (table 16) is the full description of the codes on what they represent and which theme in the qualitative interviews that they are associated with.

Table 16. Description of codes and their related theme.

Code and Full Statement	Survey	Theme
2. I have a good a good grasp of how to write ECOs	DE	ECO and ECM Challenges
P. I feel like the design engineers have a good understanding of what information to put in the ECO.	PC	ECO and ECM Challenges
3. I have a good understanding of why I am writing an ECO and who the recipients are.	DE	ECO and ECM Challenges
5. When my deliverables are delayed, I notify the affected parties that rely on them accordingly.	DE	ECO and ECM Challenges
N. When there are changes made to an ECO that I have already processed, I am notified accordingly.	PC	ECO and ECM Challenges
8. I reach out to R5A (product coordination and geo. assurance) when I need assistance with issues that are not structure-related.	DE	Project Setup and Implications
U. I often get distracted by other inquiries that take up a	PC	Project Setup and Implications

large chunk of my time.		
9. The product coordinators are actively trying to involve themselves in project discussions from an early phase.	DE	Systematic and Unsystematic Integration Mechanisms
O. I consider that it is important to be involved early in the project.	PC	Systematic and Unsystematic Integration Mechanisms
11. Projects that introduce something new in the vehicle require more ECOs.	DE	Project Setup and Implications
K. Projects that introduce something completely new in the vehicle entail more work than other types of projects	PC	Project Setup and Implications

Appendix C: Rest of the solutions

3D PMI

Brief Description
Implementation of 3D PMI introduces fully interactive 3D CAD models with 2D annotations for a more accurate representation of the model that is being studied (compared to 2D drawings).

Solution Range
- Improves understanding of product’s functionality.
- Simplifies estimation of ECO size (required work).
- Proven effectiveness in empirical studies - decreased ECO lead time

Schematic Overview

Input
In addition to producing 2D representations of individual parts, the DEs will export interactive 3D models with embedded PMI.

Output
The PCs will introduce a new item in the KS (example visualized in figure 83 below) that contains the interactive 3D object that they can use when working on defining the structural conditions for a part.

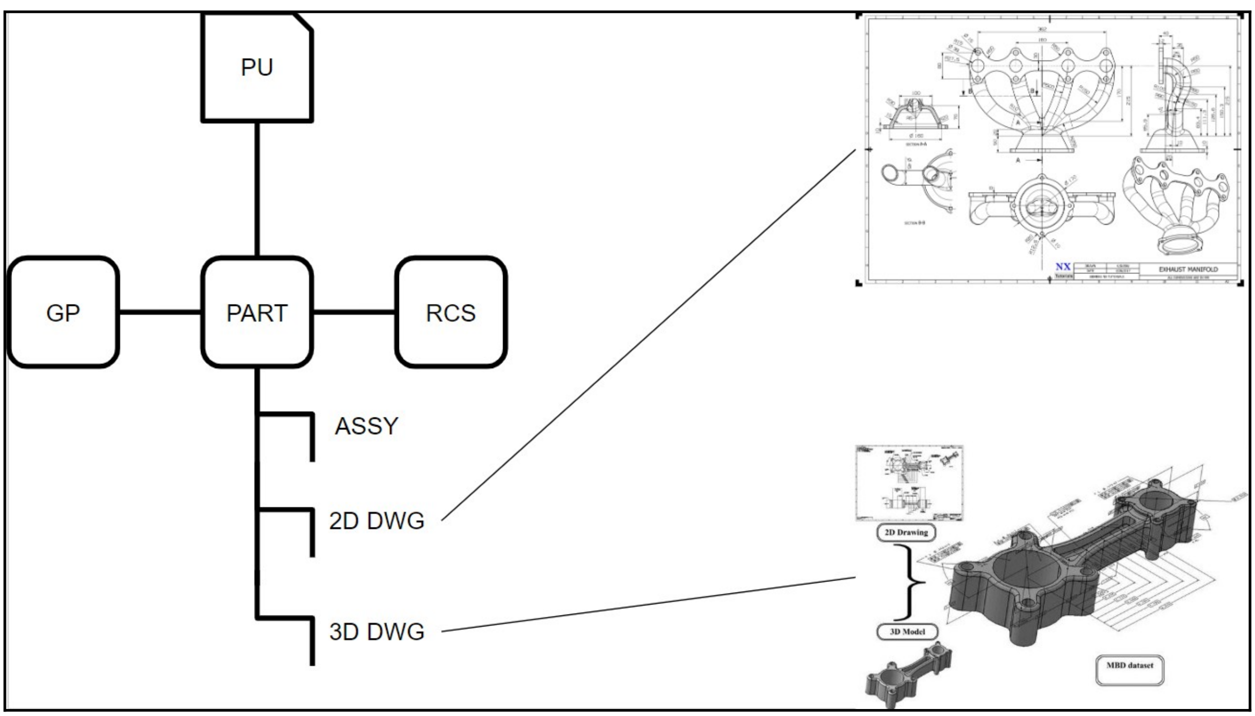

Figure 79. Simplified overview of the KS structure with the proposed 3D PMI elements (3D DWG)

Implementation strategies and enforcement

Own initiative: As this solution is linked to the individual way of working to understand the product better while working, the best way to implement this is by making sure that individuals themselves try to use this while they work on ECO tasks on a daily basis.

POIA - Project and Object Involvement Approach

Brief Description

Electing PCs from each group that systematically attend ODF/PDF meetings to represent PCs' main interests and then share contents of the meeting with their respective groups. This, so that they can get a better understanding of the product and continuously follow up ECO time plans via an automated status update system.

Solution Range

- Improves and increases awareness of DE-induced delays.
- Simplifies estimation of ECO size (required work).
- Becomes part of a common integration approach within R5A.
- Systematic integration mechanism between DEs and PCs.
- Closer project involvement [S].
- Facilitates better understanding of PCs' role.
- Enforces FREQUENT follow-up status with respect to ECO time plan deviations, replanning and responsibilities.

Schematic Overview

Input

One PC from each PC group (4) is chosen to attend all ODF and PDF meetings to get a better overview of both the projects and the domain-specific objects that their groups will work on. At the meetings, the PCs also ensure that R5A5's role and interests are being catered to. After attending the meetings, the PC will present the object and project at the weekly group meeting to educate their peers on what the project is about and how the object is related to the product as a whole. Figure 84 below shows a flow of the proposed process.

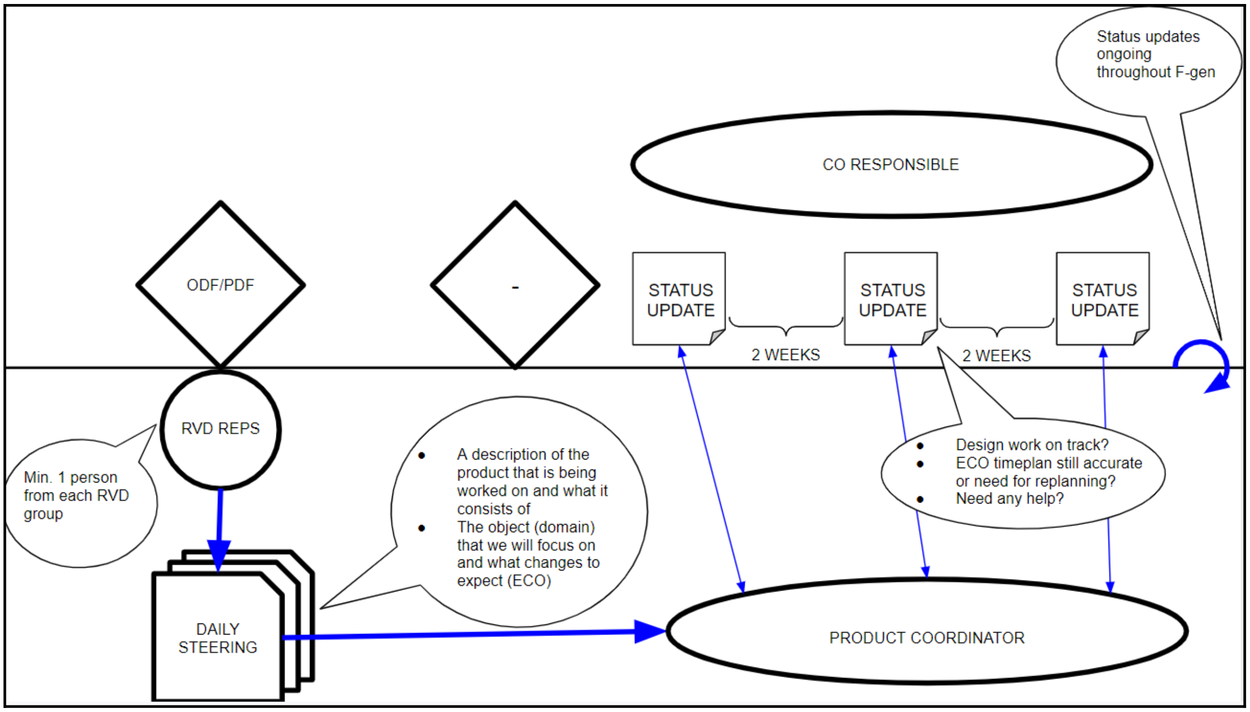

Figure 80. Flow of the process

Output

After getting briefed about the project and object, the individual PCs then send out (automated) status update sheets to the DEs in the project. Status updates are communicated via Email-linked sheets and share similarities with the ***Green Arrow Portfolio*** syntax, utilizing red, yellow and green color codes to indicate status of ECOs. More specifically, the status updates briefly check to see if the ECO timeplan is still accurate. This process is automated, being sent in by the PCs via a recurring Email list (***automated Emailing*** in Outlook).

Implementation strategies and enforcement

The concept can be implemented in two ways:

1. Own initiative, seek to gradually attach R5A to front-end product discussions (ODF/PDF meetings) and to assert structure ownership by initiating status update dialogs with CO-responsible DEs of one's domain.

2. Structural change via project management, ask for PCs to receive invitations to all ODF/PDF meetings and make status updates a mandatory part of the PC-DE interaction. Involve project management in spreading this information to all ECO-writing functions.

Process Improvement Workshops

Brief Description

An workshop initiative within R5A groups to improve the existing processes by activities such as group discussions and interactions. Discussions are centered around the topics like improvement of work methods, ECO standards unification, improvement related to Scania Home, innovative ideas to transform the existing work and how to make the workplace a better environment.

Solution Range

Allows employees to focus only on process improvement without distractions.

- Promotes internal collaboration
- Potential for more unified ways of working – standardized.
- Allots time to process improvement which addresses a huge problem reflected in the survey results.

Schematic Overview

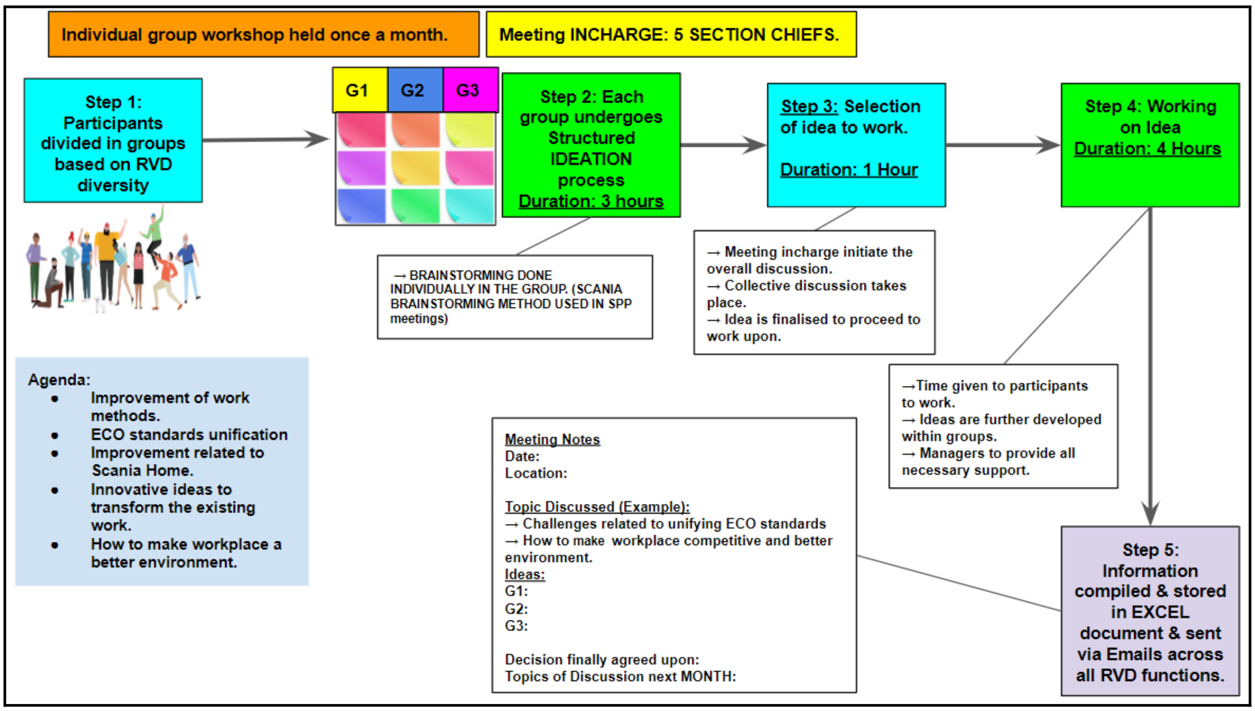

Figure 81. Basic overview of the improvement workshop in scenario 1

This workshop is scheduled to be held one day a month.

The people responsible for organising and maintaining this workshop are the group managers of all the R5A departments.

Step 1: The participants are divided into groups based on the diversity. (i.e Each group should have members from different R5A groups)

Step 2: After divisions of the groups, each group individually works in the IDEATION process for 3 hours. Brainstorming is done within the groups using the standard (SCANIA BRAINSTORMING METHOD USED IN SPP meetings).

Step 3: In this step ideas are selected that need to be further developed.Around 1 hour is spent on this activity.
The meeting incharge takes initiates the discussion with every group.
After the discussions, collective decision is taken about the idea to be worked with.
IDEA is selected to be worked with.

Step 4: After selecting the idea in the previous step, the idea is being worked upon in this step. In this step TIME is given to the participants to work on the idea selected. Managers should make sure that all the resources and support should be provided to the participants.

Step 5: After developing the idea, the information is compiled, documented and stored in a form of Excel sheet. The excel sheet is sent to everyone in R5A via email.
The meeting notes which will be circulated will have the format as shown below:

<u>Meeting Notes</u>
Date:
Location:

<u>Topic Discussed (Example):</u>

- Challenges related to unifying ECO standards
- How to make the workplace a competitive and better environment.

<u>Ideas:</u>
G1:
G2:
G3:

Decision finally agreed upon:
Topics of Discussion next MONTH:

SCENARIO 2: In the case of an already existing idea, the participants can start working on it. They are not required to be in the initial step 1,2 and 3, they can just focus on the existing idea from step-4. Below is the schematic representation of how the process works

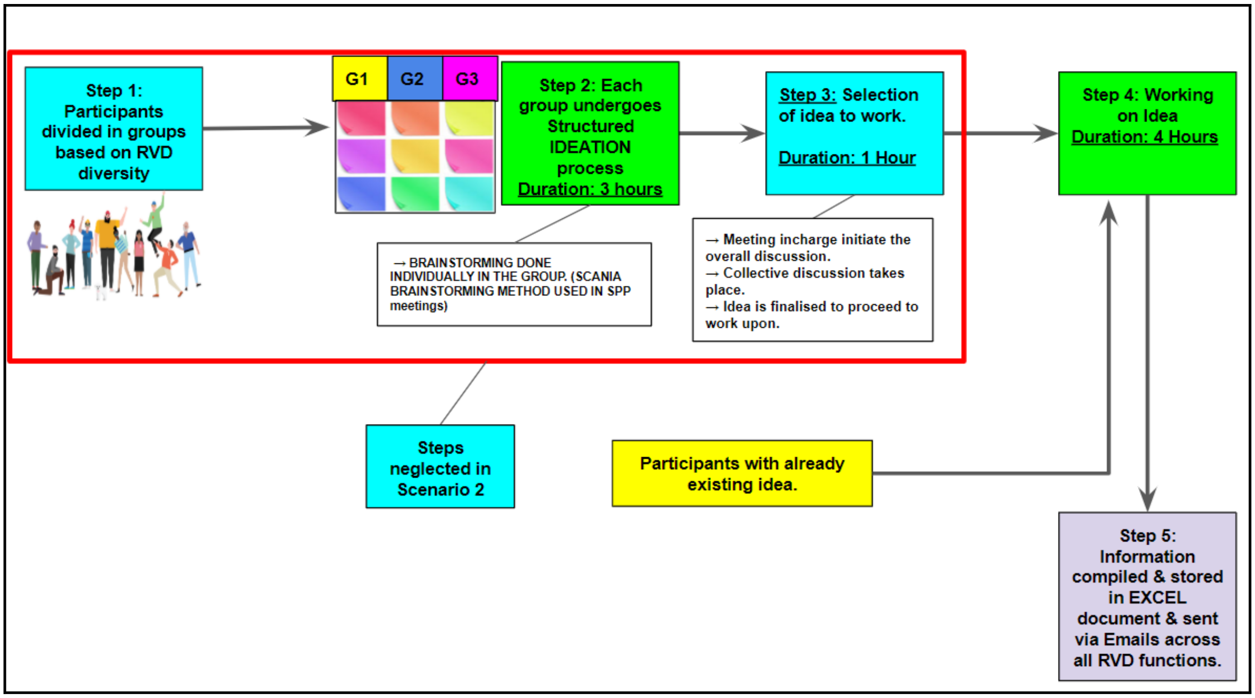

Figure 82. Basic flow of the improvement workshop in scenario 2.

Implementation strategies and enforcement

The people responsible for organising, scheduling, inviting participants and maintaining this workshop are the **GROUP MANAGERS** of all the R5A departments.

ECO Workshop

Brief Description

From the interviews we had findings from different respondents that the quality of ECOs being written and sent in was not satisfactory.And also many ECOs did not have all the necessary information. With that in mind an workshop initiative to improve the ECO writing process by activities such as group discussions and interactions between Designers and Product Coordinators. With the help of this workshop the quality of influx of ECOs can be improved.

Solution Range

- Better understanding for DEs about ECO writing.
- Proven benefit R5A3 among others - Quality of ECO’s improved after the workshop.
- Bridges CF gaps and thus improves PC-DE collaboration.

Schematic Overview

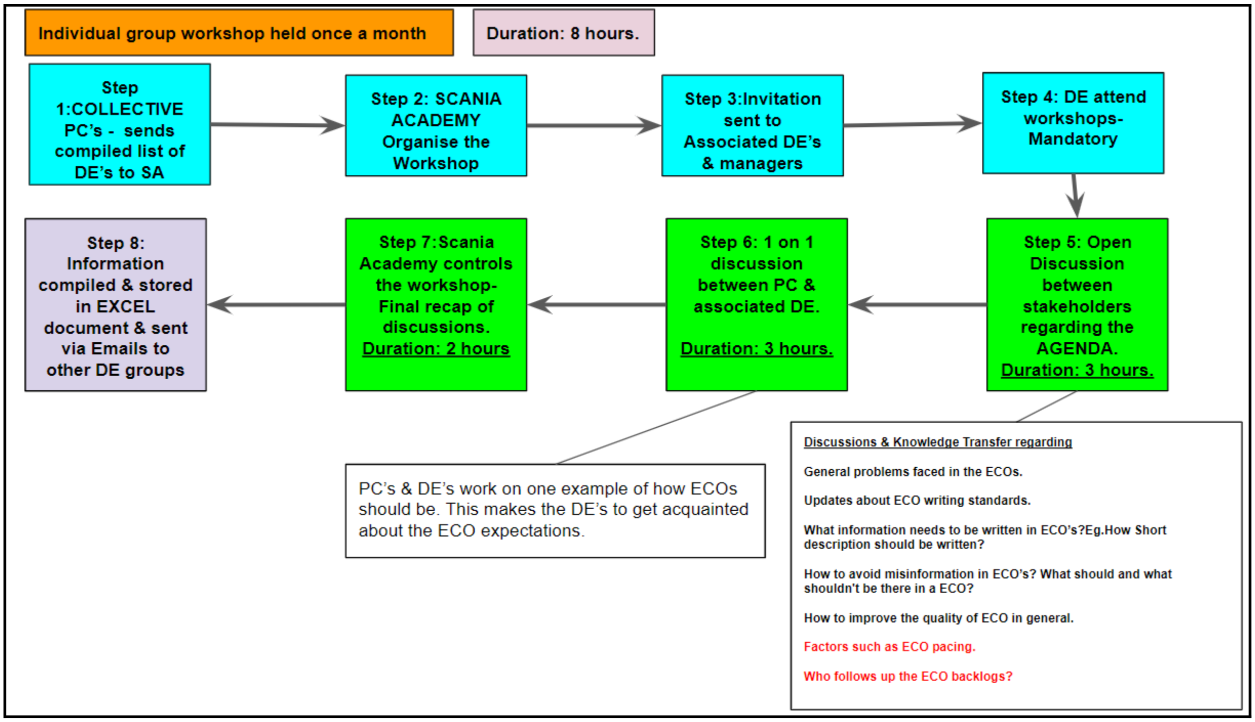

Figure 83. Flowchart of the ECO workshop

This workshop is held once a month
This is collectively for all the PC groups.

Step 1: The collective PC's send the compiled list of Design Engineers to the Scania Academy. The selection of Design Engineers is based on the factors

1. History of ECOs sent which were backlogged often
2. Which DEs ECOs were problematic- had missing information, misinformation.

All groups select a total of 25 DE's i.e 5 from each R5A group. Then, Collective PC groups send the list of 25 DE's to SCANIA ACADEMY.

Step 2: Scania Academy organises the workshop with the aim to improve the ECO writing quality.

Step 3: Scania Academy after receiving the list of DEs, now sends the invitation to the DE's and DE managers.

Step 4: After receiving the invitation, the DE's attend the workshop.

Step 5: In this step there is an open discussion with all the stakeholders.The stakeholders are the Design Engineers and the Product coordinators who are mandatory, but other participants are Design managers, R5A group managers, Object leaders who attend these discussions when they have time. With the aim to improve the ECO writing of the DE's topics which are discussed in detail are

1. General problems faced in the ECOs.
2. Updates about ECO writing standards.
3. What information needs to be written in ECO’s? Eg.How Short description should be written?
4. How to avoid misinformation in ECO’s? What should and what shouldn't be there in an ECO?
5. How to improve the quality of ECO in general.

Step 6: After the group discussion with all the stakeholders, the next step of the process is individual sit down meetings between the associated Product Coordinators and the Design engineers. In this step the PC and DE team up to write an example ECO together where they have the ability to build rapport and agree on standardized understanding of the information in the ECO. The main purpose of this step is so that Design Engineers can understand what the associated Product Coordinator expectations are in an ECO. For eg. the short description- how can that be written? The duration of this step is 3 hours.

Step 7: In the next step Scania Academy takes control over the workshop. The point of this step is Scania Academy concludes with a final discussion of what happened in the previous steps. This is again a discussion with all the stakeholders who were in step 5.

Step 8: After the final discussions, the points are written down in the EXCEL sheet and stored for repository purposes. The Excel sheet is also sent to other DE groups with the help of an email. With this other DE groups will be aware of the happenings in this workshop.

Implementation strategies and enforcement

SCENARIO 1

- Scania Academy organises the workshop with the aim to improve the ECO quality.
- Scania academy enforces DEs to attend the workshop.
- Scania Academy makes sure the smooth functioning of the workshop and checks if the objectives of the workshop are met.

The involvement of Scania Academy makes this workshop official in the process and this makes the workshop to be conducted and attending compulsory.

SCENARIO 2

Instead of SCANIA ACADEMY enforcing this workshop, this workshop can be an internal R5A initiative.

Each R5A group selects an individual based on experience and knowledge. This workshop happens in individual groups.
And the selected individual conducts the workshop.

It is the respective group manager and the R5A manager to enforce this workshop by making sure this workshop is being conducted every month.

The drawback of this scenario is that as it is an internal R5A initiative, there is a high probability of this workshop not being followed regularly.

ECO Coordinator

Brief Description

The ECO coordinator is a floating role concept whose purpose is to be representative for the respective PC groups to attend multiple meetings and keep the PC's updated about the happenings in the projects and improve the product knowledge. From the interviews we had findings from different PC respondents that they would like to be involved earlier in the projects such as SPP meetings, and Object meetings. But because of TIME constraints they are not able to involve themselves. With that in mind, this concept of ECO COORDINATOR is proposed to address those problems.

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Solution Range

- Better understanding of the product.
- Opinions/voices of PC represented at SPP meetings - closer object and project involvement.
- Influences ECO time plans.
- Influence DE's regarding Workload and ECO Pacing.

Schematic Overview

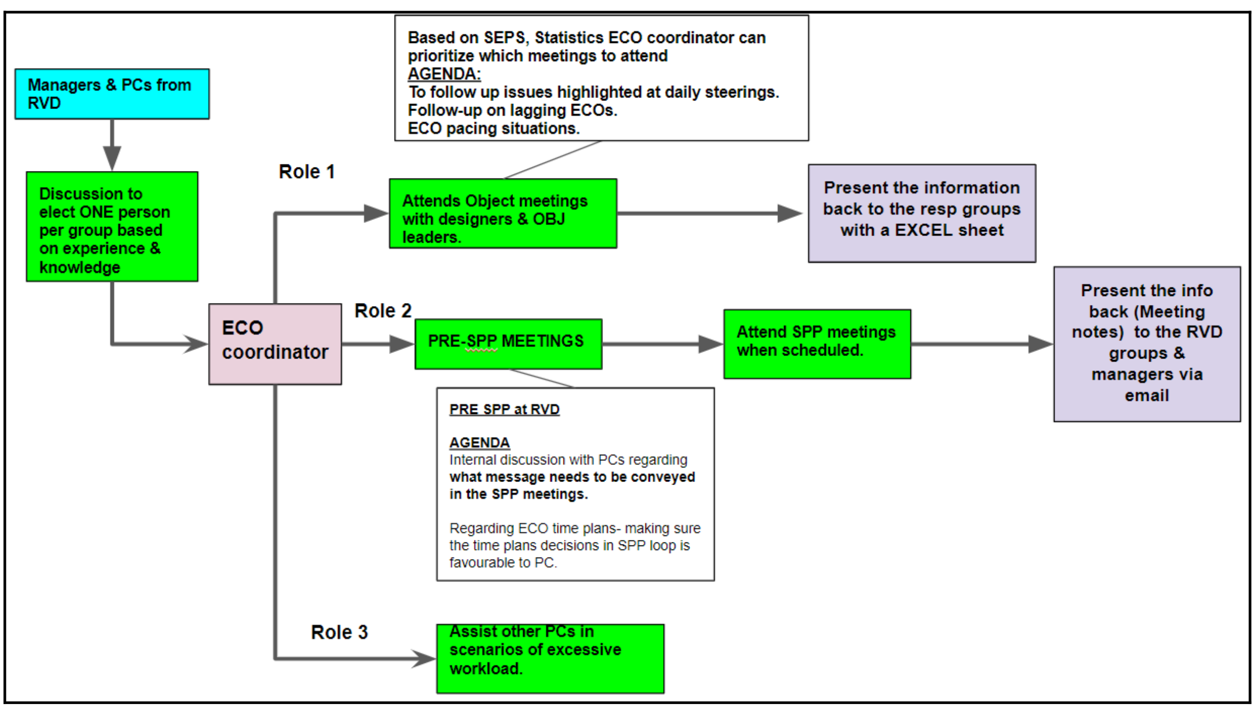

Figure 84. flowchart of the ECO coordinator’s key activities. Full explanations to each step are given below.

The managers and the members of the group have a discussion and ELECT one member as a “ECO Coordinator”. The selected individual is based on the experience and knowledge of attending meetings such as TS and SPP. Because in order to attend the meetings it is required to have competence and understanding of the contents being discussed in the meeting and to convey it back to the respective groups.

Role 1: Attend Object meetings with Designers and OBJ meetings.
The ECO coordinator attends the **Object meetings** with the object leaders and the designers. In this meetings the topics which will be discussed are

1. Following up of lagging ECO’s.
2. Situation regarding ECO pacing.
3. To follow up on the issues which are discussed in the respective steering meetings.

The outcome of the meeting is presented back to the respective groups in the daily steering and stored in the excel sheet for repository purposes.

One thing to be noted here is as there are a number of projects the PCs are involved in, it is difficult to decide which Object meetings ECO COORDINATOR should attend,because there will be many object meetings which they have to choose from. That decision to attend which Object Meeting can be done with the help of our modular solutions tools such as Simple ECO Prediction System (SEPS) and ECO statistics. From those tools ECO Coordinators get insights about which Object Meeting should be prioritized over the others.

After attending the meetings, the ECO coordinator conveys the meetings notes to the respective groups in the daily steering meetings and compiles it in an EXCEL document for future repository.

Role 2: Attends SPP meetings.
Step 1: Before attending the SPP meetings, there is an internal Pre- SPP meeting which happens. In this Pre- SPP meetings, there are discussions within the individual R5A groups regarding

- What message needs to be conveyed in the SPP meetings from our side?
- Just to make sure if the timeplan decisions taking place in SPP meetings are favouring the PC groups.

Step 2: After internal discussion within the teams, the ECO coordinators from the respective groups attend the SPP meetings. In the SPP meetings, they convey the message of what was discussed in the previous step, and note down the points being discussed.

<u>Step 3:</u> After attending the meetings, the ECO coordinator conveys the meetings notes to the respective groups in the daily steering meetings and compiles it in an EXCEL document for future repository.

Role 3: Assists PC's in workload.
In many situations, PCs often have more workload to deal with. At that point of time, they do not get assistance from other PC's due to time constraints and workload. But the other important role of ECO Coordinator is they can help the other PC in their groups when they need help in the scenario of overload.

Implementation strategies and enforcement

- Daily meetings need to be changed and a 5 mins slot must be given to ECO Coordinators to give updates and findings from SPP meetings and OBJ meetings.

- Enforce the role of ECO Coordinator by making them an official part (activity) of the PD process that is the PC equivalent of "design reviews". Also, instruct all project leaders to remind OBJ leaders and DEs to attend the meeting with the ECO Coordinator when instructed by them.

OAS Command Prompts
Brief Description
This concept is to assist the Design Engineers while writing the ECOs in the OAS software. A concept proposal of a prompt appearing in the OAS text box helping the Design Engineers in writing the information in the ECOs.

Solution Range

- Reduce influx of incomplete ECOs.
- Will guide and help DEs who are not familiar with ECO writing.

Schematic Overview '

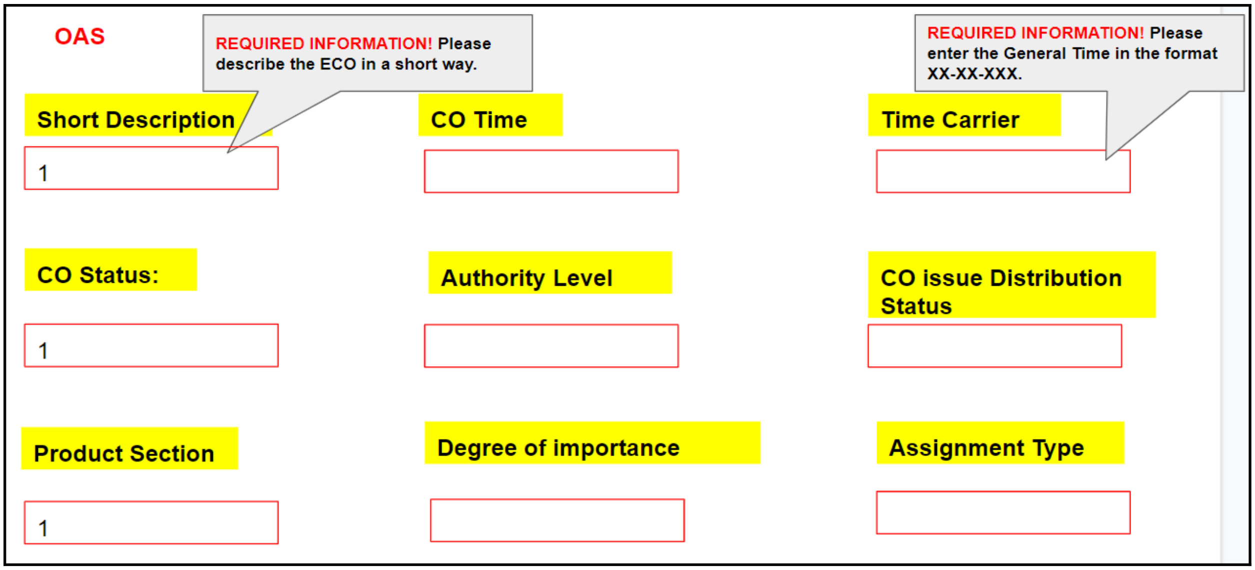

Figure 85. Illustration of the flow

Steps:

- First all the columns which the DEs interact with are selected.
- Then prompts with the message to be displayed for each column needs to be decided
- While answering the questions in the OAS, in the text box a command prompt keeps displaying the information of what needs to be filled in the text box. By implementing this there will be less errors in ECO misinformation or incomplete ECOs.

Implementation strategies and enforcement

Need the IT department to implement this prompt.

Role Awareness Meetings/Dialogs

Brief Description

In order for the roles of the Product Coordinators, R5A5, Weight Calculations to be well aware in the Product Development cycle an initiative has been taken where during project meetings kick off the roles are being conveyed to the Object leaders who conveys it to their respective Design Engineers..

Solution Range

- Informs about the role of R5A functions

Schematic Overview

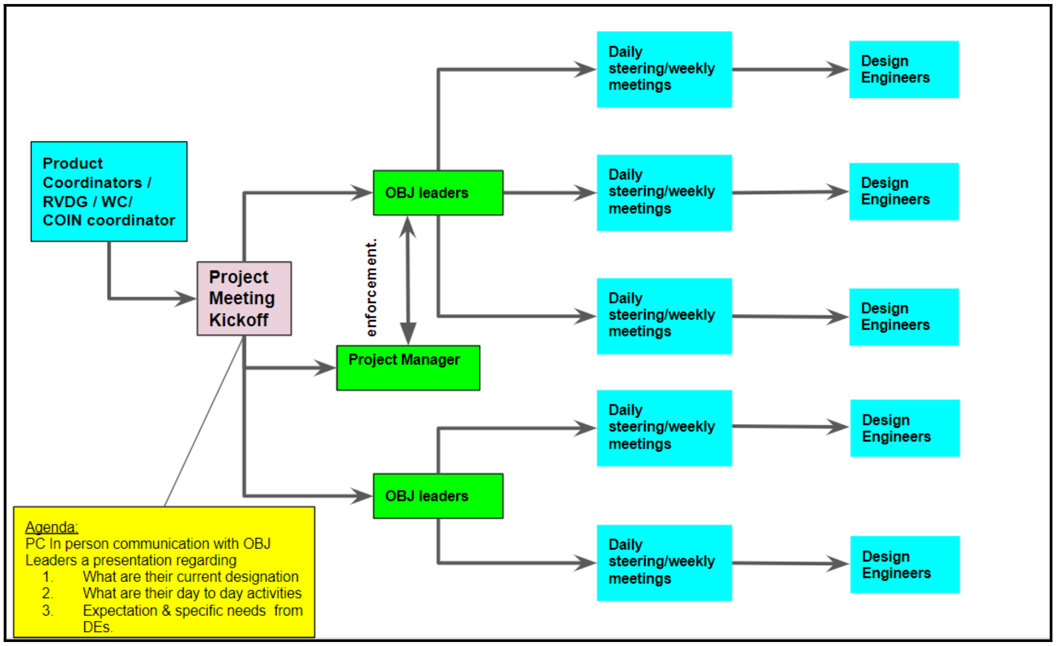

Figure 86. Illustration of the flow of the role awareness meetings. Full explanations to each step are given below.

Step 1:
In this step the members of the PC, WC, R5A5 attend the project kick off meetings. In the kick off meetings they have interactions and discuss with the OBJ LEADER2 regarding

- What is their designation
- What are the day to day activities
- What are their expectations and specific needs from the DE's?

Step 2:
After getting inputs about the PC/WC/R5A5 roles and designation, the Object leader's next step is to convey this information about role perceptions to their DE's. This is done with the help of daily meetings that is scheduled with the DE's.

Implementation strategies and enforcement

The "project manager" is the enforcement strategy here. The project manager enforces the Object leaders to make sure the information is passed to their design engineers. The project manager asks the Object leaders on a regular basis whether they conveyed the roles of PC/WC/R5A5 to their design engineers.

Sprint Based Process

Brief Description
A proposal for suggesting a sprint based way of working to improve the efficiency of the work done/tasks performed in the product development process by the PCs.

Solution Range

- Streamlines plan and makes it easier for managers to allocate resources.
- Focus efforts on main work and eliminates wasteful intrusion activities such as enquiries.
- Encourages continuous improvement
- Proven benefits - design teams implementing this method have been successful.

Schematic Overview

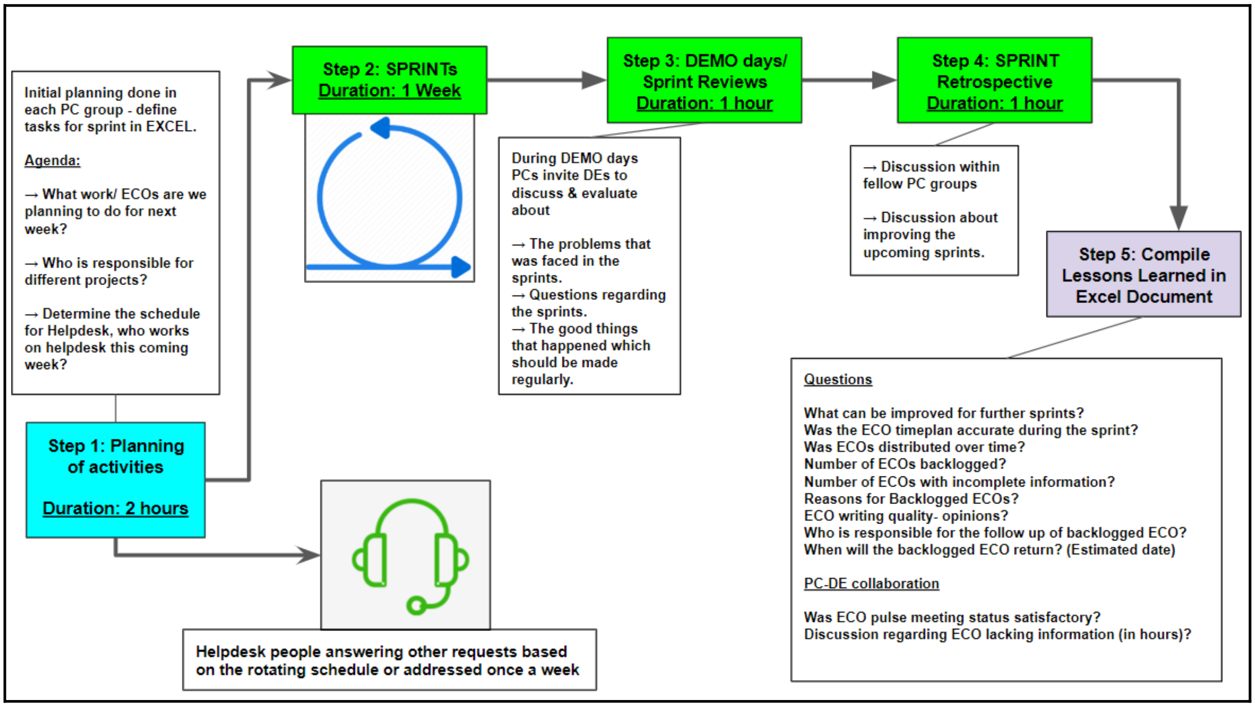

Figure 87. Steps involved in the sprint based process.

Step 1: The first step is this planning of activities. In this step initial planning is done in each R5A group. The duration of this activity is 2 hours.

The Initial Planning activities can be explained in the following points:

- What tasks/ ECOs are going to be worked for next week?
- Who is responsible for different projects?
- Who is responsible for the help desk and decides on the schedule of the helpdesk?

Each group lists down the points and is documented in the EXCEL sheet.

Step 2: The sprints(Actual work) takes place in this step. In this step the list of activities which was decided and agreed on the previous step is being worked upon. The duration of the sprint is one week.

Step 3: The next step is “DEMO days/sprint reviews”. The duration of this sprint review is one hour.In DEMO days, the Product Coordinators invite all the Design engineers, and the other stakeholders for **discussion and evaluation** of topics below:

- The problems that were faced in the sprints.
- The positives that happened in the sprints.
- Any questions regarding the sprints.

Step 4: The next step is Sprint Retrospectives. The duration of this retrospective is one hour. The purpose of this sprint retrospectives is for internal discussions within the Product Coordinators. The topics for discussion generally involve how to improve the upcoming sprints.

Step 5: The next step is compiling and documenting the lessons learned in the EXCEL document for repository purposes. The main purpose of lessons learned is to draw inspiration The lessons learned generally has details such as

- What can be improved for further sprints?
- Was the ECO timeplan accurate during the sprint?
- Was ECOs distributed over time?
- Number of ECOs backlogged?
- Number of ECOs with incomplete information?
- Reasons for Backlogged ECOs?
- ECO writing quality- opinions?
- Who is responsible for the follow up of backlogged ECO?
- When will the backlogged ECO return? (Estimated date)
- PC-DE collaboration
- Was ECO pulse meeting status satisfactory?
- Discussion regarding ECO lacking information (in hours)?

After step 5, it indicates the completion of one cycle. The next step is again The planning of activities for preparation of the next sprint.

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