House of Quality for Complex Software Development Decisions in Mobile, Wearables and IoT

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Abstract

The process of decision making for complex software such as that for mobile devices, Wearables and IoT (Internet of Things), is a challenging task. The software design complexity and high level of interdependencies, along with crunched schedules and market pressures, make decision making even harder. How can we take decisions quickly that are technically accurate, address market needs and also communicate effectively to management?

House of Quality (HoQ) is a popular tool in the manufacturing world that enables quick decision making, better product definition, and strategically prioritizing efforts while also being an effective communication tool among stakeholders including marketing, engineering and senior management. At Intel, while developing software for mobile features, optimization of power-and-performance (PnP) are given high importance. We decided to validate HoQ for one of the software trade-off decisions that was highly complex and took significant time and resources to arrive at.

The paper explains how the product development team built the House of Quality to verify the decision taken by making a single picture, covering several dimensions and comparing the ease of taking this complex decision through HoQ. We find that the learnings are apt for decision making in such high complexity and schedule constrained world of mobile devices, Wearables and IoT.

Biography

Manini Sharma is a Platform Software Quality Engineer at Intel, based in Bangalore, India. She works on software for Tablets and Internet of Things based on Intel Architecture. She's worked in a variety of roles in the past decade including Product Marketing, Software Development and Application Engineering. She's been focused on Software Quality for the past four years.

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1 Introduction

Quality Function Deployment (QFD) has been around since 1960s having multiple manifestations (Quality Function Deployment 2015). However, it's based on a single unambiguous concept; that of keeping customer needs central to product decisions. "House of Quality" (HoQ) is a matrix tool to implement QFD. It was first developed by Mitsubishi Heavy Industries in 1972 and been used by several manufacturing organizations, such as AT&T, HP and GM (Hauser and Clausing 1988). HoQ, in itself has gone through changes. Modern QFD recommends non-matrix tools, such as the Blitz QFD® (Blitz QFD (R) 2015).

For this paper, we apply the HoQ to a power-and-performance (PnP) scenario to demonstrate the benefits that can be derived for mobile devices and discuss its applicability to Wearables and Internet of Things. The paper is structured as follows: in section 2 we elaborate on the problem of complexity in decision making and section 3 details the House of Quality concept. Section 4 is dedicated to the power and performance case study, in section 5 we discuss the key benefits and limitations of the HoQ and finally in section 6 we elaborate on applicability of HoQ to Wearables & IoT.

2 Problem: Large amount of unstructured data slowing down decision making

With new innovations in technology happening alongside rapid go-to-market cycles (Stamford 2014), organizations are aggressively competing to get to the market first. New breakthroughs require companies to morph quickly and accept new realities or else wilt away (Kocher, Chris 2014). In such fast paced environment, strategic and product design decisions also need to be made fast.

At the same time, information overload makes it difficult to understand a problem and to make decisions. Some cognitive scientists highlight the distinction between raw information and information in a form we can use. Decision makers performing complex tasks would need excess cognitive capacity to process the raw or disorganized information. Hence information overload may be better viewed as organization under-load (Wikipedia 2015). Therefore, there is need for a structured and intuitive way to organize key information such that relevant information becomes apparent and enables accurate decision making.

3 Structuring data using House of Quality

To structure the information for decision making, we investigate the ability of HoQ tool to organize the information and accelerate the decision making process. While there are slight variations in the way the HoQ is created (N. R. Tague 2005) (Lowe 2000) (Carroll 2007), for this case study, we have used it mostly as per the Harvard Business Review article on HoQ (Hauser and Clausing 1988) with some optimizations elaborated later in this paper.

To create this HoQ, first the customer needs are identified and prioritized. This can be achieved using quality tools such as affinity diagram, matrix diagram, etc. (N. R. Tague 2014) The result is a structured list of customer attributes, often in the words of the customers. Each of the customer attributes have a priority value assigned, representing its relative importance to the customer. Another list is created for engineering characteristics or specifications of the product, as measured by the organization. A matrix is then developed for the interrelationship between these "Customer Attributes" (CAs) and "Engineering Characteristics" (ECs). The ECs in this matrix are picked based on the impact that they have on the identified CAs. Customers' perception of the product and its competitors is documented to the right of the matrix, which helps in understanding the product's relative positioning. Technical complexity index and competitive specification are added below the matrix to decide on the final engineering targets. A roof is added on top of the ECs for inter-relationships between them. Finally, the matrix is filled with weighted value of the interrelationship between the CA and EC. See Figure 1 below for the structure. Decisions are taken by identifying trade-offs. (Hauser and Clausing 1988)

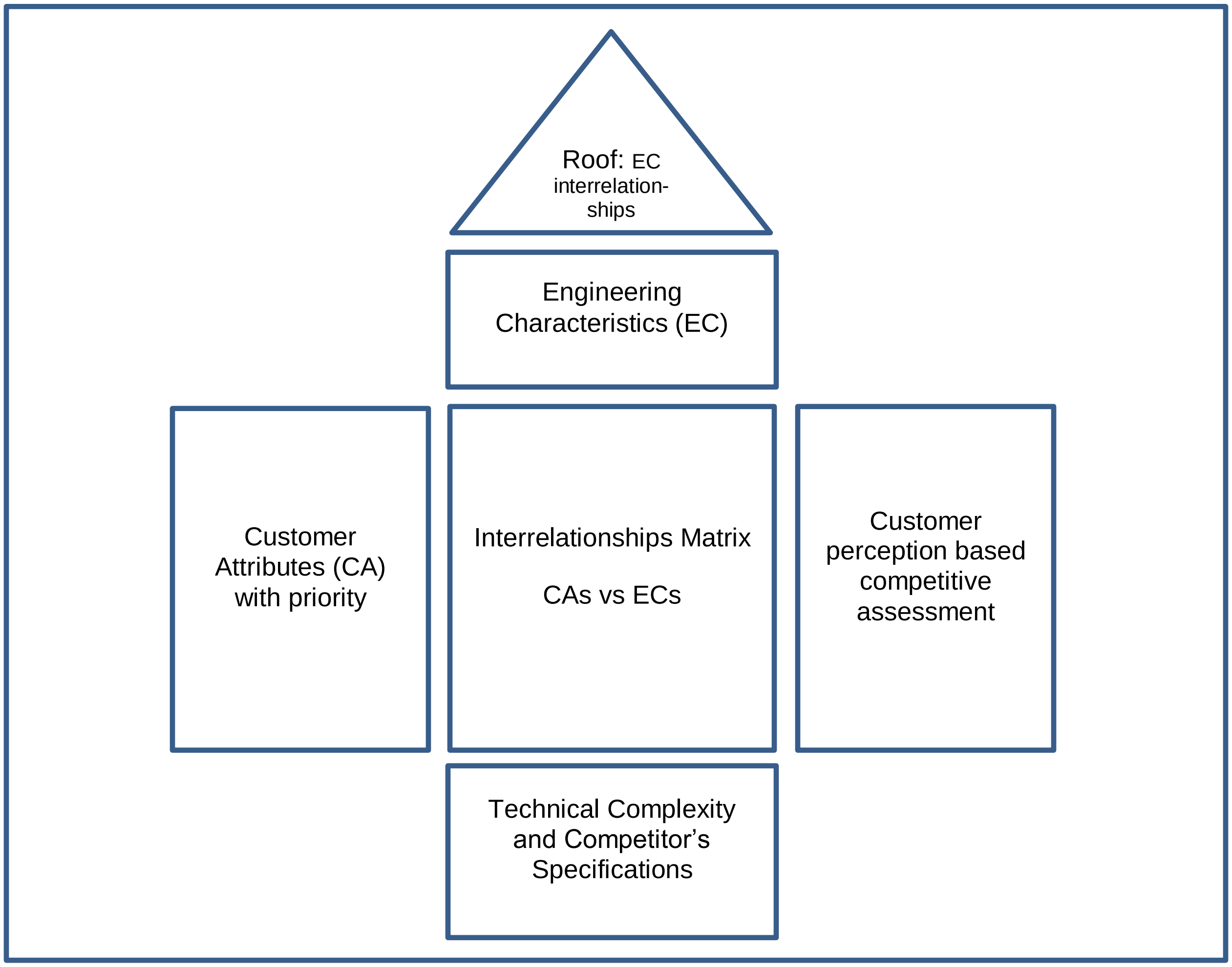

Figure 1: Framework of the House of Quality (Hauser and Clausing 1988)

4 Case study: PnP Trade-offs

4.1 Background

Battery life and high performance are both top considerations for mobile devices (Atluri, et al. 2012). Manufacturers of mobile devices constantly work towards adding new features, improving overall performance and battery life of their products.

It has been established that battery life is inversely proportional to power consumed, which in turn is directly proportional to the performance of the device (Puttaswamy, Choi and Park 2002). Hence, tradeoffs need to be made between power, performance and product features. A poor design choice without considering quantitative impact of interdependent engineering aspects, customers, marketing feedback and competitive data, can lead to failure of the product in the market (Atluri, et al. 2012).

On one of the Intel mobile device platforms, the 'Video Record' use case had a significant gap between the desired and actual power utilization. The excess power consumption reduced battery life of the device by 20%. Since the product launch date was fast approaching, a quick decision needed to be taken on possible trade-offs to close this gap in battery life. For decision making, inputs were needed from multiple teams - engineering, program management, product validation and marketing. With such a large set of stakeholders, it took weeks to go over complex interdependencies and get consensus. The decision was finally reached just in time for product launch.

4.2 Building the HoQ

For enabling faster decisions in the future, the team decided to validate their decision using HoQ. This was done to pilot the use of HoQ in software product development, as well as to evaluate if HoQ could speed up the decision making process.

The process of building the HoQ was as below:

1. Finding what the Customer Attributes of this context are: The marketing team provided this list for the Video Record use case and helped prioritize the CAs.
2. Identifying the dependencies and building the EC list: This refers to the correlation between SoC (System-on-Chip) and components with respect to CAs supported by the platform. The EC list was built based on this. This was an engineering input. The identified CAs and ECs were placed as headers in the interrelationship matrix.
3. Entering the CA data: CA data is entered on the right and shows the customer's perception of the CAs for the Intel and competitor product. These were taken from the competitive analysis data which was already done.
4. Entering the EC data: EC data is entered at the bottom, showing the technical specifications between Intel and the competitor for each identified EC.
5. Technical difficulty grading: Complexity of developing or changing the given ECs was graded on a 10 point scale. This helped in gauging the effort that would be needed to trade-off a given EC. These were placed at the bottom as well.
6. Creating the roof with ECs correlations: The interrelationships between the ECs were created by the Engineering team.
7. Filling in the Matrix: This was done based on joint discussion between the Technical-Marketing and Engineering team.

The HoQ that emerged is shown in Figure 2.

The time taken to build the matrix was couple of hours' activity from Engineering as well as Marketing teams each. Comparing that to the number of meetings and discussions that were originally done, the speed gained was significant – from weeks of meetings and email exchanges to just few hours. The final step was to discuss the HoQ and decide how to attain the additional battery life.

4.3 Deriving the trade-off decision based on HoQ:

There is a direct correlation between battery life and the power utilization. Power, in turn, is dependent on various SoC and platform components on a mobile device. Looking at the HoQ, it became clear that there were several ways to reduce the power utilization:

1. Power is directly (positively) correlated to the number and frequency of various SoC components such as processor cores, Graphics Processing Unit (GPU), and Image Signal Processor (ISP) and platform components such as memory frequency. Therefore, in order to reduce the power utilization, we could reduce the frequency at which these components run.
2. Power is also impacted by the resolution of the camera sensors. Higher the resolution, more the power utilization. Hence, in order to reduce power utilization, we could reduce camera resolution.
3. Another way to address this problem is to increase the battery size. Increasing the battery size would offset the higher power consumption, but increase the cost and also the dimensions of the device.
4. The display also uses power. Higher resolution displays consume higher power. Hence, lowering the display resolution could reduce power consumption.

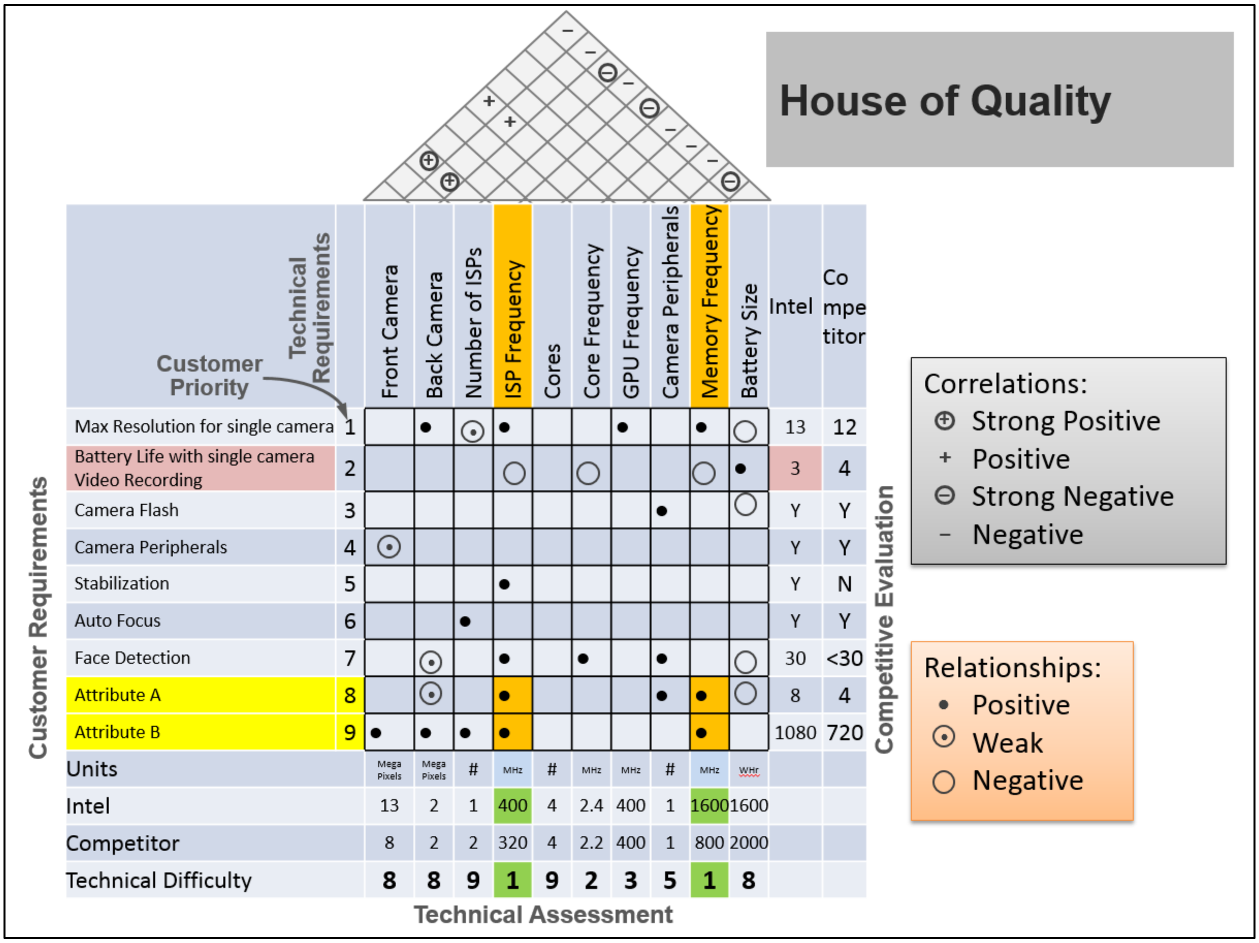

Figure 2: House of Quality built for the PnP Scenario

The following were inferred by taking a quick glance at the HoQ:

1. The CA - 'Battery life during video recording', is strongly correlated with ISP frequency, Core Frequency and Memory Frequency. Reducing these ECs would improve the battery life.
2. The changes to ISP Frequency and Memory Frequency ECs are the lowest in technical difficulty, hence would be easier to modify in software given the crunched schedule.
3. The lowest priority features of Attribute A and Attribute B have a strong correlation with ISP Frequency and Memory Frequency. These features are driving the high ISP Frequency and Memory Frequency values.
4. Based on competitive analysis, Intel's product is significantly higher in ISP Frequency (400MHz vs 320MHz) and Memory Frequency (1600MHz vs 800MHz). This gives Intel leeway to trade-off these characteristics to improve battery life.
5. Removing the low priority features like Attribute A and Attribute B (masked for confidentiality reasons) would remove the need for running ISP and Memory at high frequencies and thus reduce overall power.
6. A quick check of the impact of these changes is done by reviewing the other dependent CAs, such as Stabilization, Face Detection and Max Resolution for Single Camera.

Hence, in one discussion, the decision of this trade-off was validated. Had the team used the HoQ for the original decision making process, this decision could've been reached much faster and with same accuracy.

One of the key stakeholders, who approves these decisions, and runs the Change Control Board, is the Program Office. Using this visual tool to explain the rationale behind the decision as well as the technical and marketing impact led to quick approval and execution of the proposed modifications.

5 Optimizations, benefits, and limitations

5.1 Optimizations to “Slim Down” the HoQ:

Critics of the HoQ often prescribe to the rigidity of its structure and need for comprehensive information (What Software is Best for QFD 2015). However, as seen in the case of PnP scenario, these can be overcome by focusing on the essential and discarding the non-essential aspects of the HoQ based on context.

One may ask, why build the matrix/house at all, if we will discard a large chunk of the data? The answer is, we need to visually and mentally be aware of the customer attributes and engineering characteristics while making the trade-off decisions. The decision-making process includes making sure, with reasonable confidence that the dropped attributes or characteristics are in fact, low priority and low risk. Keeping the context of customer need central to the building of the matrix guides the way to creating a suitable HoQ.

To apply the HoQ to the PnP case, some optimizations were made. These were departures from the originally referenced HoQ diagram (Hauser and Clausing 1988):

1. Although display resolution has a positive correlation with power consumption, it was fundamental to the product specification and could not be altered; hence it was excluded from the HoQ EC dimension.
2. While battery size was included in the EC dimension, it was ruled out as an option because it would’ve led to increased cost, larger dimensions and additional weight.
3. Some of the EC changes such as number of cores, GPUs, ISP, etc. that would need complex hardware changes, were also ruled out immediately.
4. ECs that had dependencies on other ECs impacting high priority CAs, were kept in the HoQ. CAs or ECs that customers find critical or are central to the product offering were also kept in the HoQ.
5. The comparison of low priority CAs (Attributes A & B) dependent on low technical complexity ECs (ISP frequency & memory frequency) helped find the right trade-off between product features and power, which was acceptable to both customers and engineering teams without compromising on project timelines.
6. The interrelationships diagram uses “Positive”, “Weak” and “Negative” nomenclatures instead of High, Weak, Low. This was found to be more appropriate for this context. Note: Here Weak implies there is almost no relationship.
7. We didn’t use all the elements of HoQ, like directions on the ECs (which direction improves the product – higher/larger versus lower/smaller). These were not relevant to the problem at hand and thus, were unnecessary.
8. Mathematical weight calculations became unnecessary since the decision making didn’t require it.

Such optimizations were made to achieve focus and speed in decision making. Similar optimizations can be applied to “slim down” the HoQ relevant to the context in which it is being applied.

5.2 Key Learnings and Benefits Derived:

There were several learnings and benefits from building the HoQ in the PnP scenario:

1. The use of HoQ significantly reduces the effort to bring out the complex interdependencies by creating a structured and objective view of the problem which helps in making quick decisions.

2. If the data needed for building the basic structure of the HoQ is available, the decision making process can be accelerated. Hence, assigning priorities to customer requirements and including market survey results to the existing product development documentation would be beneficial.
3. If the data needed for building the HoQ is not available, trying to build the HoQ will make this immediately obvious: the decision cannot be made in a fact-based way at this point. Without the clarity of the HoQ, this could go unnoticed in weeks of meetings and email chains, or worse, lead to gut-based, random decisions.
4. The Engineering teams are most suited to drive this process. They can establish the list of ECs and take responsibility of filling in the interrelationship matrix between ECs and CAs. This helps in accelerating the decision making process.
5. Using HoQ in day-to-day processes like software qualification can help in quickly assessing whether missing a particular goal is acceptable or not. It can also help teams streamline efforts towards working on high importance tasks.
6. This single visual method of organizing the complex information and decision making makes it easy for key stakeholders to understand the problem and rationale behind the decision.

5.3 Criticism and Limitations of HoQ

The HoQ tool has received a fair amount of criticism. The diagram of HoQ and the amount of information it holds can increase exponentially. For a 1000x1200 dimension matrix, the number of intersecting cells is 1.2 million. It has been found that typically 95% of the data that is filled in the intersecting matrix is unimportant. (What Software is Best for QFD 2015) Hence, spending one's energy on comprehensiveness of this tool may become time-consuming and exhausting. The complexity of its output may not yield the best decision easily.

At the same time, reducing the dimensions and oversimplification of its use, can lead to poor decisions; defeating the entire purpose of the tool (Modern QFD and Traditional QFD 2015). The challenge is thus to find the right balance between over simplification and exploding complexity.

Another criticism is that the use of ordinal scale in customer input may not reflect the correct mathematical interpretation of actual need. E.g. If customers are asked to rank features in order of importance, something that is ranked 4 may not be twice as important as something that is ranked 2. (Modern QFD and Traditional QFD 2015).

These criticisms are founded in sound logic. However, by intelligent and balanced use of the HoQ, making sure that the tailoring being done meets the need of the situation at hand, without oversimplifying or overcomplicating, one can arrive at decisions quickly and with high accuracy. As with any tool, the key to success lies in the user's skills and knowledge of the tool. This will be the case when the users are stakeholders who have full context knowledge and know what areas need attention and which are unimportant (N. R. Tague 2005). Similarly, when using statistical techniques, the numbers generated from the HoQ can be correctly interpreted only when the stakeholders provide correct values.

At the same time, one must remember that HoQ is only a tool for *getting to* a decision, not the decision itself. It structures and visualizes input data, and helps identify important interrelations that might go unnoticed otherwise. It helps organize the key information elements in an easily interpretable way. In the end, a human must make the decision. For example, in the PnP scenario, increasing the device size was not an option at all, however the numbers may look.

6 Extending the application of HoQ to Wearables and IoT

As seen in the case study, the application of HoQ can save considerable time in decision making in mobile devices context. The pilot showed a reduction in decision making time from weeks to few hours with the same accuracy. As in the case of mobile devices, Wearable product design and development process is complex, which is exaggerated by rapidly changing technology, society trends, life style and user behavior. This complex combination of triggers, including signs, novelty, technology, aesthetics, and culture, interact with one another, leading to customers' desire for fashionable Wearables (Kao, et al. 2013). Here the importance of customer preferences cannot be overstated. The HoQ can be effectively used to make design and trade-off decisions, keeping the evolving fashion in mind. If there are conflicting customer requirements, the customers can be segmented and then prioritized based on target marketing strategy. The final priority of a customer attribute in the HoQ can be weighted based on relative priority of the customer segment (N. R. Tague 2005).

In the larger context of Internet of Things (IoT), companies are understanding the need to be nimble. Rapid evolution in IoT is expected to consume unanticipated resources that will diminish an organization's ability to add new core functionality. Slow adoption will slip schedules and slow down revenue generation. Evolving architecture, protocol wars and competing standards necessitate the need to evolve and adapt quickly (Kocher, Chris 2014). New use cases are emerging and products under development need to be modified on-the-fly to be competitive when they launch. Devices are expected to get smaller, less expensive and more integrated than before. This will have implications on Security, Privacy, and Complexity of platforms that need to be supported (Kocher, Chris 2014). Here, HoQ can enable quick decision making for adding functionality when products are under development. Trade-offs can be identified using HoQ to make the product attractive at the time of launch. Intelligent "slimming down" of the HoQ, based on the context of the product decision would help a team focus on the relevant information. By structuring the complex interdependencies through HoQ, we can enable the stakeholders to arrive at and align on a decision quickly.

7 Conclusion

The Intel mobile platform development team spent weeks of effort in dealing with complex interdependencies and meetings for getting consensus with stakeholders. This inspired a search for a tool that would speed up decision making in such scenarios. House of Quality tool was piloted to validate and verify whether the same or better decision could be arrived at, faster. The result from HoQ tool was perfectly in line with that of the rigorous lengthy process. The time taken was reduced from weeks to few hours.

We believe that the HoQ can be easily extended to other scenarios within mobile platform development and also to software development in general, especially for complex products like Wearables and IoT.

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