EVOLUTIONARY PERSPECTIVE ON SYSTEM GENERATION ENGINEERING BY THE EXAMPLE OF THE IPHONE

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ABSTRACT

Industrial practice shows that products are developed in generations. Innovation success with complex technical systems can only be achieved economically by using existing solutions as references. These references come from predecessors, competitors, and even industry-external sources. The model of SGE – System Generation Engineering describes these relationships. The iPhone is often used as an example of an innovative product developed in generations. Multiple studies have examined the iPhone. However, none of these studies systematically considers the influence of the product context on references and variations. In this contribution, an evolutionary descriptive model based on the model of SGE is applied to 15 iPhone product generations. The central result is an overview of the variation shares over the generations and the relationships between context factors, reference-based variation activities, and innovation success and hypotheses for causalities. This is one of a series of case studies to investigate these causalities. The study showed how the iPhone remained successful in its context: not through a high new development share, but through strategically placed variations and the use of references from various sources.

Keywords: Innovation, Product modelling / models, Design methods, Design management

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Cite this article: Pfaff, F., Götz, G. T., Rapp, S., Albers, A. (2023) ‘Evolutionary Perspective on System Generation Engineering by the Example of the iPhone’, in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.172

1 INTRODUCTION

Industrial practice shows that products are developed in generations. Innovation success with complex technical systems can only be achieved economically and with manageable risk by using existing solutions as references. References come from predecessors, competitors, and even industry-external products or concepts from research. The model of SGE – System Generation Engineering describes these relationships. (Albers and Rapp, 2022)

The iPhone is often used as an example of a product developed in generations and of a successful, even disruptive, innovation. Multiple studies with different focuses have examined the iPhone. Biswas et al. (2022) focused on realizing the pattern of product family evolution along with a proper estimation for future products. Li et al. (2022) focused on uncovering the evolution characteristics of product structural properties and concluded that the complexity of a product is decreasing while core components (e.g. the logic board) are becoming more complex. Nadadur et al. (2014) applied their Generational Variety Index to derive design recommendations from the first five iPhone Generations and compared them with the real development of the next generations. However, none of these studies systematically considers the influence of the product context on development activities. Speaking of product generations, the discussion about "evolution" comes up. While the evolution analogy is heavily used, the state of research lacks descriptive models that include the product context and approaches to support the development of new product generations with "evolutionary" knowledge from past ones (Pfaff et al., 2022b).

Such an evolutionary descriptive model was developed by the authors and applied to two case studies, Google Glass and Toyota hybrid drive (Pfaff et al., 2022a). In this contribution, the descriptive model is applied to 15 iPhone generations. The central result is an overview of the variation shares over the generations and the relationships between changing context factors, reference-based variation activities, and innovation success. With these data, hypotheses for causalities between changing context factors, reference-based variation activities and innovation success are tested and new ones are derived.

2 STATE OF THE ART

2.1 Innovation as a successful invention in a product context

Innovation can be defined as an invention realized in a product and successfully established on the market (Schumpeter, 1934). Therefore, innovations can only be classified as such retrospectively and for a specific context (Bauer, 2006). When considering a product in development, we can therefore only speak of its *potential* to become an innovation. Various approaches exist to retrospectively classify a product as a failed invention or an innovation (e.g. Bauer, 2006; Baccarini, 1999; Cooper and Kleinschmidt, 1987; Griffin and Page, 1996). All classification approaches include the economic success of the provider as a necessary criterion.

Albers et al. (2018) propose, based on Schumpeter's understanding of innovation, that three elements are necessary for a successful innovation process: Product profile, invention, and market launch. The demand situation and the intended customer, user, and supplier benefits of the product are modelled with the product profile. To fulfil the product profile, an invention consisting of an idea and technical implementation is needed. The third necessary element for innovation success is a successful market launch.

In the constantly changing context of markets, society, law, politics, and the environment, product developers have to design products to enable progress and survive against competitors (Arthur, 2009). To develop products with innovation potential, product profiles, boundary conditions, objectives and requirements must be derived in and for this dynamic context. Up-to-date, activity-based process models such as the model of product design from VDI 2221 (VDI, 2019) take this dynamic into account with the help of context factors (Gericke et al., 2013; Hales and Gooch, 2004).

2.2 SGE - system generation engineering

The percentage of actual "new developments" in modern-day engineering is below 10% (Albers et al., 2015; Kirchner, 2020, p. 8), which is why the classic subdivision into "new design, adaptive design, and variant design" lacks practicability, as Pahl and Beitz already stated (Pahl et al., 2007, p. 4).

The model of SGE - System Generation Engineering according to Albers is an explanatory model which supports planning, controlling, and product development itself (Albers and Rapp, 2022). In existing

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research papers, the term "model of PGE - Product Generation Engineering" is often used because the origin of the explanatory model lies in the research field of product development (Albers et al., 2015).
The model is based on two fundamental hypotheses based on practical observations. First, each new product generation is developed based on references from existing or already planned sociotechnical systems and the associated documentation - also "new designs" without a direct predecessor. These references and their interrelations are described as reference system elements (RSE) of the reference system R_n. RSE often come from reference products (RP). (Albers et al., 2015; Albers et al., 2019)
Second, the subsystems of the G_n are developed by three types of variation: Carryover variation (CV), attribute variation (AV) and principle variation (PV). This description is possible on different system levels and in different system domains of mechatronic products, function levels, and property levels. With CV, the corresponding RSE is carried over and is, if necessary, only adjusted at the interfaces during the system integration. AV is the new development of a subsystem while retaining the solution principle of the RSE and changing function-determining attributes or parameters. With PV, the function of the RSE is fulfilled by an alternative solution principle in the corresponding subsystem of the G_n. (Albers and Rapp, 2022)

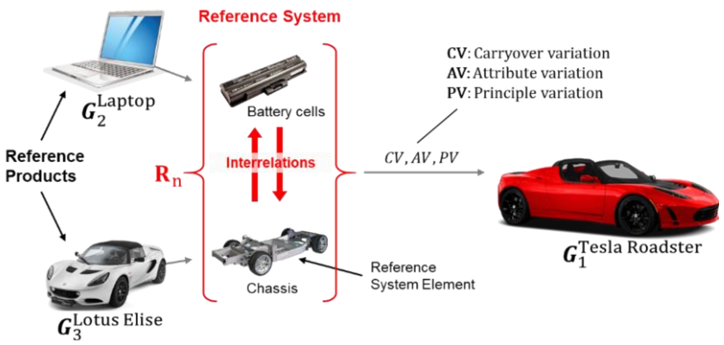

Figure 1: The reference system in the model of SGE (Albers et al., 2019). Tesla roadster: the chassis of the Lotus Elise was carried over (CV). The battery cells from the reference product (RP) laptop were integrated with a new configuration (AV).

The variation share of the three variation types δCV, δAV and δPV is calculated by the ratio of the number of subsystems developed by a particular variation type to the total number of subsystems of the new product generation (Albers et al., 2015). The sum of δCV, δAV and δPV for a system under consideration is therefore always 100%. Indicators for the identification of variation types are defined using the Contact-and-Channel-Approach (C&C²-A) (Albers et al., 2016).
The system model considered influences the calculation of variation shares. The more subsystems a system is divided into, the more often AV or CV are detected since microscopic observation tends to bring fewer principle variations with it. Vice versa it can be assumed that PV identified on the supersystem level is accompanied by AV and CV on the subsystem level. (Albers et al., 2020)
A variant is a product generation that has a high CV share to its variant reference product. These are subject to the same product generation cycle and exist largely in parallel on the market. (Peglow, 2021)

3 MATERIALS AND METHODS

The overall aim of this research project is to identify causalities between changing context factors, reference-based variation activities (SGE), and innovation success. This paper is one of a series of case studies in which hypotheses for these causalities are derived and will be followed by further studies.
The research methodology for generating and testing hypotheses in case studies is inspired by, but not based on, grounded theory (Corbin and Strauss, 1990). With the help of the evolutionary descriptive model (Pfaff et al., 2022a), the variation activities between the reference system (including the previous generations) are related to context factors. Key figures on the market success of the respective product generation are also considered. From the resulting formalised research data, hypotheses for causalities are formulated for the case under consideration. The newly formulated hypotheses are tested against the case studies that have already been conducted and will be tested in the following case studies. Hypotheses which can be seen as "confirmed" and address similar

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phenomena are then merged into categories to form the basis for a theory. Two research questions were derived for this study:

- RQ1: What relationships can be observed between changing context factors, reference-based variation activities (SGE), and innovation success for the iPhone product generations?
- RQ2: What hypotheses can be derived for causalities between changing context factors, reference-based variation activities (SGE), and innovation success for the iPhone product generations?

In this case study, all existing iPhone models at the time this study was conducted (Feb 22- Aug 22) were analysed (15 generations and 34 variants). To structure the case study, the existing evolutionary graph of Biswas et al. (2022) was extended to include the iPhone models 12, 13 and SE and divided into 15 product generations with associated variants. Second, a structural system model with eleven subsystems for a consistent analysis with the model of SGE was defined. The subsystems were: case, connectors, physical operating controls, display, camera, sensors, battery, cellular & connectivity, storage, processor, and operating system (software).

For each generation and its variants, a technical analysis with a classification of the variation types (CV, AV, PV) based on the C&C²-A criteria and a factor-based analysis of the product context according to Gericke et al. (2013) were conducted retrospectively and literature-based. Sources for the technical analysis were primary sources from Apple (e.g. support, newsroom), scientific studies, and journalistic texts such as reviews or teardowns (e.g. iFixit and Snell). *The list of references of the study linked to the product generations is available in the complete dataset: https://doi.org/10.5445/IR/1000153312*. In section 4, the most impactful context factors and their relationships to variation activities are explained. The relationships (RQ1) are modelled in a summarising visualisation (c.f. Figure 3). The variation shares for the high-end models are visualised in Figure 4 to provide a macroscopic overview. We recommend using these two central visualisations as a common point of orientation for reading the details in section 4. In section 5, the hypotheses derived from previous case studies are discussed and new hypotheses are derived (RQ2).

4 CASE STUDY OF THE APPLE IPHONE

G_1 iPhone (2007): Acknowledging a saturated mobile phone market in 2007, Apple saw potential in the union of mobile telephony and personal computing in a handheld device. This meant a long-lasting battery and a new solution principle for the physical operating controls.

Apple used failed concurrent devices as external RPs (e.g. Nokia 9000) and subsystems of the iPod as internal RSEs (case, the connectors, CPU). Thus, δPV was mitigated. West and Mace (2007) mention that the decision for a user interface design with a minimum of physical operating controls and to exclude third-party developers in the new OS iOS, which was based on MacOSX as RSE, was due to a failed cooperation with Motorola (Motorola Rokr). 1.6 million units were sold in 2007 (Statista, 2022).

G_2 iPhone 3G (2008): The second generation was characterized by 54% δCV. The popular multi-touch display and the home button were carried over (CV). New was the integration of the 3G technology to meet the latest cellular standard. Apple reacted to consumer criticism and integrated a Software Development Kit into iOS 2 to open up for third-party developers and added the requested GPS sensor. Instead of the aluminium case of the iPhone, iPhone 3G got a new plastic case (AV) to reduce production costs, produce more units, and reach more countries. The sales figures rose to over 11 million in 2008 and the market leader Blackberry was replaced (Statista, 2022).

G3 iPhone 3GS (2009): Besides the CV for the established subsystems case, connection, battery, and home button, there was 63% δAV for iPhone 3GS and again no PV. According to Blahnik and Schindelbeck (2021), Apple's main generation was to improve the camera. The authors also mention that for reaching this goal the three-megapixel cameras of Sony's K800i and Nokia's N73 served as RSEs. To catch up with the latest technology in the field of cellular & connectivity, Bluetooth 2.1 standard was integrated (AV). Over one million units were sold during the first three days (Statista, 2022). Reaching this goal without any PV implies that the first laid the cornerstone for constantly rising sales figures.

G_4 iPhone 4 (2010): The iPhone 4 was the first generation after the iPhone to feature a PV. Additionally, there was a high 63% δAV. Apple improved the camera by using the Samsung S8500 Wave as an RP and integrating a new front camera. The new CPU was based on the internal RP iPad (AV). The iPad was the reason to create new excitement factors. Otherwise, facing the functions of the

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iPad, the iPhone may have turned out redundant. So PV for the case and AV for the display took place. Promoting the iPhone 4 as the thinnest smartphone of all time and presenting the new features through a live video call helped to show the customers that the iPhone was not redundant. Apple sold more than 1.7 million units during the first three days after sales started.

G_5 iPhone 4s (2011): In the year Steve Jobs died, Apple released the iPhone 4S, later renamed as iPhone 4s. With 54% δCV, many subsystems were carried over. All other subsystems were developed with AV. For closing the gap between Samsung and Apple in terms of smartphone photography, Apple constantly used external products as RPs, e.g. the camera of the Samsung Galaxy S II as RSE for the iPhone 4s. To keep the processor as an excitement factor, Apple integrated a dual-core processor, already proven in the iPad 2 (AV). iCloud and Siri were new features in the field of the OS (AV). Apple was confronted with complaints targeting reception issues with the iPhone 4 in the US. To fix this issue Apple changed the antenna design and integration. The sales figures rose to over 4 million units during the first three days.

G_6 iPhone 5 (2012): The development of the iPhone 5 was dominated by 63% δAV and the optimization of existing subsystems. E.g. the higher electricity demand of the new cellular standard LTE made the optimization of the battery necessary. Characteristic for the sixth iPhone generation was the Lightning Connector (PV), which made thinner iPhones possible and replaced the Dock-Connector. Apple raised their market share (Statista, 2022) and over 5 million units were sold during the first three days.

G_7 iPhone 5s (2013): The iPhone 5s was characterised by 45% δCV, 45% δAV, and 10% δPV. The subsystems cellular & connectivity, case, connectors, display, and storage were carried over (CV). Touch ID was integrated into the Home Button and the subsystem sensors had to be changed through AV. As for the display technology for the first iPhone (absorbing Fingerworks), Apple gained their know-how for biometric technology for the iPhone 5s from absorbing AuthenTec, which resulted in an AV. This technology raised security concerns regarding the storage of fingerprints at Apple. The A7 containing the 64-bit ARM-v8 architecture (Institution of Engineering and Technology, 2013) set a new standard in smartphone processing. Precisely promoting the new features of the iPhone 5s, over 9 million sold units during the first three days.

G_8 iPhone 6 Plus (2014): The iPhone 6 Plus was the high-end model of the eighth iPhone generation. Its development is characterized by 81% AV and 19% CV. Besides the Lightning Connector and the Home Button, all other subsystems were changed. According to Snell (2013), recognizing the consumer's desire for larger displays and competitors such as HTC induced major changes. Apple significantly increased the size (iPhone 5s: 4" to iPhone 6 Plus: 5.5") and added IPS technology to the display. For integrating the new display and an added NFC antenna the case had to be changed. For not needing a PV and getting along with an AV the case of the internal RP iPad Air served as RSE. Apple broke their sales record with more than 10 million units sold during the first three days. Customers complained about bending iPhones 6 Plus ("Bendgate").

G_9 iPhone 6s Plus (2015): The iPhone 6s Plus was developed with 54% AV, 46% CV, and again no PV. After introducing several new features in generations seven and eight, the technical analysis showed that Apple decided to carry over many subsystems, such as the Home Button or the sensors. The mentioned "Bendgate", had to be solved with an AV and the new case consisted of a more solid aluminium alloy. The sales figures increased to over 13 million sold units during the first three days.

G_{10} iPhone 7 Plus (2016): Continuing the "Plus" models as high-end models, the iPhone 7 Plus had 72% AV, 28% CV, and again no PV. Most important was the AV for the CPU. For the first time, Apple used ARM's big.LITTLE technology for their A10 Fusion chip. Adding a larger battery should guarantee a better battery performance compared to the criticized iPhone 6s Plus. Apple no longer released its sales figures during the first three days. According to Knight (2016), Apple's explanation is, that these numbers don't have value anymore, because all produced units would be sold anyway.

G_{11} iPhone X (2017): The outspoken goal for the tenth anniversary iPhone X was to set another "innovative milestone" and to technologically shape the upcoming years. The variation shares (19% δCV, 62% δAV, 19% δPV) indicate major changes within iPhone X. A larger battery (AV) was integrated to handle the upcoming new features. Face ID replaced Touch ID and was integrated through an infrared sensor and TrueDepth technology. Face ID made it possible to remove the Home Button and add an all-screen display. Shaping the front of the new case for the all-screen display also

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the back was made of glass to integrate wireless charging. Considering that Apple again didn't release the starting sales figures, technically the goal was reached. Several new features generated excitement among customers and reviewers (e.g. Brownlee and Swan, 2017; Savov, 2017; Snell and Moren, 2017). According to Ecott (2017) and Sørensen (2017), there were societal concerns about Apple collecting data from Face ID and infringing on privacy rights.

G_{12} iPhone XS Max (2018): The high-end successor of the iPhone X was the iPhone XS Max. By raising the display size from 5.8" to 6.5", Apple followed the identified constant consumer desire for larger displays (AV) and highlighted a difference between iPhone X and iPhone XS Max. For the integration of the eSIM technology (AV), the Apple Watch served as an internal RP, with its eSIM as RSE. Many of the subsystems of the iPhone X were carried over because of the major changes achieved there (e.g. the operating controls, and sensors), which resulted in 46% δCV, 54% δAV, and 0% δPV. Statista (2022) indicates that there was a clear decline in overall sold units looking at the business years 2018 (selling iPhone generation 11) and 2019 (selling iPhone generation 12). In numbers, the volume dropped from 217.72 million units in 2018 to 185.6 million units in 2019.

G_{13} iPhone 11 Pro Max (2019): For the high-end successor of the iPhone XS Max, the iPhone 11 Pro Max, we saw 54% δCV and 46% δAV. According to Kilani (2020), Apple concentrated on getting competitive at the top of smartphone photography. For this reason, they integrated an advanced three-camera system into iPhone 11 Pro Max (PV), which was supported by the newly synchronized OS. Additionally, an important technological step for services like Airdrop was made by integrating an ultra-wideband chip for better spatial orientation. The overall sales increased from 185.6 million units in the business year 2019 to 189.8 million units in the business year 2020 (Statista, 2022).

G_{14} iPhone 12 Pro Max (2020): Due to the corona pandemic, the presentation of the iPhone 12 Pro Max was the first to be held completely virtual. After two years of a high δCV and no PV, we see now for the iPhone 12 Pro Max a small share of 28% δCV, but a bigger share of 63% δAV and also 9% δPV. Apple integrated a LiDAR scanner to optimize depth perception using the earlier released iPad Pro as RP. Another critical AV was the integration of the new 5G cellular standard. The PV for the case marked a drastic design change. The form was varied in the style of the RP iPad Pro, the MagSafe technology was added at the back, and a so-called Ceramic Shield was added at the front cooperating with Corning Inc. According to Statista (2022), the overall sales figures increased to 238.3 million units and settled a new sales record.

G_{15} iPhone 13 Pro Max (2021): The iPhone 13 Pro Max is characterized by 46% δCV, 54% δAV, and 0 % δPV. As the variation shares indicate, after the major changes for iPhone 12 Pro Max, there are minor changes for iPhone 13 Pro Max. Reacting to consumer criticism, Apple increased the capacity of the battery for the iPhone 13 Pro Max. Apple's goal to lead the market in terms of data privacy increased cyber criminality, and thus increased consumer focus on that subject, leading to major updates for data privacy functions in iOS 15. In the business year 2022, Apple sold 237.9 million units, which was a slight decrease from 2021 (Statista, 2022).

In Figure 3, we summarized the most impactful reference products, variation types, context factors and their relations. The contextual factors are divided into the levels of Ma = macroeconomic, Mi = microeconomic, C = company, P = project (Gericke et al., 2013).

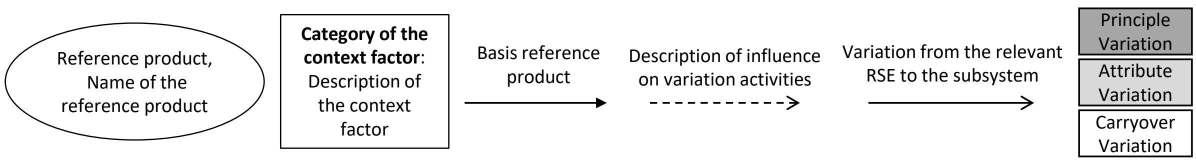

Figure 2: Legend for the visual elements in Figure 3

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4.1 Relationships between context factors and reference-based variation activities

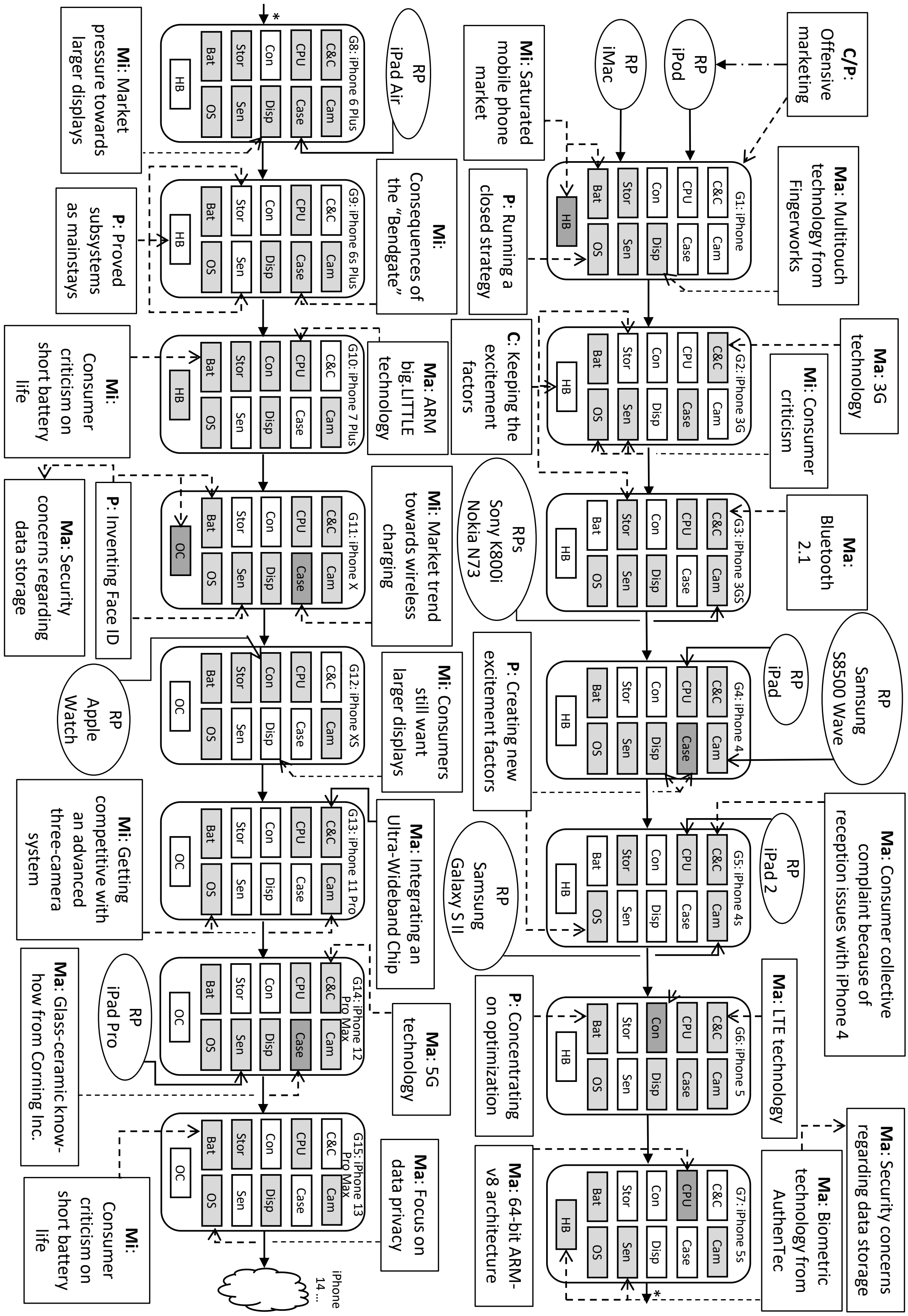

Figure 3: Relationships between context factors and reference-based variation activities. Abbreviations used: RP = Reference product, BRP = Basis reference product, C&C = cellular (mobile telephony) and connectivity, Cam = camera, CPU = Central processing unit, Con.= connectors, Disp.= display, Stor. = storage, Sen. = sensors, Bat. = battery, OS = operating system & software, HB = home button, OC = operating controls.

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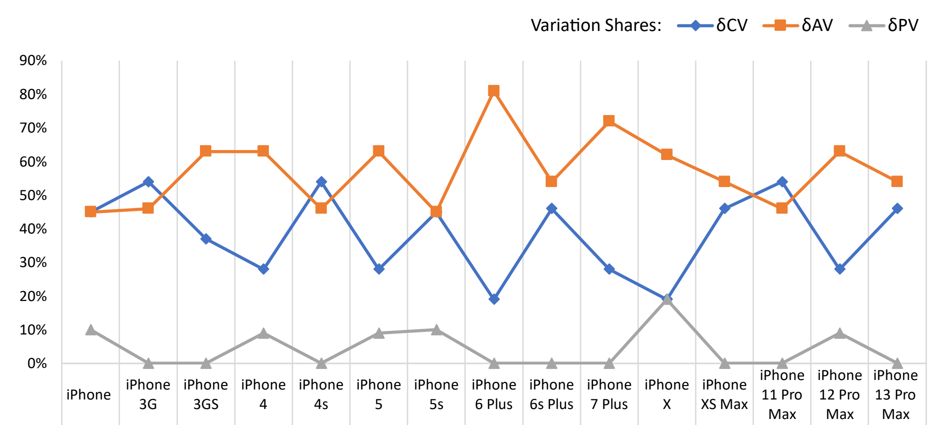
4.2 Variation shares

From the seventh product generation onwards, there are at least two variants per generation. The high-end variant was always selected for the presentation from the seventh product generation onwards. This represents the maximum change compared to the previous generation and the aim of taking a cross-generational look at the variation shares can be achieved. Figure 4 visualises the variation shares for the high-end variants.



	iPhone	iPhone 3G	iPhone 3GS	iPhone 4	iPhone 4s	iPhone 5	iPhone 5s	iPhone 6 Plus	iPhone 6s Plus	iPhone 7 Plus	iPhone X	iPhone XS Max	iPhone 11 Pro Max	iPhone 12 Pro Max	iPhone 13 Pro Max
δCV	45%	54%	37%	28%	54%	28%	45%	19%	46%	28%	19%	46%	54%	28%	46%
δAV	45%	46%	63%	63%	46%	63%	45%	81%	54%	72%	62%	54%	46%	63%	54%
δPV	10%	0%	0%	9%	0%	9%	10%	0%	0%	0%	19%	0%	0%	9%	0%

Figure 4: Variation shares of the 15 iPhone generations (high-end variants).

The consistently high δAV and the high δPV in the iPhone X are noticeable. From the iPhone 3GS onwards, δCV and δAV converged and separated cyclically. The largest share of variation falls on δAV in most generations. δPV was consistently low compared to the δCV and δAV. In nine out of 15 generations, δPV was 0%. After a high-end variant with a δPV larger than 0%, δCV and δAV converged to the point of overlap in four cases, so that in these cases δCV represented the largest share. Afterwards, the development is inverse. δPV in combination with δAV above 50% occurred in two to three generation cycles, but never in two successive high-end variants.

5 DISCUSSION

The referenced hypotheses and product generations refer to the case studies on the Toyota Hybrid drive system Gearbox (THS-G) and Google Glass. The formulation of the hypotheses was partially adapted from the first publication (Pfaff *et al.*, 2022a).

1. *Successful product generations with many new or improved customer-relevant product features use external RSE to keep the share of PV low.* ($G_1^{THS\text{-}G}$, $G_5^{THS\text{-}G}$, $G_3^{Google\ Glass}$). Figure 4 shows that the iPhone always had δPV below 20% in the high-end variants. External RSEs of competitors' products are mainly used in the first generations (G_3^{iPhone}, G_4^{iPhone}, G_5^{iPhone}), as Figure 3 shows.
2. *Successful product generations without an (internal) predecessor generation ("G_1") and new product profiles keep the share of PV low through internal and external references.* ($G_1^{THS\text{-}G}$, $G_1^{THS\text{-}G}$). The G_1 of the iPhone as a product generation without a direct predecessor and the first "smartphone" had variation shares of δCV = 45%, δAV = 45% and δPV = 10% (cf. Figure 4) and supports this hypothesis.
3. *CV and AV of subsystems are not sufficient in the long term to deal with more progressive legal frameworks and changing social conditions. PV in subsystems or changes in the product profile are necessary* ($G_2^{Google\ Glass}$, $G_3^{Google\ Glass}$, $G_6^{THS\text{-}G}$). The iPhone faced problems with acceptance, especially regarding data security in G_7 (TouchID) and G_{11} (FaceID). In these two generations, apple reacted with marketing measures, not with changes in the product itself. As this trend continued, the OS of the G_{15} received major updates for data privacy functions which, however, cannot be called PV at the level of the OS. The hypothesis cannot be supported in its current formulation.
4. *Open innovation strategies result in parallel development paths or branches which provide valuable RSE resulting in a lower δPV which leads to decreasing cost and risk* ($G_5^{THS\text{-}G}$). The

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fourth hypothesis is lacking empirical support in the present case study of the Apple iPhone within the sources examined. External know-how and reference system elements were acquired over the product generations by buying up technology companies (e.g. G_1^{iPhone}: Fingerworks) and analysing competitor products (G_3^{iPhone}, G_4^{iPhone}, G_5^{iPhone}: Camera).

5. *The successful development of a product generation with a high δPV is supported by a special internal context such as core team management, and motivational structures for staff and resources* (G_1^{THS-G}). Also for the fifth hypothesis, there is a lack of concrete sources that specifically prove the factors of core team management, motivation of employees or special use of resources in connection with the iPhone.

The product generations that served as the basis for the new hypotheses are referred to in brackets.

6. *Successful product generations with many new technologies use external RSE to keep the share of PV low.* (G_1^{iPhone}, G_6^{iPhone}, G_{14}^{iPhone})
7. *The slightly delayed introduction of new technologies compared to competitors can help to require few PVs and thus reduce the cost and development effort. If functionality is then guaranteed accordingly, this practice has no discernible negative impact on sales figures.* (G_8^{iPhone}, G_{11}^{iPhone}, G_{13}^{iPhone}, G_{14}^{iPhone}, G_{15}^{iPhone})
8. *In a product family that is established on the market, large CV shares* (G_2^{iPhone}, G_5^{iPhone}, G_7^{iPhone}, G_9^{iPhone}, G_{11}^{iPhone}, G_{13}^{iPhone}, G_{15}^{iPhone}) *and targeted generations with higher PV shares* (G_4^{iPhone}, G_{11}^{iPhone}, G_{14}^{iPhone}) *occur periodically.*
9. *In the case of simultaneous cost & innovation pressure on a 1-variant product generation, a split into variants is beneficial. The predecessor generation is used as a basic reference product and differentiating features are created for the high-end variant through targeted PV in a few subsystems and the cheaper variant(s) can be cost-optimised through CV and AV.*
   This hypothesis originates from the variant split in G7 iPhone (5s, c), G11iPhone (X, 8, 8 Plus), G12iPhone (12, Pro, Max, mini). The data on the non-high-end variants can be found in the data set (cf. section 3).

Limitations of the study's research method lie in the sources used, the system model applied and the underlying SGE-Variation classification. Many online sources and grey literature were used. By involving teardowns and using a variety of sources, the validity of the study was improved. The applied system model with 11 subsystems provides a sufficiently high level of detail at the architectural and embodiment level but is not always adequate to the importance of the software, which is seen as a further subsystem in the system model. This approach was chosen because of the mechatronic research focus of the author team.

6 CONCLUSION AND OUTLOOK

Two of five ongoing hypotheses for causalities between changing context factors, reference-based variation activities (SGE), and innovation success could be supported with the case study. The third hypothesis could not be supported and for two hypotheses the data obtained from the study was not sufficient. Four further hypotheses could be derived. The results obtained indicate that the evolutionary descriptive model based on the model of SGE according to Albers fulfilled its purpose and proved to be suitable for analysing the "evolution" of product generations in their context. The data basis must be expanded with further case studies to arrive at valid statements on the causalities and form a "bigger picture". This "evolutionary knowledge" will be made available to product developers through design support. Initial studies are being conducted in innovation formats with playbook approaches.

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https://doi.org/10.1017/pds.2023.172 Published online by Cambridge University Press