# Design Space Exploration for Aerospace IoT Products

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**Abstract: '**When aviation takes off again, we (industry stakeholders) must ensure it is on a more sustainable flight path, COVID-19 gives us a chance to design an aviation industry fit for the future' – World Economic Forum [14]. IoT in Aerospace & Defense produces more smart and connected products which offers better operation & control, material & energy management, traffic planning, staff & passenger information management, data analytics, and others. The longer life cycle in the A&D sector presents fewer opportunities to introduce capability advancements to stay ahead of the competition. Strong product strategy decisions can make the difference between success and failure in winning business during the available window of opportunity. Developing Product strategy and identifying suitable product in quicker time is more relevant in the current pandemic scenario with reduced spending for research and development initiatives.
The investigative research is targeted towards developing a design space exploration methodology to develop IoT products in A&D. This methodology helps in identify the gaps in the existing methods and improvement opportunities to develop the IoT products, quick launch in the market to stay ahead of competition and to stay in the market. This methodology could help A&D players to develop optimized product development strategy by identifying the IoT Values which yields customer benefits with qualitative early decisions in IoT product development cycle.

**Keywords:** Internet of Things (IoT), Aerospace Systems, Design Space, IoT Value, Aerospace & Defense, Product Development

## 1 Introduction

Digital transformation is the heart of business strategies and it begins with the executive mandate. There is a strong sense of urgency among executives as the threat of digitally enabled competitors and disruptive technologies remain high on the list of concerns [12]. Internet of Things (IoT) is becoming more and more important in many industry sectors and domains (see Fig.1) for the global IoT aerospace and defense market. Digital Technology evolution is happening rapidly and within no time will impact every business. However, digital transformation is essentially a commitment by organizations to innovate which would add value to their customers [2].

In the two decades since, the concept of IoT—which now encompasses a global ecosystem of sensors, embedded computers and smart devices that communicate with each other and share data—has exploded. Today, approximately 14.2 billion connected devices are currently in use around the world. By 2021, that figure is expected to jump to more than 25 billion due to a combination of cloud computing power, decreasing hardware cost and faster 5G data transfer that will accelerate growth. These devices include smart home appliances and wearable trackers, as well as a large variety of industrial innovations to improve manufacturing and operational efficiency. In the business world, IoT is already having a major impact, from changing the methods of business operations to transforming the way information is collected and exchanged. And every sector is impacted—including aerospace [16].

The Internet of Things is one of the biggest value generation technology in Aerospace and Defense (A&D) industry despite economic downturns. Long term increase in travel demand, development of new technologies and security threat for nations are fueling increase in aircraft production, defense budgets and the need for global supply chain [1]. Aircraft manufacturers and operators are always on the lookout to improve the vehicle performance adopting more connected and smarter systems to achieve the fuel efficiency, zero downtime and route optimization [2].

As there are multifold opportunities opens up due to IoT product, the exploration of design space increases the engineer's understanding of the design problem [4]. The exploration must be done carefully due to a large number of design alternatives. A large system may have millions, if not billions of design alternatives, and it may have infinite alternatives for some design problems [3]. In addition, a larger complex system also has a larger number of design constraints that must be satisfied by every valid design alternative or solution. Furthermore, the analysis of these design alternatives includes higher computational costs.

Design space exploration (DSE) refers to the activity of exploration and investigating design alternatives prior to system implementation. DSE is used for rapid prototyping, optimization and system integration [3]. In rapid prototyping, DSE helps to generate several prototypes before the system implementation. By simulating these prototypes, engineers can increase the understanding of the impact of design decisions. In optimization, DSE can be used to eliminate the lower quality designs and selecting a set of design candidates for further analysis. The elimination is done by comparing one design to another using predefined metrics, for instance, design requirements. In system integration, DSE can be used to find legal assemblies and configurations that satisfy all global design constraints for the integration of multiple components into a working whole system [15].

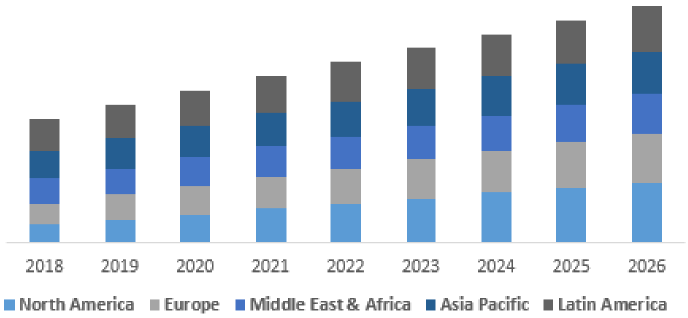


**Fig. 1.** Global IoT Aerospace & Defense Market [5]

A SITA air transport study found that 67% of airlines have plans to invest on airline IoT by 2030. One of the drivers is passenger demands for seamless in-flight connectivity. Stimulating this investment is an enabler for IoT, if the passenger demand wasn't there, airlines would not be adding the Internet to the airplane at the rate they are with 50 billion or more IoT devices expected to be in circulation in the world by 2030. In the aviation industry, IoT has the potential for operational improvements in areas including aircraft performance, air traffic control and maintenance schedules — all of which ultimately lead to greater customer satisfaction. Similarly, for supply chain management, IoT has implications for improving product flow and warehouse efficiency, resulting in improved customer experiences and loyalty [17].

### 1.1 Objective of the paper

The design of aircraft systems is an extremely complex task involving multidisciplinary studies that address the behavior of the design from mechanical, electrical, aero thermal and producibility aspects. In the early phase of aircraft systems development, engineers rapidly explore the design alternatives or design concepts to achieve design solutions that meet all requirements. This task is called design space exploration. It involves high-fidelity physics-based numerical simulations to evaluate each design concept [6] [7]. Due to the time constraints of simulations, it is impossible to explore all these design alternatives. At the same time, exploring very few design concepts result in design issues in later stages. Thus, it is a crucial phase where engineers need support to evaluate design concepts and to prevent product failures.

The concept of IoT bringing new capabilities to interact with products or systems, independent of the core (certified) function of the system. A generator still has to generate, but IoT enables us to do more (predictive maintenance, performance tuning, etc.). Aerospace industries are currently adopting agile way of developing of minimum viable systems/products and are investing heavily to adapt IoT technologies which can yield long term value and benefit to customers. IoT technologies are evolving rapidly, and these have the opportunity to change the product landscape in the aerospace industry as well. However, there is no established approach to identify such systems/products. The objective of this paper to develop methodology that would help in developing minimum viable system/product by A&D industry to focus, while recognizing it must be adapted to fit alongside core certified designs without interference in the core function. There is strong motive in A&D industry to develop IoT products focusing on customer experience and enhanced product capabilities. This exploratory research is targeted towards develop design space exploration methodology for aerospace & defense IoT enabled products.

## 2 Methodology

A process that facilitates the creation of new functionalities, products, and services thereby making provision for better revenue streams, transform business models, drive measurably better outcomes for customers and every business sector including A&D [18]. The Methodology (see Fig.2) i). Customer need identification ii). Product selection iii). Minimum Viable Product is developed around these three key steps. All these steps would be iterative till all the stakeholders are satisfied with identified product and its service to customer. First step Customer need identification is the critical one and majority of the time to be spent on this to understand customer interest. As there is no conclusive research findings available to find the best approach to identify the customer need regarding Aerospace IoT products, a survey has been conducted among aerospace and aviation professional group. Remaining two steps would takes less time if the well-defined problem emerges out of customer need identification.

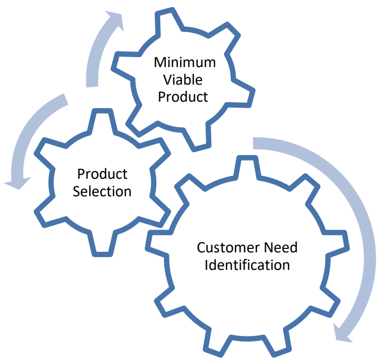


**Fig. 2.** Design Space Exploration Methodology for Aerospace IoT

### 2.1 Customer need Identification

Customer Needs Identification is the process of determining what and how a customer wants a product to perform. Customer Needs are non-technical, and they reflect the customers' perception of the product, not the actual design specifications, although frequently they are closely related [13].

There are three ways to identify the customer need Aerospace IoT products (see Fig.3) Option-1: Customer Feedback, Option-2: Product Improvement opportunities, Option-3: End user level opportunities.

As there is no conclusive research findings available to find the best approach to identify the customer need, a survey has been conducted among aerospace and aviation professional group.

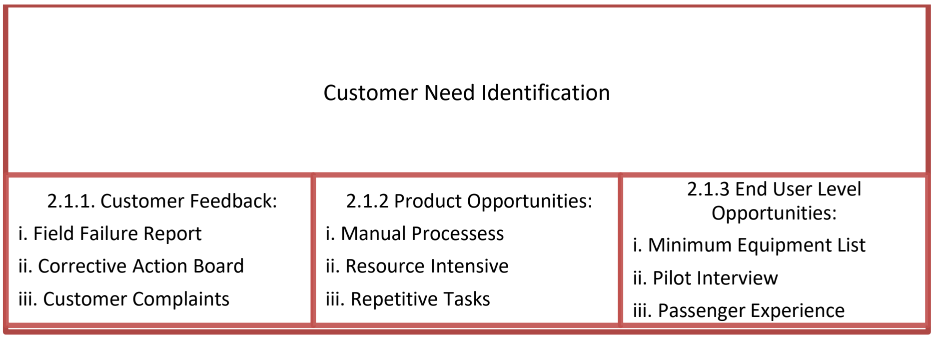


**Fig. 3.** Customer Need Identification methodology for Aerospace IoT

### 2.1.1 Survey Participants Details

Shown below the (see Fig.4) survey participants' details with respect to aerospace industry experience, role in the industry and their IoT expertise.

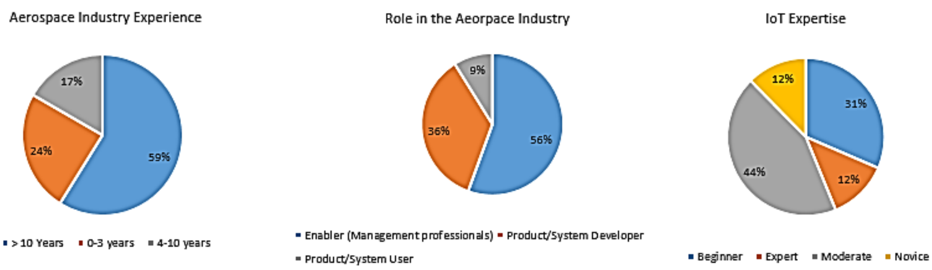


**Fig. 4.** Survey Participant details

### 2.1.2 Customer feedback

Customer feedback could be obtained in multiple ways, mentioned below three best possible ways.
i). Field failure report ii). Corrective action board iii). Customer complaints

All the mentioned items shows the unhappy customers and their unsatisfied needs. Items i & ii are generally received as a document from company nodal point like MRO, Business Development team etc. While analyzing these documents one should pay attention through written language and think like customer to identify their pain areas.

Generally item iii was communicated directly by customer, sometimes they aren't complaints, customer gives ideas that would make a good product to better. Company should effectively apply design thinking techniques and empathies customers untold needs to identify them. Survey results shows (see Fig.5) that customer complaints is the area to look for potential IoT products.

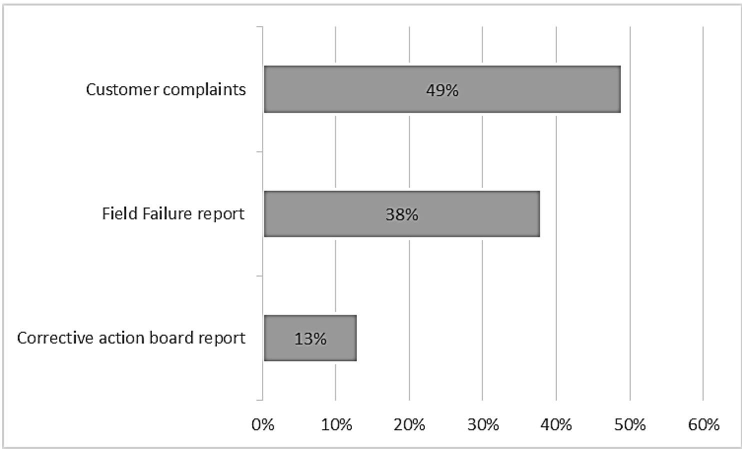


**Fig. 5.** Survey Results on Customer Feedback Parameters

### 2.1.3 Product Improvement Opportunities

Products/process could be improved when there is a manual, resource intensive and repetitive tasks. Not all the mentioned opportunities could be automated due to compliance, safety and security requirements in A&D. There should be tradeoff between the product improvements and all the mentioned requirement and customer willingness to pay (Value). Shown below (see Fig.6) survey results for product improvement opportunities. As per the survey results A&D companies could explore repetitive tasks to develop IoT products.

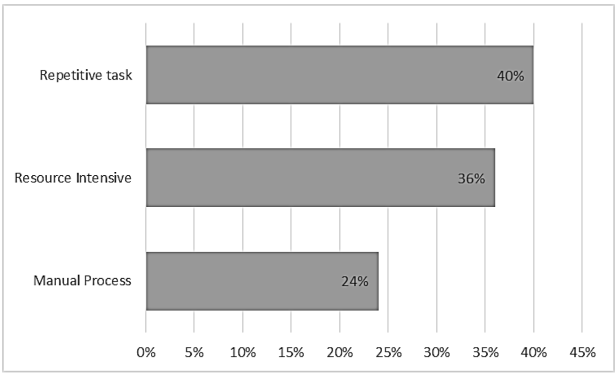


**Fig. 6.** Survey Results on Product Improvement Opportunities

### 2.1.4 End User Level Opportunities

Aerospace products end users are pilots, cabin crews, maintenance teams and passengers. Minimum equipment list tells flight and maintenance crews if they are able to dispatch an aircraft with a failed piece of equipment. IoT products have the potential to make airline employee tasks more effective or efficient, to engage and empower employees, and to allow the airline to optimize their workforce. Finally, these improvements can also make the passenger experience better, both by providing personnel more time to spend engaging customers, or to empower the passenger to self-serve, helping to retaining the customer for future business. Survey results (see Fig.7) reveals that passenger experience is the area in which companies could explore and develop IoT products.

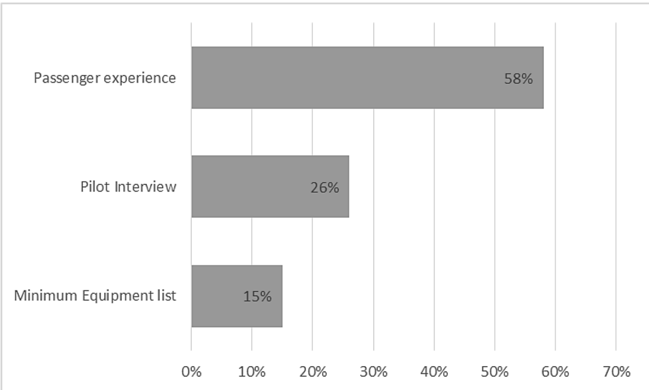


**Fig. 7.** Survey Results on End user level Opportunities

## 2.2 Product Selection

This step introduces the idea of a portfolio of products from a company and the methodology that helps them prioritize the order of products to invest in and what capabilities to introduce. The steps are iterative in nature (see Fig.8) which would help to pick the most strategic products and determine the associated IoT maturity, Value offering and minimum viable benefits to the customer.

Step-1: IoT Value Identification
Step-2: Value Curve Analysis
Step-3: Benefit Analysis

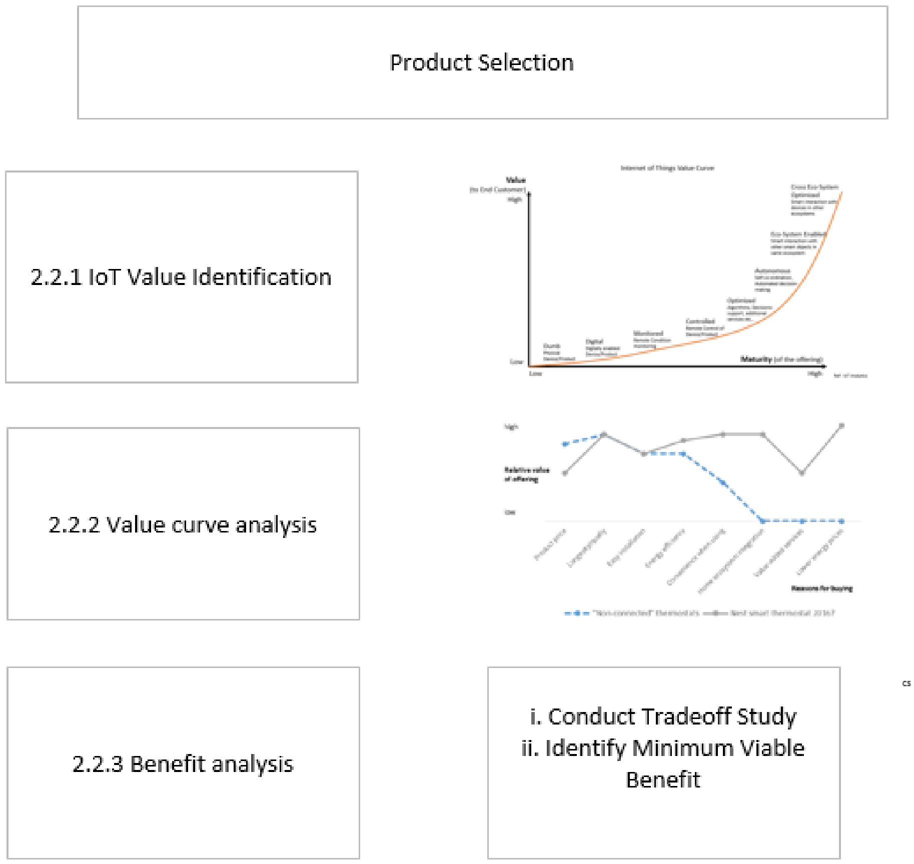


**Fig. 8.** Proposal of product selection methodology for Aerospace IoT

### 2.2.1 IoT Value Identification

The value of the Internet of Things increases exponentially on a relatively stable and foreseeable maturity curve. What starts with a “dumb” (non-connected) device should in theory end in a completely cross-ecosystem automated solution [8]. Physical products have been isolated for hundreds of years in aerospace (i.e., not connected or digitally enhanced). Starting in the 1980s, many aerospace devices underwent a digitalization trend. Longevity of the product in A&D sector is the key to decide the maturity of the offerings as the decision should be made align with company product strategy and along with industry requirements (airworthiness, flight safety etc.)

Once the customer needs are identified, the firms should start with value maturity curve to select their product initial offerings and end user value identification. An IoT value curve (see Fig.9) can help firms understand their current product offering to compare with competitors and position themselves with their new offerings. This curve also helps to develop product launch strategy while developing a roadmap for long run product success.

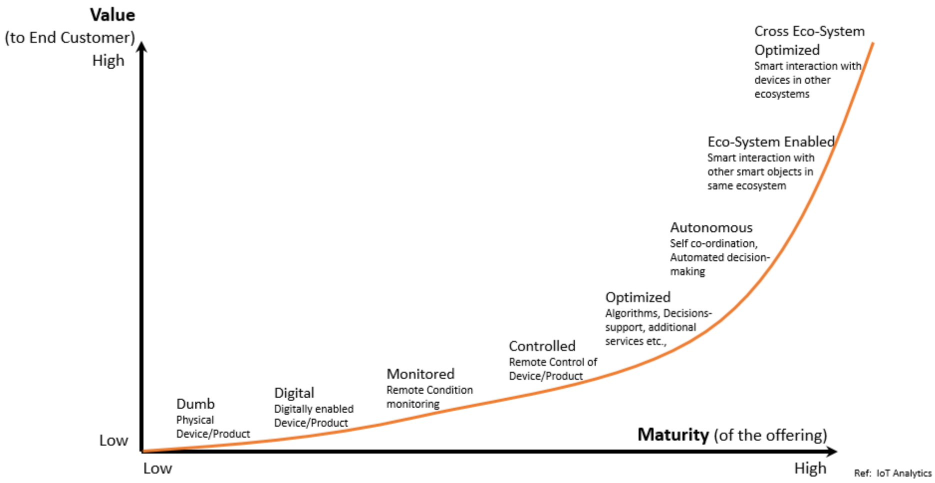


**Fig. 9.** Generic Internet of Things Value maturity curve [8]

Value potential of aerospace IoT varies; not every product will generate benefits by going all the way up the curve. As part of the iterative process, you have to be able to generate incremental value (now or future) as you move up each level of the curve.

### 2.2.2 Value curve analysis

Generic value curve analysis (see Fig.10) establishes the relative value of offerings between IoT and Non-IoT products. From customer stand point the benefits that can be experienced along the value/maturity curve of IoT are numerous and they vary significantly by industry and application [8]. Once the product launch strategy is firmed up the next step is to characterize the customer value Identification for the specific aerospace applications between the IoT and Non-IoT products.

There are generic list of customer values in the Internet of Things given in appendix-1 which could be good starting point to analyze potential value for the customer. Plot the chart between the relative value offerings between the IoT & Non-IoT product (see Fig.10) by selecting appropriate parameters (see Appendix-1) in the IoT product.

As an example for the benefit type process (see Appendix-1), category daily operations there are 6 different customer value parameters. These value parameter are plotted as relative value offerings between IoT and Non-IoT products.

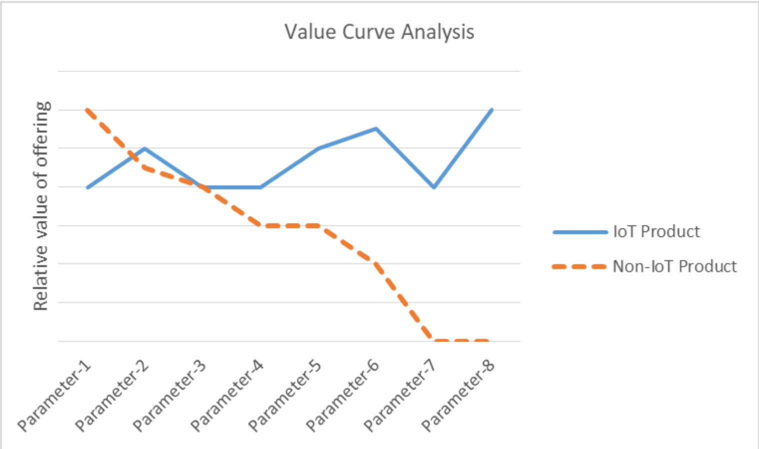


**Fig. 10.** Generic Value curve analysis for IoT & Non-IoT product

### 2.2.3 Benefit analysis

In this step tradeoff study to be conducted to select the best possible cost effective approach to develop the IoT product. Along with minimum viable benefit to be selected which could help in developing the minimum viable product in the next step. There are multiple tools available to conduct trade-off study, subject matter experts input is the key to consider all the possible design options while evaluating the cost effective product development. Cost Benefit Analysis (CBA) is a process businesses use to analyze decisions. The business sums the benefits of a situation or action and then subtracts the costs associated with taking that action. A cost-benefit analysis will also factor the opportunity cost into the decision-making process. Opportunity costs are alternative benefits that could have been realized when choosing one alternative over another [19].

## 2.3 Development of Minimum Viable Product

The Minimum Viable Product (MVP) is a product with just enough features to satisfy early customers that provides feedback for future development [9]. Some experts suggest that in B2B, a MVP also means saleable. "It's not an MVP until you sell it. Viable means you can sell it". Gathering insights from an MVP is often less expensive than developing a product with more features, which increase costs and risk if the product happens to fail due to incorrect assumptions. An MVP can be part of a strategy and process directed toward making and selling a product to customers [10]. In aerospace, this may require us to look for ways to trial a product prior to locking the design and completing the certification/qualification of the product. Once this process is complete, changes become much more costly. This is one of the key differences between aerospace and non-aerospace product development. Things to be considered to develop minimum viable product (see Fig.11). Identifying the IoT elements and its constraint is the first step to start the product development effort. Then develop MV product with minimum feature identified in step 2.2.3.

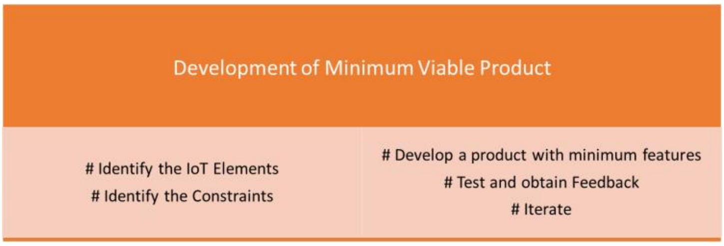


**Fig. 11.** Methodology for Development of Minimum Viable Product

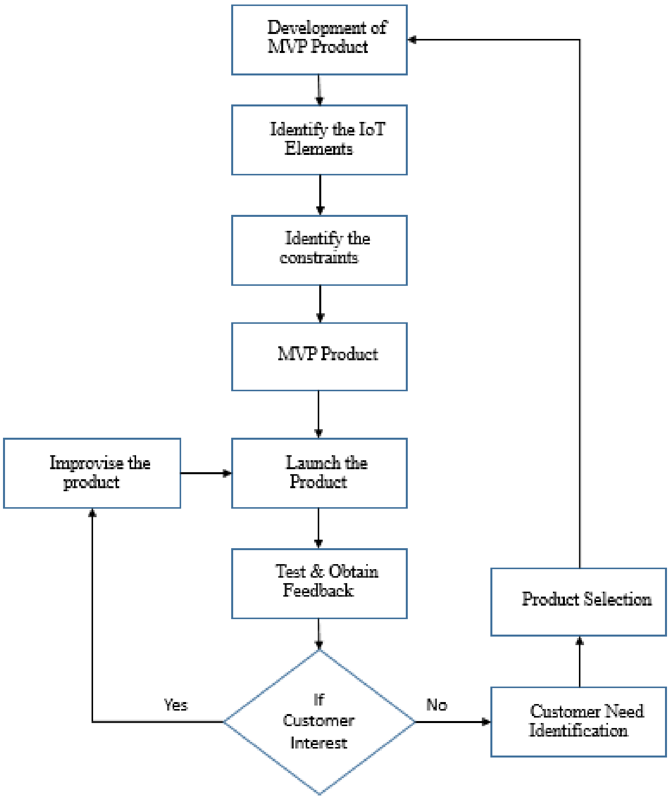


**Fig. 12.** Flow chart for Development of MVP

Once the product is developed to satisfy the mentioned conditions it is time to test the product in the field. Customer feedback is an essential asset while maturing an MVP, as their inputs will help in improving the product in the market. Feedback could come in two areas. The first one is on the design of the product and user interface, which could improve the product usability. The second one is about the value realization in terms of its tangible and intangible benefits and cost reduction. Flow chart (see Fig.12) shows the step by step approach to develop MVP. Logical conclusion for the product is when customer interest turned out to be 'NO'. When we reach this state it is suggested to go back to customer need identification and restart the process of design space exploration methodology.

## 3 Challenges in Aerospace IoT design exploration

The IoT is, in a sense, a hyper-scale System of Systems problem with multiple environments, requirements, governance structures and millions of stakeholders. Metcalfe's Law reminds us that three interconnected components result in a maximum of three interconnections, but with four the maximum number of interconnections rises to six, and with ten components, designers must deal with 45! This law illustrates how so any connected devices will challenge the system design [11]. Design space exploration methodology for aerospace products is having its own challenges some of them listed but not limited to such as criticality of its intended function and IoT capability cannot interfere with that function. Design Constraints such as size and weight of the product which could change the overall system design. Cyber security in the aerospace IoT becomes a critical element when developing connected products for aerospace. Data Ownership is another complication in IoT products as it generates terabytes of data with no defined guidelines on who has rights to use the data. Data access is important aspects in the IoT device if the product controls the function of the system if there is no deterministic/real-time data access.

## 4 Conclusion

Aerospace and Defense industries are increasing investments in developing IoT products to capture the increased value their product portfolio can deliver to customers and end users. IoT product development should pivot around the customer value as a center point. Systematic methodology and qualitative decision making while identifying the IoT product selection should drive customer adoption while minimizing the iteration in the product development cycle.

The exploratory research developed a methodology based on the both theoretical and industry expertise of authors. This paper proposed step by step approach starting from problem definition based on customer need identification narrowed down using detailed survey conducted among A&D and IoT experienced audience. Then the product selection three step approach IoT value Identification, Value curve analysis and Benefit analysis.

Finally developing the minimum viable product with bare minimum feature could reduce the product launch time and obtain the customer feedback to improvise the product with increased value and benefit the customer with bottom line growth. Survey results indicates that focusing on both end user level opportunities and delivering operational efficiencies are the key areas to consider for the next potential IoT aerospace product.

The limitations of the study is customer need identification as there is lack of robust methodology to identify customer need regarding Aerospace IoT products. Though authors used survey techniques to narrow down the pain points however there are limitation to use the survey results. Another limitations is due to value curve analysis as the graph is plotted using relative value offering which is heavily depend on the Aerospace and Defense expertise and their knowledge in IoT which would play major role completing the value curve analysis. Future scope of research would be to develop a robust framework for customer need identification and extend the analysis to more international markets.

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# Appendix-1

| Benefit Type | Category | Customer Value (Parameter) |
|---|---|---|
| Product/ Machine | Daily Operations | • Monitoring<br>• Localization<br>• Control<br>• Safety |
| | Optimization | • Functionality<br>• Convenience<br>• Cost |
| | Maintenance/ Service | • Availability<br>• Cost |
| Process | Strategic Information | • Choice of Machines<br>• Sales optimization |
| | Daily Operations | • Monitoring<br>• Control<br>• Billing<br>• Documentation<br>• Contract Management<br>• Usability |
| | Optimization | • Availability<br>• Quality<br>• Automation<br>• Costs |
| Emotional | Safety | • Personal Security<br>• Employment<br>• Health<br>• Property |
| | Esteem | • Self-esteem<br>• Confidence<br>• Achievement<br>• Respect |
| | Self-actualization | • Creativity<br>• Morality<br>• Problem solving<br>• Acceptance of facts |
| Business | Customers | • Customer retention<br>• Customer satisfaction<br>• Lead Generation<br>• Offer Optimization<br>• Sales Proposition |
| | Products | • Requirement Management |
| | New Markets | • Data as a product<br>• IoT as catalyst |
| | New Business Models | • Added-value offering / new services<br>• Pay-per use / Product as-a-service<br>• Contracting |