VISP - Värde och flexibilitetsinverkansanalys för hållbar Produktion

Publik rapport

Författare: Ola Isaksson, Iñigo Alonso Fernandez, Massimo Panarotto
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1 Sammanfattning

VISP-projektet har kulminerat i en rad betydande resultat och bidrag till området produktplattformsarkitektur, särskilt inom fordonsindustrin. Ett av de centrala resultaten av projektet är valideringen av att använda en parametrisk plattformsarkitektur för kontinuerlig utveckling av individuella produktvarianter. Detta tillvägagångssätt har visat sig vara avgörande för att hantera den intrikata balansen mellan flexibilitet och de inneboende begränsningarna inom produktplattformar, vilket underlättar integrationen av ny teknik samtidigt som plattformens integritet och prestanda bibehålls.

Ett anmärkningsvärt bidrag från projektet är den ytterligare förfining av måttet Value Weighted Flexibility Outdegree (VWFO). Detta innovativa mått ger ett kvantifierbart sätt att bedöma produktplattformar med avseende på deras förmåga att integrera ny teknik, och skiljer mellan underbegränsade, överbegränsade och balanserade plattformar. Tillämpningen av VWFO har erbjudit ett pragmatiskt ramverk för att fatta välgrundade arkitektoniska beslut, som styr mot att uppnå en balanserad plattform som optimerar avvägningarna mellan flexibilitet och tvång.

Vidare har projektets utforskning av elastiska designobjekt banat väg för ett mer proaktivt tillvägagångssätt för att designa flexibla produktplattformar. Genom att identifiera och isolera begränsningar tidigt i designfasen, förbättrar dessa designobjekt plattformens anpassningsförmåga till framtida tekniska framsteg. Denna strategi adresserar inte bara den snabba tekniska utvecklingen utan utökar också plattformens relevans och tillämpbarhet över tid, vilket bidrar till en mer hållbar livscykel.

Övervägandet av fälteffekter i den tidiga layoutfasen av komponenter dök upp som en avgörande insikt, som hjälpte till att identifiera potentiella riskområden inom systemarkitekturen som skulle kunna hindra framtida teknikintegration. Detta framåtblickande tillvägagångssätt bidrar väsentligt till att undvika kostsamma omkonstruktioner och förbättrar plattformsutvecklingsprocessens effektivitet och effektivitet.

Framöver har projektet skisserat flera lovande riktningar för fortsatt forskning. Att utvidga den utvecklade metoden och metriken till produktionsplattformar utgör en betydande möjlighet att fördjupa vår förståelse för samspelet mellan produktdesign och tillverkningsprocesser. Denna utvidgning kan leda till mer integrerade och effektiva produktionssystem, som tillgodoser det allt mer komplexa och teknikdrivna tillverkningslandskapet. Att utforska rollen av flexibla produktplattformar inom den cirkulära ekonomin är en annan värdefull väg för framtida arbete. Att undersöka synergierna mellan flexibilitet och hållbarhet kan avslöja nya strategier för att designa produktplattformar som stödjer återanvändning, återtillverkning och återvinning, i linje med globala hållbarhetsmål. Integreringen av de utvecklade mjukvaruverktygen i ett gemensamt digitalt laboratorium för systemtekniks design erbjuder potentialen att effektivisera plattformsutvecklingsprocessen. Genom att främja samarbete över produktutvecklingsspektrumet i en enhetlig digital miljö kan intressenter dra nytta av delade insikter och data för att driva innovation mer effektivt.

VISP-projektet har etablerat en robust grund för att avancera produktplattformsarkitektur, leverera handlingsbara insikter och verktyg för att navigera i komplexiteten i modern fordonsutveckling. När projektet övergår till nästa fas kommer fokus på att utvidga sina metoder till produktionsplattformar, utforska samspelet mellan flexibilitet och hållbarhet och främja digital integration utan tvekan att forma framtiden för systemtekniks design inom fordonsindustrin och utanför.

2 Executive summary

The VISP project has culminated in a series of significant findings and contributions to the field of product platform architecture, particularly within the automotive industry. One of the central outcomes of the project is the validation of using a parametric platform architecture for the continuous development of individual product variants. This approach has proven instrumental in managing the intricate balance between flexibility and the inherent constraints within product platforms, facilitating the integration of new technologies while maintaining the platform's integrity and performance.

A notable contribution of the project is the further refinement of the Value Weighted Flexibility Option (VWFO) metric. This innovative metric provides a quantifiable means to assess product platforms in terms of their capability to integrate new technologies, distinguishing between under-constrained, over-constrained, and balanced platforms. The application of VWFO has offered a pragmatic framework for making informed architectural decisions, steering towards achieving a balanced platform that optimizes the trade-offs between flexibility and constraint.

Further, the project's exploration of resilient design objects has paved the way for a more proactive approach to designing flexible product platforms. By identifying and isolating constraints early in the design phase, these design objects enhance the platform's adaptability to future technological advancements. This strategy not only addresses the rapid pace of technological evolution but also extends the platform's relevance and applicability over time, thus contributing to a more sustainable lifecycle.

The consideration of field effects in the early layout phase of components emerged as a crucial insight, helping to identify potential risk areas within the system architecture that could hinder future technology integration. This forward-looking approach significantly contributes to avoiding costly redesigns and enhances the platform development process's efficiency and effectiveness.

Looking ahead, the project has outlined several promising directions for continued research. Extending the developed method and metric to production platforms represents a significant opportunity to deepen our understanding of the interplay between product design and manufacturing processes. This extension could lead to more integrated and efficient production systems, accommodating the increasingly complex and technology-driven manufacturing landscape. Exploring the role of flexible product platforms within the Circular Economy presents another valuable avenue for future work. Investigating the synergies between flexibility and sustainability could reveal new strategies for designing product platforms that support reuse, remanufacturing, and recycling, aligning with global sustainability goals. The integration of the developed software tools into a common digital laboratory for systems engineering design offers the potential to streamline the platform development process. By fostering collaboration across the product development spectrum in a unified digital environment, stakeholders can leverage shared insights and data to drive innovation more effectively.

The VISP project has established a robust foundation for advancing product platform architecture, delivering actionable insights and tools for navigating the complexities of contemporary automotive development. As the project transitions to its next phase, the focus on extending its methodologies to production platforms, exploring the interplay between flexibility and sustainability, and fostering digital integration will undoubtedly shape the future of systems engineering design in the automotive industry and beyond.

3 Background

The transportation manufacturing industry is currently undergoing a significant transformation, driven by the rapid integration of novel technologies such as digitalization, electrification, and automation into both products and production processes. This evolution is propelled by the dual forces of market demand and societal expectations, pushing manufacturers towards the adoption of more advanced and flexible product and production platforms. Historically, manufacturers have relied on product and production platforms as mechanisms to ensure efficiency, cost-effectiveness, and quality. However, the pace of expected technology introductions and the increased variety offered to the market are challenging the flexibility of these traditional platform-based approaches. As a result, there is a risk of new products inducing late-stage changes and adaptations during production, leading to inefficiencies and increased costs.

The shift towards hybrid and electrified drivelines, along with technologies for autonomous driving and connected services, is fundamentally altering the integration of components into complete vehicles. This shift impacts established manufacturing processes, fixtures, tools, and investments in assembly stations. Concurrently, the advent of "smart manufacturing" is revolutionizing production systems, offering increased adaptability and efficiency through the use of Internet of Things (IoT) technologies, analytics, and logistics optimization. This scenario presents a dichotomy where, on one hand, there is a push to maximize market value through innovation, and on the other, there is a necessity to maintain production efficiency and cost-effectiveness.

Against this backdrop, it is critical for manufacturers to pre-emptively understand the implications of introducing novel technologies on the market, the product platform, and the production platform. Making informed decisions early in the design phase is essential to prevent committing to cost-intensive changes in production to accommodate technologies that are incompatible with current platforms. In the worst-case scenario, this could lead to the need for complete overhauls of product platforms and their associated production systems every few years, resulting in significant resource consumption and economic strain.

The VISP project addresses the **need for a systematic approach to planning and designing product platforms that can accommodate technological innovations while maintaining or enhancing production efficiency**. This involves trading off the benefits of new technological insertions against their impact on the overall platform and finding flexible, modular solutions that allow for the efficient introduction of new technologies over time. These decisions must be made early in the design process, where changes are less costly and time-consuming, despite the potential lack of comprehensive information.

The VISP project emerged as a response to these industry challenges, aiming to provide manufacturers with a model-based decision support system that enhances the flexibility of product and production architectures. By enabling precise decision-making in the integration of new technologies, VISP sought to minimize late-stage modifications and adaptations, thereby supporting the industry's shift towards more sustainable and efficient manufacturing practices in the face of rapid technological advancement.

4 Purpose, research questions and method

4.1 Purpose

The VISP project aimed to develop a model-based decision support system for enhancing the flexibility of product and production architectures, facilitating the integration of new technologies without compromising production efficiency. By bridging the gap in existing tools, VISP gives system architects and platform development teams the capability to effectively balance the diversification driven by technological advances with the need for efficient production. **The purpose of the project was to enable precise decision-making in the design of flexible and modular product architectures, minimizing late-stage modifications and adaptations, through the creation of a methodology and tool**. This initiative is meant to support the manufacturing industry's shift towards integrating novel digital, electrical, and autonomous technologies into both products and production processes, driven by market demands and societal expectations.

4.2 Research Questions

Research questions are used to guide researchers in the search and development of competitive decision support approaches.

RQ1: What is the impact on the flexibility of product platforms when introducing, or replacing, technologies?

RQ2: How can the flexibility of a product platform be defined, assessed and traded against customer needs and the requirements for a resource-efficient production system?

RQ3: How can a flexible product platform be modelled in an early stage?

4.3 Method

In VISP, empirical data about industrial needs were collected through semi-structured interviews and workshops with the project partners (Descriptive studies). Once the "as-is" and "to-be" situations were defined from the interaction with the industrial partners, the research moved into developing the VISP methodology, and the VISP tool (Prescriptive Studies). An applicable research framework was the Design Research Methodology (DRM) (Blessing and Chakrabarti, 2009).

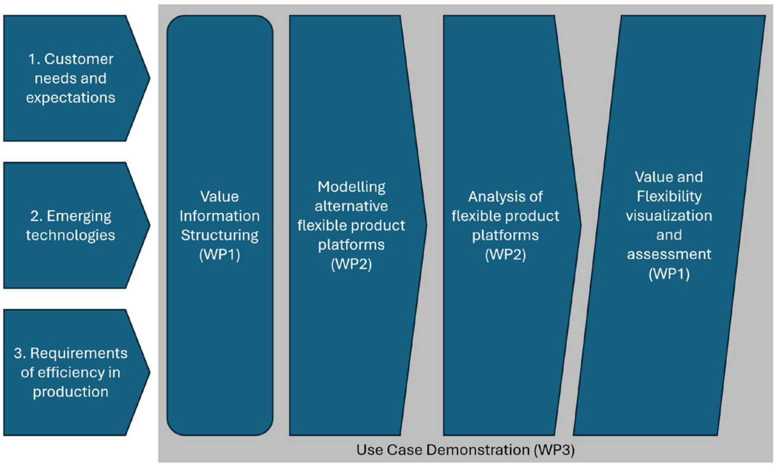

Figure 1 Illustration of the VISP methodology, linking the input (needs, technologies, requirements for production efficiency) via modelling and simulation to assess the impact of the flexibility of the platform on value.

Figure 1 depicts the research methodology, visualizing the connection between the different work packages. In VISP, value information was initially collected and structured (in terms of customer needs and requirements for production efficiency). Subsequently, alternatives for flexible platform architectures were modelled concerning future insertions of emerging technologies. At an initial stage, this phase was performed using the Configurable Component Modeler (CCM) software developed at CHALMERS, later on, more advanced ad hoc tools were developed for this. After flexible platforms were modelled, analysis and simulation mechanisms were called upon to allow the visualization of value and flexibility information for agile decision-making. This process, applied to the selected case studies, drove the co-development and refinement of the VISP methodology and web-based tool. The methodology and tool were applied to selected studies within the use cases provided by the industrial partners, which served both as a method validation and as a means to disseminate the methodology to other parts of the organizations, ensuring practical exploitation of the results.

5 Goals

The primary goal of the VISP project was to develop a sophisticated **model-based decision support system designed to enhance the flexibility of product and production architectures** within the manufacturing industry. This system aimed to facilitate the seamless integration of new and emerging technologies into existing manufacturing frameworks without compromising the efficiency and effectiveness of production processes. By addressing the gap in current modelling and simulation support, the project sought to empower system architects and platform development teams with the tools necessary to navigate the complex trade-offs between technological diversification and production efficiency.

A key objective was to minimize the resource-intensive process of managing diversification resulting from the introduction of radically new technologies. This included the aim to reduce unwanted adjustments and changes in production that typically follow such introductions, thereby streamlining the transition of products from the design phase to production. The VISP methodology, encapsulated in a user-friendly tool, was developed to support the effective design of flexible and modular product and production architectures. This tool was envisioned to improve decision-making precision when introducing and integrating new technologies by connecting expectations and needs to product and production platform characteristics, allowing for the configuration and comparison of multiple options.

Another significant goal was to reduce the risk associated with the late-stage changes and adaptations as products enter production. This involved creating a framework that could pre-emptively evaluate the impact of new technologies on both product designs and production systems. The VISP project aimed to deliver a public and web-based version of the tool based on the developed methodology, facilitating its widespread adoption and validation within the automotive industry and beyond.

The project also aspired to foster collaboration and continuous validation of the modelling capabilities through real-world applications provided by industry partners. By achieving a high Technology Readiness Level (TRL), the project intended to demonstrate the practical applicability and effectiveness of the VISP methodology and tool in addressing the current and future challenges faced by the manufacturing industry in integrating novel technologies.

Ultimately, the goals of the VISP project were aligned with the broader objectives of advancing the theoretical and practical understanding of flexible platform development. By equipping manufacturers with the tools to make informed early-stage design decisions, VISP has aimed to contribute to the development of more innovative, competitive, and sustainable manufacturing practices that can adapt to rapid technological changes and evolving market demands.

6 Results and goal achievement

Despite unforeseen challenges, the project team successfully met the primary objectives outlined in the "Goals" section. The VISP project was structured into several work packages (WPs), each designed to target specific aspects of the project's overarching goal of enhancing the flexibility of product and production architectures. The deliverables for each WP highlight the project's multifaceted approach and collaborative efforts across various domains of research and application.

Work Package 1: Value Assessment and Visualization focused on developing a comprehensive model for structuring value information relevant to both customer expectations and production efficiency requirements. This WP culminated in the creation of a sophisticated template for value data collection, allowing for a systematic and structured approach to capturing customer needs and expectations.

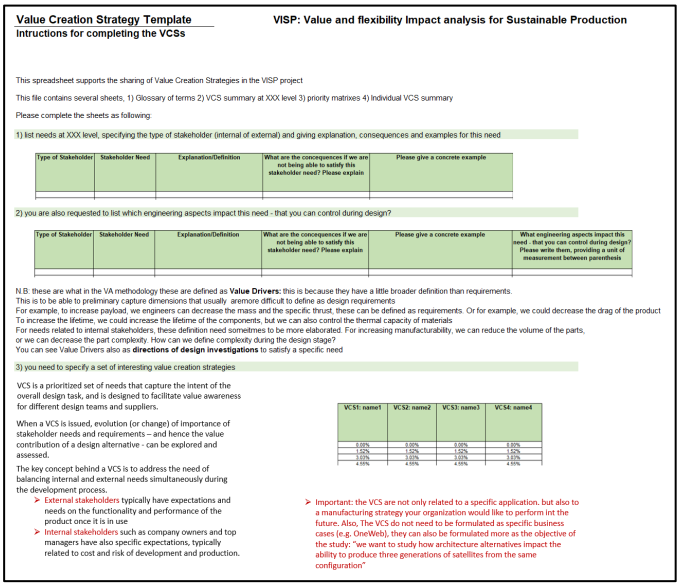

Figure 2 Screenshot of the data collection template frontpage.

Furthermore, a model for value assessment was developed, incorporating strategies for visualizing information to facilitate the decision-making process. The methodologies established in this WP provided a foundational framework for assessing the trade-offs between flexibility, customer satisfaction, and production efficiency, thus enabling more informed decision-making.

The findings of our 'Identification of Technology Integration Challenges at Two Global Automotive OEMs' paper (I. Alonso Fernández, Panarotto, and Isaksson 2020), presented DESIGN Conference, emphasize the intricate challenges automotive industry faces when integrating new technologies into existing product platforms. This research pinpointed a substantial gap in the methods used to evaluate the value related to a product platforms' adaptability to technological advancements. The paper sheds light on the internal hurdles and decision-making processes that hinder the seamless incorporation of new technologies. That particular study calls for a refined approach to early-stage decision-making in platform development, advocating for a deeper understanding of the challenges at hand and a more flexible elicitation process to enhance automotive OEMs' ability to adapt to technological evolution effectively.

Work Package 2: Innovation and Architecture Modelling and Analysis aimed to develop methodologies for modelling new flexible platform architectures and assessing them using the value model established in WP1. This WP delivered architectural models that included innovations for conceptualizing flexible product platforms, as well as analysis methods for evaluating architecture flexibility and strategies for technology insertion. These deliverables have been instrumental in defining the concept of flexibility within product platforms and integrating this flexibility into the overall value model, thereby facilitating the exploration of various technology insertion strategies and their implications for product design and production processes.

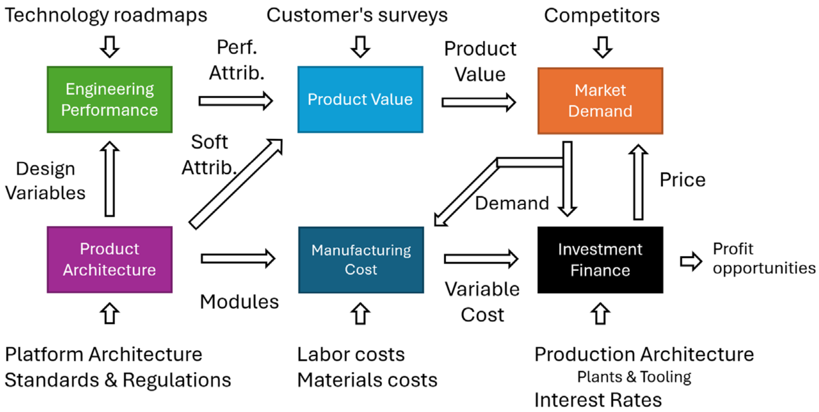

Figure 3 Models and their interactions.

This modelling approach (Figure 3), as well as a first iteration of the web application development environment, was presented in the NordDesign conference, under the title 'Interactive Model-Based Decision-Making Tools in Early Product Platform Design' (Alonso Fernandez, Panarotto, and Isaksson 2020).

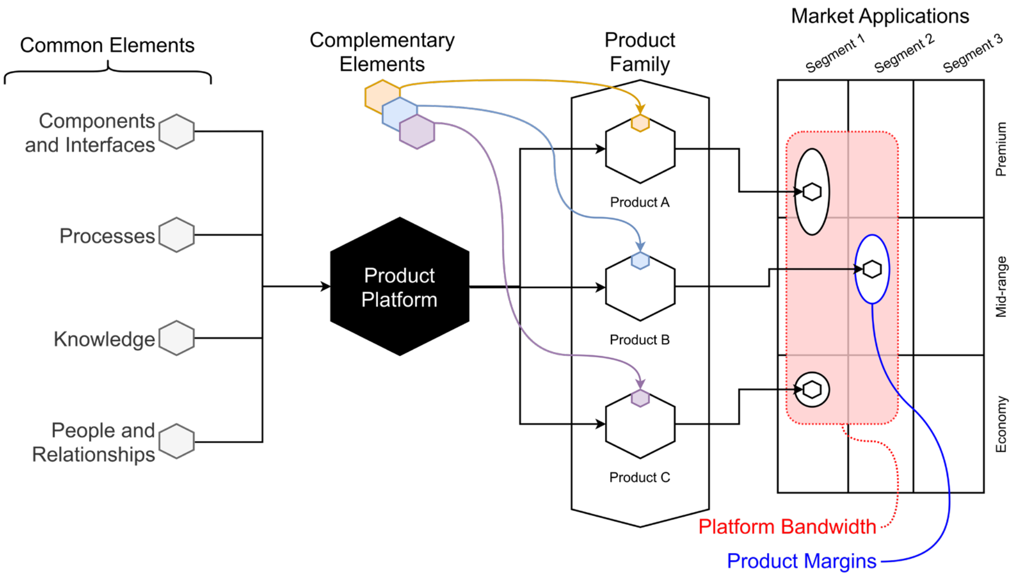

Figure 4 Product platform definition and interaction with bandwidth and design margins concepts.

Work Package 3: Use Case Demonstration applied the models and methodologies developed in previous WPs to real-world industrial cases, providing a practical demonstration of the VISP tool's applicability and effectiveness. This WP produced detailed use case descriptions from industry partners, highlighting specific challenges in terms of flexibility and value. Moreover, value assessment demonstrators were developed for these use cases, showcasing the VISP tool's capability to model and assess the impact of flexible solutions on product design and production efficiency. These demonstrations not only validated the project's methodologies but also provided valuable insights into the practical challenges and opportunities associated with implementing flexible platform strategies.

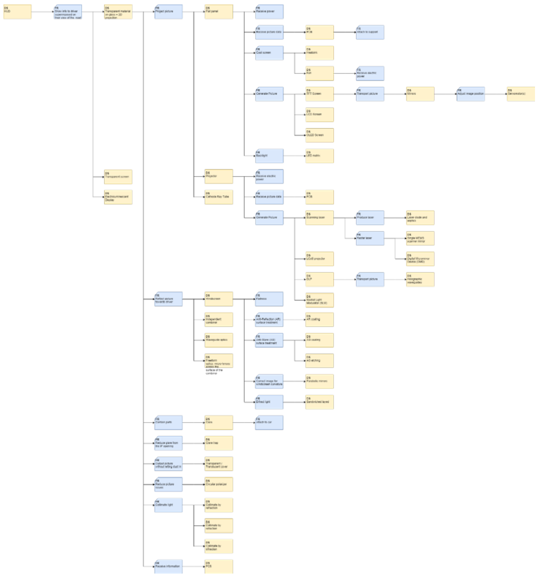

Figure 5 EF-M model of the HUD component from the Volvo Cars case.

The primary VCG use case within the VISP project centred on the integration and development of a Heads-Up Display (HUD) system for the upcoming second generation of Volvo's Scalable Product Architecture (SPA 2), debuting with the new XC90 model. This initiative aligns with Volvo Car Group's (VCG) strategic goals to embrace the major automotive trends of autonomy, electrification, connectivity, and sharing, by embedding core capabilities such as safety, scalability, and evolvability into their products. VCG's approach employs a common architecture to meet these business goals, fostering a product system that encapsulates the company's vision for future mobility. The architecture strategy hinges on deploying architectural tactics that enable and constrain product development, ensuring that business goals are met efficiently. These tactics, such as product modularization and the use of a central computational cluster, underscore VCG's commitment to flexibility, highlighting the strategic importance of being agile in the face of technological uncertainties.

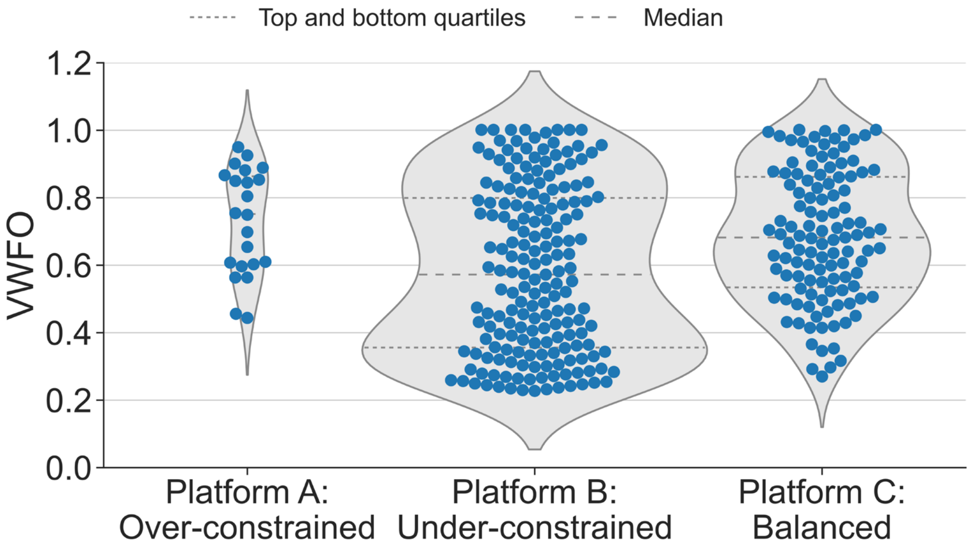

Figure 6 Platform alternatives comparison using thew VWFO metric (for each considered design alternative, blue dots) for the HUD use case.

In the specific context of the HUD, the use case elaborates on the technical and architectural challenges of integrating this advanced system into the SPA 2 architecture, while adhering to VCG's business and customer expectations. The HUD, aimed at enhancing driving safety and convenience by projecting critical information into the driver's field of vision, embodies the complex interplay between technological innovation and customer-centric design. The integration challenges span across various dimensions, including development lead times, technology maturity, and interface management, underscoring the need for a flexible, adaptable architecture that can accommodate future technological advancements and evolving customer preferences. The resulting platform design balances the value derived from allowing a wide range of options regarding the external variety that the platform can provide, with the constrained number of production alternatives needed to manufacture them (lower internal variety). This use case not only showcases the practical application of the VISP project's objectives but also reflects the broader industry trend towards software-dominated automotive products, where flexibility and adaptability become key competitive advantages.

The primary VGTT use case within the VISP project focused on the architectural challenges and strategies surrounding the lower front area of truck cabins, a critical component ensuring the protection of vital parts against the rigors of usage and in the event of collisions. This use case reflects Volvo Group Trucks Technology's (VGTT) strategic aims to embrace major industry trends such as electrification, automation, and connectivity, through a multi-brand approach that emphasizes market differentiation while leveraging synergies across the organization. The Common Architecture and Shared Technology (CAST) platform exemplifies VGTT's solution to achieving cost-efficiency in product development without compromising the unique value proposition of each brand. Moreover, the adoption of Nvidia Drive AGX for autonomous driving solutions underscores VGTT's commitment to innovation in addressing future transportation challenges.

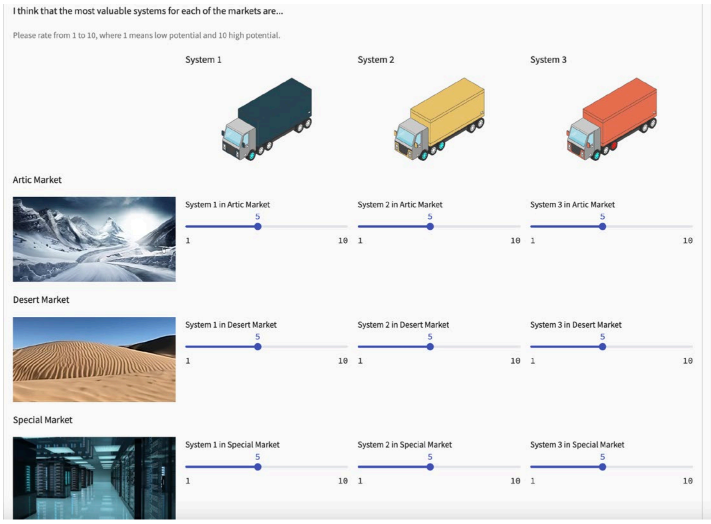

Figure 7 Web interface screenshot for the truck steering use case workshops.

Addressing the specificities of the lower front use case, VGTT identified key drivers of change including regulatory updates, customer preferences, and technological advancements in autonomous driving and electrification. Challenges such as uncertainty management, interface management, and technology maturity were highlighted, illustrating the complexities involved in developing a flexible, yet brand-distinctive, modular architecture. Through the Enhanced Function-Means method, the project decomposed the functions of the lower front, exploring various scenarios to align with Value Creation Strategies like quick market facelifts and future-proof platforms. This analytical approach facilitated a comprehensive understanding of stakeholder expectations, from minimizing development costs to maximizing aerodynamics and safety, thereby guiding the modular design towards meeting global requirements while accommodating brand-specific needs and innovations.

With both VCG and VGTT, additional use cases were explored to different degrees. For example, the Steer-by-Wire system at VCG and the development of a completely new Zero Emissions Refuse truck at VGTT, both contributed to the development of the method and tools. These cases highlighted additional

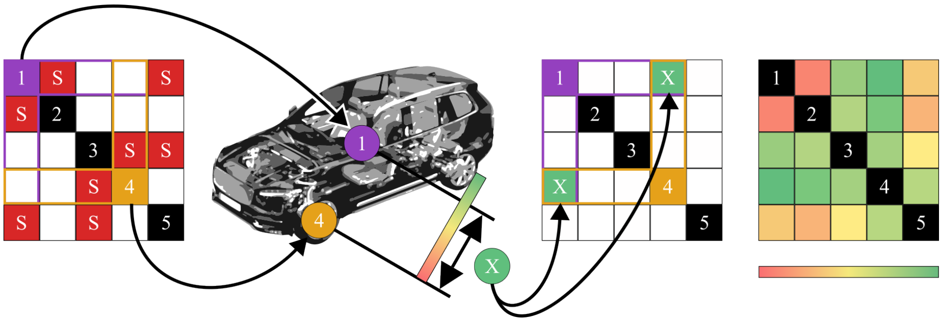

Figure 8 Definition od the Distance DSM, a numerical DSM used to evaluate the change propagation due to field effects.

considerations that had to be addressed, such as the introduction of field effects (Küchenhof et al. 2023) and resilient objects (Iñigo Alonso Fernández, Panarotto, and Isaksson 2022; Panarotto et al. 2023; Panarotto and Alonso Fernández, n.d.), and the challenges around multi-site development teams. An additional VGTT use case regarding the steering of the rear axle was the main topic of the workshop run at the International DSM Conference where the use of distance DSMs was tested with industry experts and a web interface.

Work Package 4: Dissemination was dedicated to sharing the project's findings with a broader audience, encompassing both academic and industrial stakeholders. This WP emphasized the importance of disseminating the results through various channels, including workshops, seminars, scientific publications, and an open-access, web-based version of the VISP tool. The dissemination of the project's findings and the publication of results have thus been comprehensive. Details of specific dissemination activities and publications are provided in the following "Dissemination and publication" section. These activities have ensured that the knowledge and methodologies developed through the VISP project have reached a broad audience, including industry practitioners, academic researchers, and stakeholders interested in the integration of novel technologies into manufacturing processes.

Work Package 5: Project Management ensured the smooth execution and coordination of the project's activities, from inception to completion. This WP was crucial in managing the challenges posed by the COVID-19 pandemic and unforeseen parental leave, implementing adaptive strategies to mitigate their impact on the project timeline. The final report, a key deliverable of this WP, encapsulates the project's achievements, lessons learned, and recommendations for future research and application in the field of flexible product and production platform development.

The development and validation of the VISP tool represent a significant achievement of the project. This tool, designed to aid in the effective design of flexible and modular product and production architectures, has proven instrumental in improving decision-making precision when introducing and integrating new technologies. The tool's ability to model expectations, needs, and platform characteristics allowed for the configuration and comparison of multiple options, highlighting its utility in reducing late-stage modifications and adaptations as products transition from design to production.

The project's focus, however, shifted more towards enhancing flexibility rather than directly addressing sustainability aspects. This emphasis on flexibility was deemed essential in light of the rapid pace of technological change within the manufacturing industry and the need to integrate these technologies efficiently without compromising production efficiency. The flexibility-driven results, while somewhat divergent from the initial sustainability-oriented expectations, have nevertheless contributed valuable insights into managing diversification and technological integration within the constraints of existing production systems.

Despite the project's timeline being impacted by external factors such as the COVID-19 pandemic and parental leave, the VISP project successfully achieved its primary goal of developing a decision support tool focused on enhancing flexibility in product and production architectures. The project's outcomes, while more focused on flexibility than initially anticipated regarding sustainability, represent a significant contribution to the field of manufacturing and product development. The forthcoming "Dissemination and Publication" section will further detail how these results have been shared with the wider community, ensuring the project's impact extends beyond its completion.

7 Dissemination and publication

7.1 Dissemination of knowledge and results

How are/are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the area	X	See Publications below, including academic journals and conferences, such as: - DESIGN International Conference - NordDesign International Conference - ICED International Conference on Engineering Design - Journal of Engineering Design - ASME Journal of Mechanical Design Other events: - Internal workshops and demonstrations at the companies also disseminated the method and results to train practitioners. - A full day workshop was developed and run at the International Design Structure Matrix (DSM) Conference - Regular public updates were presented at the Winquist Laboratory Annual Seminars. - Workshop at the International Product Architecture Design Summer School (PAD)
Carried forward to other advanced technical development projects	X	Collaboration and cross-pollination occurred with other projects: - Digital Sustainability Implementation Package - DSIP - Development of efficient DIgital product FAMily design platform to increase cost efficiency - DIFAM
Forwarded to product development projects	X	Functional Product Architecture Modelling has been brought into PD work at foremost Volvo AB along the project.
Introduced to the market		N/A
Used in investigations/regulations/permit matters/political decisions	X	Used in the development of a Licentiate Thesis and a Doctoral Thesis.

7.2 Publications

Alonso Fernández, I., M Panarotto, and O Isaksson. 2020. 'Identification of Technology Integration Challenges at Two Global Automotive OEMs'. In *Proceedings of the Design Society: DESIGN Conference*, 1:2245–54. doi:10.1017/dsd.2020.314.

Alonso Fernandez, Iñigo, Massimo Panarotto, and Ola Isaksson. 2020. 'Interactive Model-Based Decision-Making Tools in Early Product Platform Design'. In *Proceedings of NordDesign 2020*, 1— – 12. Lyngby, Denmark: The Design Society. doi:10.35199/NORDDESIGN2020.15.

Alonso Fernández, Iñigo, Massimo Panarotto, and Ola Isaksson. 2022. 'Designing Multi-Technological Resilient Objects in Product Platforms'. In *DS 118: Proceedings of NordDesign 2022, Copenhagen, Denmark, 16th - 18th August 2022*, 1–12. doi:10.35199/NORDDESIGN2022.40.

Küchenhof, Jan, Markus C. Berschik, Julia Beibl, Iñigo Alonso Fernández, Kevin Otto, Dieter Krause, and Ola Isaksson. 2023. ‘Incorporating Field Effects into the Design of Modular Product Families’. *Proceedings of the Design Society* 3 (July). Cambridge University Press: 2275–84. doi:10.1017/pds.2023.228.

Panarotto, Massimo, and Iñigo Alonso Fernández. n.d. ‘Local Absorption of Uncertainty in Complex Systems Using Resilient Objects’. *Journal of Engineering Design*. Taylor & Francis, 1–19. doi:10.1080/09544828.2024.2327913.

Panarotto, Massimo, Vito Giordano, Filippo Chiarello, Arindam Brahma, Iñigo Alonso Fernández, and Gualtiero Fantoni. 2023. ‘Text Mining of Resilient Objects Absorbing Change and Uncertainty’. *Proceedings of the Design Society* 3 (July). Cambridge University Press: 3325–34. doi:10.1017/pds.2023.333.

“Impact of Field Effects on Product Architecture – Design and Analysis of Innovative Products/ Product Families”, submitted to the ASME Journal of Mechanical Design.

“Reconciling Platform Vs. Product Optimisation by Value-Based Margins on Solutions and Parameters”, submitted to the Journal of Engineering Design.

8 Conclusions and continued research

The VISP project, through its comprehensive exploration of the Volvo Cars Group (VCG) and Volvo Group Trucks Technology (VGTT) use cases, has elucidated several pivotal findings pertinent to the advancement of product platform architecture in the automotive sector. One of the project's core revelations is the validation of using a parametric platform architecture to effectively manage the trade-offs between flexibility and constraints inherent in product platforms. This approach not only facilitates the nuanced balancing act required in platform development but also underscores the necessity of a dynamic framework capable of adapting to evolving technological, market, and regulatory landscapes. By implementing a parametric architecture, the project demonstrated a systematic methodology for accommodating new technologies while maintaining the integrity and performance of the product platform.

A significant contribution of the VISP project is the development and application of a metric for assessing the flexibility of product platforms concerning technology introduction, known as the Value Weighted Flexibility Option (VWFO). This metric provides a quantifiable means to evaluate platforms in terms of their under-constraint, over-constraint, and balanced states. The application of VWFO within the VCG and VGTT case studies has highlighted its utility in guiding architectural decisions towards achieving a balanced platform. This balance is critical for ensuring that the platform can efficiently integrate new technologies without necessitating extensive redesigns or compromising on performance and safety standards.

Furthermore, the project's exploration into resilient design objects has paved the way for a proactive approach to designing more flexible product platforms. By identifying and isolating constraints early in the design process, these resilient design objects allow for greater adaptability in integrating future technological advances. This strategy not only mitigates the risk associated with the rapid pace of technological evolution but also enhances the platform's overall value proposition by extending its relevance and applicability over time.

Another key insight from the VISP project is the importance of considering field effects in the early stages of component layout. By doing so, the project was able to identify potential risk areas within the system architecture that could impede future technology infusion. This forward-looking approach is instrumental in avoiding costly and time-consuming redesigns later in the development process, thereby enhancing the efficiency and efficacy of the platform development cycle.

The VISP project also served as a catalyst for inspiring practitioners across participating companies to delve into supporting subjects such as functional modelling, architectural structure modelling, and value-driven design. Rather than offering a structured courseload, the project introduced these concepts through various interactions and discussions, sparking curiosity and a desire for further exploration among practitioners. This approach encouraged individuals to seek out additional knowledge and apply these methodologies in a manner tailored to their unique professional contexts. The project's role was to highlight the importance and utility of these subjects in modern engineering practices, thereby laying the groundwork for ongoing learning and application in the participants' future projects.

Furthermore, the introduction of the concept of field effects during the project has led to a growing interest in further investigating how this approach can be integrated into existing processes. The exploration of field effects—understanding how changes within one part of a system can influence others—has begun to influence how practitioners think about product development. The project's influence has opened doors to new ways of thinking and encouraged a proactive stance towards potential systemic impacts of design choices. This subtle yet impactful shift towards recognizing the interconnectedness within product systems is a testament to the VISP project's role in fostering an environment of intellectual curiosity and innovation within the automotive industry.

Looking forward, the extension of the method and metric developed in the VISP project to production platforms represents a promising avenue for continued research. By applying these tools to the production environment, manufacturers can gain deeper insights into the interplay between product design and manufacturing processes, leading to more integrated and efficient production systems. This research direction is particularly relevant in the context of increasingly complex and technology-driven manufacturing landscapes.

Another fertile area for future work is exploring the role of flexible product platforms in the Circular Economy. There is a growing recognition of the synergies between flexibility and sustainability, particularly in how product platforms can be designed to facilitate reuse, remanufacturing, and recycling. This line of inquiry not only aligns with global sustainability goals but also opens up new opportunities for creating value throughout the product lifecycle.

Additionally, the integration of the developed software tools into a common digital laboratory for systems engineering design offers significant potential for enhancing the platform development process. By creating a unified digital environment, stakeholders across the product development spectrum can collaborate more effectively, leveraging shared insights and data to drive innovation. This digital convergence is particularly crucial in addressing the complex, interdisciplinary challenges inherent in developing next-generation product platforms.

In conclusion, the VISP project has laid a foundational framework for advancing the field of product platform architecture, offering valuable insights and tools for navigating the complexities of modern automotive development. As the project transitions into its next phase, the focus on extending its methodologies to production platforms, exploring the intersection of flexibility and sustainability, and fostering digital integration holds great promise for shaping the future of systems engineering design in the automotive industry and beyond.

9 Participating parties and contact persons

Chalmers University of Technology
Contact person: Ola Isaksson
Department of Industrial and Materials Science
412 96 Gothenburg, Sweden
ola.isaksson@chalmers.se
+46 31-772 82 02

Iñigo Alonso Fernandez
Department of Industrial and Materials Science
412 96 Gothenburg, Sweden
inigo.alonso@chalmers.se

Volvo Car AB
Thomas Krusell
91510, PVD 2-2
405 31 Gothenburg, Sweden
thomas.krusell@volvocars.com
+46 72 977 53 78

Volvo Group Trucks Technology
Maria Siiskonen
Gropegårdsgatan 10
417 15 Gothenburg, Sweden
maria.siiskonen@volvo.com