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THE EFFECT OF ADOPTING RAPIDLY EMERGING TECHNOLOGY ITEMS DURING THE DEVELOPMENTAL PHASE ON SYSTEMS ENGINEERING DESIGN IN AVIATION INDUSTRY

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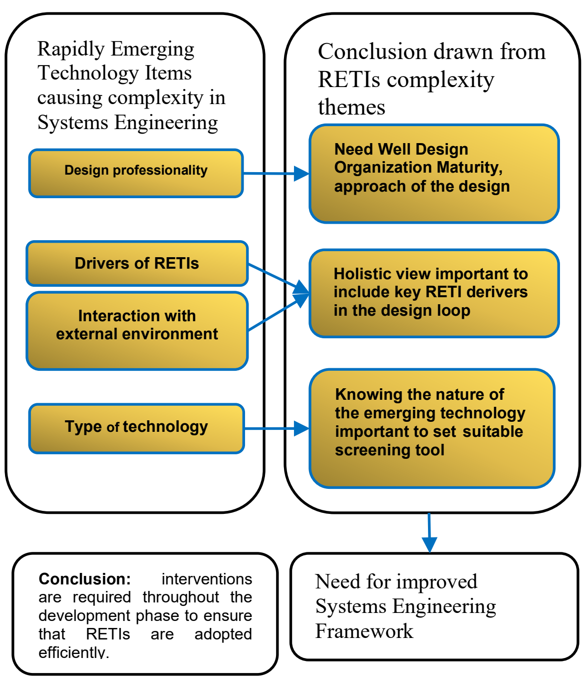
Graphical abstract



Abstract

Requests from stakeholders to include Rapidly Emerging Technology Items into the system under development during the design phase become essential to maintain competitiveness. This paper aims to analyze the effect of adopting the Rapidly Emerging Technology Items (RETIs) during the development process phase of the Systems Engineering approach. Subject matter experts were surveyed with various qualitative questions. Purposeful sampling was used in choosing participants who were "information-rich." Therefore, the individuals and sites selected should be knowledgeable people who have experience in engineering projects' technical and managerial aspects. Referring to the pattern of the data and the author's reflexivity, five themes were identified in this paper, including the problem validation, design professionality, the drivers of the Rapidly Emerging Technology Items (RETIs), the technology type, interaction between the design organization and the RETIs drivers, and the tool for evaluating the rapidly emerging technologies. The analysis of the themes revealed that, due to the adoption of RETIs, the design organization needs to re-define the requirements, re-verify and re-validate the System-Of-Interest (SOI), which leads to longer time in system design and increases the allocated budget. Finally, improvement interventions are required to ensure that RETIs are adopted efficiently throughout the development phase.

Keywords: Systems Engineering, Rapid Emerging Technology Items, Developmental Phase, Design processes, Design Organization.

1.0 INTRODUCTION

New technologies, especially in the aviation industry, are expected to deliver technically feasible, financially beneficial solutions, reduce environmental impacts, differentiate, and increase the value of the end product. Adoption/insertion of the Rapid Emergent Technology Items (RETIs), into the system, during the developmental phase of the system design causes process complexities and remains one of the main challenges facing the systems designers. However, the available Systems Engineering frameworks lack to address the problem related to the insertion of Rapidly Emerging Technologies Items (RETIs) during system development.

In the aviation industry, aircraft are extremely complex products with numerous subsystems, components, and parts. Developing a new aircraft system is a time- and cost-intensive process due to the size and technical complexity of the aircraft, as well as the high quality and safety standards in use. Besides a large number of SOI components, the design process itself faced certain challenges [1]. In the same way, aircraft design is a complex process that takes a long time to complete. A typical aircraft design time frame is shown in Figure 1, according to Kundu [2]. However, the aircraft systems design varies depending on the facilities' readiness, resources, requirements, and program funding and political commitment. Therefore, unlike the automobile industry, aircraft design cycles are measured in decades rather than years [1, 3]. An aircraft is a system made up of interconnected components to achieve a single aeronautical objective. The primary objectives include safe flight at a minimum cost. Aircraft are extremely complex products with numerous subsystems, components, and parts. Many factors influence aircraft conception, design, production, operation, and maintenance, including technical, organizational, financial, and regulatory considerations [4].

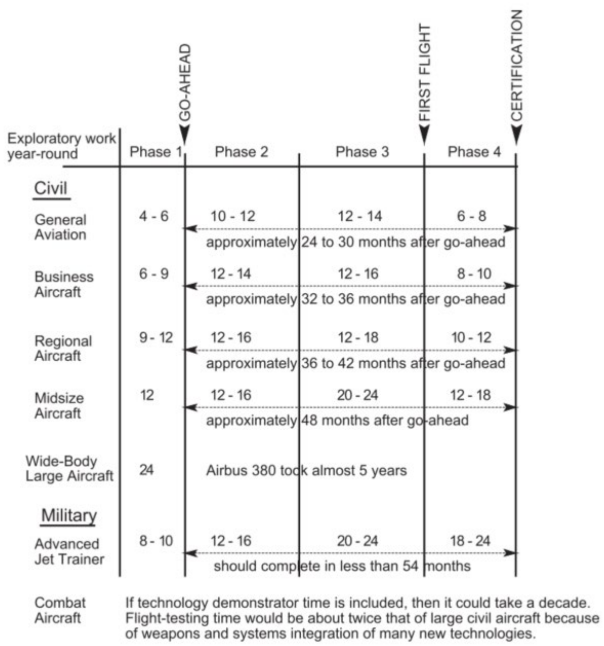


Figure 1 Typical Project Time Frame [2]

The emerging technologies are growing faster, and systems behaviour becomes more difficult to predict and control, resulting in a lack of systems performance [5, 6]. Moreover, new technologies are challenged to deliver lower costs, reduce the environmental impact, differentiate and increase the value of the end product [7].

The International Council On Systems Engineering - INCOSE defined the basic activities of the developmental phase as implementation, integration, verification and validation [8]. And these activities are iterative and take a longer time in the systems engineering lifecycle. Because the development phase is the longest in engineering design processes, any change during this phase leads to re-design of the subsystem/component, re-verification of the specifications, re-validation of requirements, re-evaluation of alternatives, recalculating and re-prototyping models.

The primary goal of this article is to explore the impacts of adopting rapidly emerging technology items during the development phase on Systems Engineering design in the aviation industry.

2.0 METHODOLOGY

Because the expert practitioners are few in systems engineering[9], purposeful sampling is used in choosing participants and sites so that they are "information-rich" [10]. Therefore, the individuals and sites selected should be knowledgeable people who have experience in technical and managerial aspects of system engineering projects.

Merriam and Tisdell [11] define data analysis as "the process of making sense out of the data. And making sense out of data involves consolidating, reducing, and interpreting what people have said and what the researcher has seen and read-it is the process of making meaning". However, there is no single approach to analyze the data [10].

A survey was designed to gather data from subject matter experts within aircraft design and Systems Engineering. This research used a questionnaire to enable the participants to find time to explore and read the entire questionnaire, especially since some of them are working in different locations or on a mission. It is a suitable method for the researcher in the situation of COVID-19 meeting restrictions.

Furthermore, the researcher had an individual discussion with some respondents to clarify some issues related to the adoption of RETIs. This enabled a more direct approach, which increased survey response rates. A qualitative analysis was used to interpret and discuss the results.

The surveys were initially conducted using web-based and mailing methods. The advantage of this approach is that it enables the researcher to reach a large number of individuals [12]. The questionnaire was distributed to 52 responders and sites, and 21 of them responded. Participants included experienced systems engineers from government agencies, private sectors and academia.

3.0 THEMES IDENTIFICATION AND THEORETICAL FRAMEWORK FOR INTERPRETING THE FINDINGS

According to Merriam and Tisdell [11], the researcher could identify the themes by himself to enable him to achieve the research objective. Accordingly, the themes were identified to draw conclusions that may help to study the effects of adopting the RETIs in the developmental phase. The themes were identified based on the features of the theories and Systems Engineering principles, found codes, and researcher reflexivity. Dodgson [13] says, "the majority of the researchers' reflexivity content is contained in the Data Collection and Data Analysis sections".

Six themes were extracted from the data, including:

1. Validation of the research problem. The expected outcome of this theme is to confirm the research gap.
2. Design Professionality. This theme includes the Design Organization's working environment, design approaches the experts use, and respondents' experiences.
3. Drivers of the Rapidly Emerging Technology Items. This theme includes the drivers of RETIs and the reasons for adopting the RETIs in the design during the developmental phase.
4. The Technology Type. The expected outcome of the theme is the types of technology that affect the design process and lead to complexity in the integration process in the form of "technology pull" or "technology push."
5. Interaction between the design organization and the RETIs drivers. This theme explores how the Design

Organization communicates with the drivers of RETIs and through which department.

6. Tool for Evaluation of the Rapidly Emerging Technologies. This theme aims to determine the appropriate technology assessment tool for adopting RETIs.

4.0 COMPLEXITY OF THE RETI ON SYSTEMS ENGINEERING

Although the RETIs was found to be the most influential factor on Systems Engineering during the developmental phase, according to Mahir, Abdelgadir [14] two questions about the effect of adopting the RETIs on engineering systems during the developmental phase have been asked due to the difficulties of RETIs during the developmental phase of the system.

The experts were given a question with several possible answers about what could happen if RETIs were taken into account during the development phase of the Systems Engineering design approach.

Table 1 The effect that RETIs could cause if adopted during the developmental phase

If RETIs are integrated into the system during the developmental phase, it might lead to the following:	Repetition count	Percentage %
re-defining the requirement	9	15.3%
re-definition of Functional Architecture	10	16.9%
re-design the subsystems	13	22.0%
re-verification & re-validation	13	22.0%
instability in the system behavior because RETIs change in deferent rates	6	10.2%
changing the integration strategy	6	10.2%
interruption in the feedback principle	1	1.7%
multi-finality	1	1.7%

The experts' responses in Table 1 came in various selection alternatives, either in the form of multiple-choice or single-choice answers. This range of several results may refer to the experts' various experiences. In general, the findings indicate that the adoption of the RETIs in the system while designing their main systems causes some challenges. These challenges force the Design Organizations to re-design the subsystems, re-define the requirements, re-verify, and re-validate the System of Interest (the main three effects).

The possible explanation that re-verification and re-validation score high reputation in the respondents' answers (22%) is that there are iterations in the processes that lead to tracing back and checking pre-defined requirements for refining the specifications and then updating the system of interest [15]. The verification and validation are processes in the developmental phase [8], and therefore, there is a need to modify these processes to be flexible with RETIs.

Some respondents (1.7%) stated that the integration of RETIs in the developmental phase creates multi-finality. One possible explanation for these multiple finalities is that some of the RETIs may include new features that were not present in the prior item. However, this type of scenario needs to be validated with the requirements to eliminate any undesirable outcomes.

Then, the respondents were asked direct questions about the influence of RETIs on Design Organizations while employing Systems Engineering to design. There are three measures evaluated here, including the complexity of the design process, the design lead time and the cost.

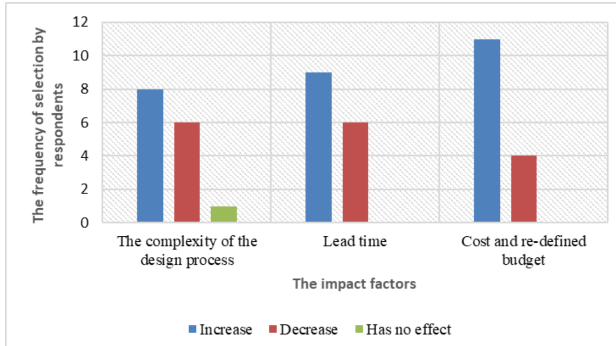


Figure 2 Perceptions of respondents regarding the impact of RETIs on the design processes and design organization

Figure 2 depicts respondents' perceptions of the design processes if the RETIs are integrated into the system being designed within Design Organizations. Generally, the results revealed an increase in the process complexity and the pre-defined time frame and cost as well. However, few professionals indicated a decrease in the criteria under investigation.

The terms "complexities," "challenges," and other synonyms have the same sense based on the reviewed literature. This study constructed descriptions and typologies to explain the complexities and challenges of Systems Engineering. Ultimately, the lead time delay and an increase in the budget are the outcomes of the complexities that occur as a result of implementing the RETIs throughout the development phase of the systems engineering life cycle.

5.0 RESULTS AND DISCUSSION

5.1 Design Professionality

This section summarizes the findings related to the design professionalism theme according to:

a) Respondents' fields of expertise,
b) Respondents' working environment and
c) The design processes used by respondents' organizations.

5.1.1 The Respondents' Fields Of Expertise

Figure 3 illustrates the fields of expertise and the numbers of specialists working in each designated field. It can be seen that the field of the project manager is the most repeated field, accounting for 25% of the total. Meanwhile, Systems Engineering practitioners made up 15.9% which placed them as the second-largest discipline that participated in the survey. In addition, avionics and aircraft conceptual designers formed 22.8% of the total respondents.

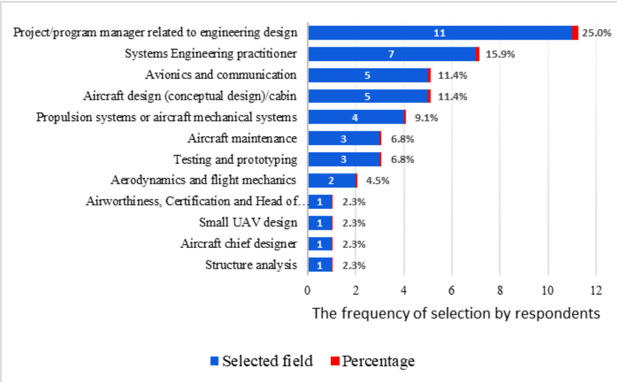


Figure 3 Fields of the participants

Overall, the survey results indicate that project managers and SE practitioners are more than twice those of other disciplines influenced by the effect of adopting the Rapid Emerging Technologies Items (RETIs) in Systems Engineering. This means that the processes related to project managers and SE practitioners are the most influenced by the complexity arising from adopting the RETIs in the development phase.

This finding agreed with Bhise [16] when he stated, "The systems engineers will usually play the key role in leading the development of the product and/or system architecture, defining and allocating requirements, evaluating design trade-offs, balancing technical risk between systems, defining and assessing interfaces, and providing oversight on verification and validation activities. The systems engineers will usually have the prime responsibility for developing many of the project documents, requirements/specification documents, verification and validation documents, certification packages, and other technical documentation."

5.1.2 The Respondents Working Environment

Figure 4 illustrates the design approaches used by the respondents' organizations. 14% of the respondents stated that their organizations were authorized as Certified Design Organizations (CDO). On the other hand, 29% of respondents use their own structured design methods. The remaining 57% stated that their company is undergoing certification approval.

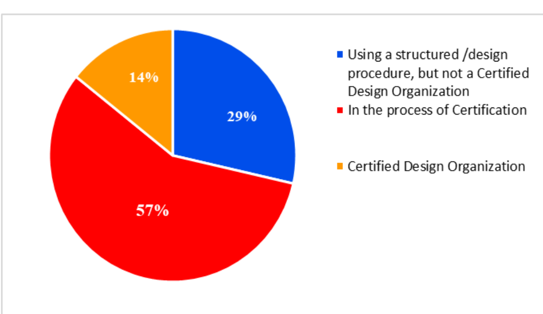


Figure 4 The design approaches of the Design Organizations

5.1.3 The Design Processes

The respondents were asked whether they use a holistic approach in their design process (e.g., systems engineering). And why? The results show that 81 % of the respondents use a holistic approach in their design processes. However, 19% of the respondents said they do not adopt a holistic design approach.

5.1.4 The Interpretation Of The Design Professionalism Theme

The initial analysis of the *Design Professionality* theme indicates that the concept of Systems Engineering is widely implemented in various disciplines. As shown in Figure 3, the respondents are from various disciplines in the Design Organization.

Table 2 was developed to show that several respondents have relevant experience with the Systems Engineering approach. Furthermore, when Systems Engineering practitioners and Project Managers are combined, the total percentage is 40.9%, as shown in Table 2. Their work in SE itself gives valuable perspectives and provides some level of confidence in the data.

Besides the respondents' experiences, the working environment shows that most of the respondents (71%) work in either a Certified Design Organization (CDO) or a Design Organization undergoing Certification approval (well-structured Design organizations). Certified Design Organizations are mature and capable companies with relevant human resources and facilities that enable them to design and validate their product. Evidently, the European Union Aviation Safety Agency (EASA) certifies the company according to its design scope [17]. EASA qualifies the key personnel in the company, including the head of the design organization, the chief officer of airworthiness, and the chief of independent systems monitoring. In addition, the standard procedures also need to be checked and approved by the authorities [17]. These approval requirements by authorities may justify the inclusion of respondents' fields and organizational approaches in this study and justify the grouping of respondents under the design professionalism theme.

Table 2 Quantifying the respondents answers according to the professionalism criteria

Design Professionality theme		Respondents Analysis	
Prof. Factor	**Elements**	**Percentage**	**Accumulation**
Field of Expertise	Structure analysis	2.3%	50.1%
	Aircraft chief designer	2.3%	
	Small UAV Design	2.3%	
	Avionics and communication	11.4%	
	Aerodynamics and flight mechanics	4.5%	
	Testing and prototyping	6.8%	
	Aircraft design (Conceptual design)/cabin	11.4%	
	Propulsion systems or aircraft mechanical systems	9.1%	

Design Professionality theme		Respondents Analysis	
Prof. Factor	**Elements**	**Percentage**	**Accumulation**
	Aircraft maintenance	6.8%	6.8%
	Airworthiness, Certification, and Head of Airworthiness	2.3%	2.3%
	Systems Engineering practitioner	15.9%	40.9%
	Project/program manager related to Engineering Design	25.0%	
Working Environment	Certified Organization	14%	71%
	In the process of Certification	57%	
	Own Structured Process	29%	29%
Design Process	Do you use a holistic approach in design	Yes	81%
		No	19 %

5.2 Drivers Of Rapidly Emerging Technology Items (Retis)

This theme discusses results and findings related to the drivers of RETIs. Firstly, an open-ended multi-choice question was asked to the respondents whether the massive changes in pre-defined requirements and components due to Rapidly Emerging Technologies Items could arise from: Suppliers, regulatory bodies, stakeholders (i.e., Customer, Owner, designer) requests, or others.

Table 3 Percentages of RETIs sources based on respondents' perceptions

Drivers of the RETIs	Suppliers	Stakeholders i.e., customer, Owner, designer	Regulatory bodies
The Percentage	25%	53%	22%

Table 3 represents each RETIs driver as an individual driver, allowing the researcher to determine which technology driver has a greater impact on the processes than other drivers. Knowing the source of the RETI enables the researcher to conduct in-depth investigations into the behavior (approach technology development or R & D method) of RETI drivers and how to include these sources in the design framework.

The findings could be summarised in the following points:

a) The requests of stakeholders to adopt the RETIs during the developmental phase of design by Systems Engineering cause complexity at a higher rate (53% of the respondents said).

b) The request of the suppliers to adopt the RETIs during the developmental phase of design by Systems Engineering causes complexity at a rate less than stakeholders' requests (25% of the respondents said).

c) The request of regulatory bodies to adopt the RETIs during the developmental phase of design by Systems Engineering causes complexity at the lowest rate compared to other types of requests (22% of the respondents said).

Moreover, the multiple-choice and open-ended questions explore why design organizations should respond to the requests to adopt the RETIs during the developmental phase. Table 4 summarizes the respondents' comments on this matter. Table 4 Comments of the respondents on adopting RETIs during the developmental phase.

Table 4 Justification for adopting RETIs

Reasons	Percentage
For better performance	13%
Respond to customer requirement	25%
Sustain the competition advantages	23%
To be cost-effective	15%
To strengthen safety and provide high-quality products	15%
All of the above	5%
depends on emerging technologies and a holistic overview.	13%
To explore new possibilities and new options	13%
Total	100 %

The justifications given in Table 4 explain the reasons for adopting the RETIs during the developmental phase of system engineering. Forty answers were collected in total to show the reasons for adopting RETIs, including the open-ended answers. According to 10 (25%) of the professionals, the most important reason for adopting the REITs in the design framework is to meet customer requirements. The second reason is to sustain competitive advantages, as evidenced by 9 (23%) of the respondents. Meeting customer requirements and sustaining competitive advantages account for 47.5% of all responses, supporting the need for a technique to reduce the complexity associated with adopting the RETIs within the Design Organization. Three reasons, including better performance, being cost-effective, and strengthening safety, form about 42.5% of the total answers, and they reflect the technical, economic, and safety aspects.

5.2.1 Interpretation Of The Drivers Of Retis Theme

This section discusses the relationship between the three drivers of RETIs and the reasons for adopting RETIs during the developmental phase into the system being designed.

Firstly, the findings in Table 3 reflect that the stakeholders' requests are the main drivers for adopting the RETIs during the developmental phase. A possible explanation for this might be that the Stakeholders include people with various roles and responsibilities in the design process, such as designers, systems engineers, decision-makers, and end-users. These stakeholders have the right to request that a particular RETIs be adopted during the developmental phase for various reasons. Therefore, it is likely that such a connection exists between the RETIs drivers and the reasons for requesting them. There are several reasons related to stakeholders' requests for adopting RETIs during the developmental phase, such as responding to customer requirements, sustaining competitive advantages, and being cost-effective. There is a rationality for grouping those reasons to justify the stakeholders' requests because they reflect the ideas of stakeholders' needs (such as customer request change or designer request for upgrade) and reflect the reasons related to a design organization's performance (such as cost-effective reasons and competitive advantages).

Secondly, regarding suppliers as external drives for adopting RETIs during the developmental phase, there are reasons related to their ongoing research and development that may result in a radical shift instead of incremental development for RETIs. The reasons correlated to suppliers' requests are more related to technical issues and indicated by the better performance of the items as an individual. However, if the holistic principle is applied, the benefits of individual RETI will improve the technical performance of the entire system.

Thirdly, the findings on regulatory authority as a driving force for RETIs during the developmental phase were linked with safety criteria that may enhance system use safety or related to environmental issues.

5.3 Technology Type

This theme discusses the several types of technology provided by RETI's drivers. Table 6 highlights three types of RETIs technologies related to RETIs drivers that lead to complexity in the design processes and integration of such technologies during the developmental phase. Table 6 Technology Type requested by RETIs Drivers

Table 5 Styles of technology type observed in RETIs correlated with their drivers

Technology Type (Drivers)	Percentage
Technology Pull (Supplier R&D)	62%
Technology Push (Stakeholder (designer)	24%
Technology Push (Regulatory bodies)	14%

Almost 62% of the respondents indicated that the complexity arising from technology pull is caused by Supplier R&D. Approximately 24% of experts agreed that the technology push requested by the designers (one of the stakeholders) increases the complexity of the design process during the developmental phase. Nonetheless, only 14% of the respondents indicated that regulatory bodies through technology-push cause complexity in the design process when asked to adopt the RETIs during the developmental phase.

5.3.1 Interpretation Of Technology-Types Theme

The significance of this theme stems from identifying the philosophies behind the type of technology. For example, technological pull, also known as market-pull recently, emphasizes that this type of technology pulls the SOI in the direction of the market trend. The stakeholders would continually seek to incorporate new technology into their SOI, for example, fuel consumption or Natural Laminar Flow (NLF) control. The NLF technology is still being developed, and recent tests on the A340 revealed a 4.6 percent reduction in fuel usage [18]. In this case, the advantages of rapidly emerging technologies developed during the development phase encourage decision-makers to include them in the SOI.

Usually, the technology types may become interchangeable and may lead to confusion regarding who pushes and who pulls. To avoid this dilemma, this study considered technologies produced by outside Design Organization suppliers as "technology pullers" or "market pull."

The study revealed that approximately 62% of the "technology pull" emerges from the R&D of the suppliers. A possible explanation for this percentage is that the design organizations typically identify the supplied technologies during the early design phases and sign contracts with multiple suppliers for the various subsystems or components. Then, as the system evolves, the suppliers produce new technology that may be appropriate for this system.

Usually, in the aviation industry, suppliers are familiar with the aviation industry's needs, such as lighter-weight items, small size, environmentally friendly items, etc. Therefore, it is essential to analyze the source and needs of RETIs before integrating them into the design processes to leverage their product advantages in SOI and avoid design process delays.

On the other hand, the technology push mentioned earlier is driven by the stakeholders and the regulators. The results in Table 6 revealed that the technology push accounts for 38% of all RETIs. The reasonable interpretation of this low percentage of the technology push compared to the technology pull is that the internal stakeholders and regulatory bodies may request fewer RETIs because the designers and systems engineering practitioners try to execute the project within the pre-defined schedule and budget. However, the customer may ask for novel technologies or items to be integrated during the detailed design for specific items.

Furthermore, Market pull/technology pull is more likely associated with novel and unexpected technologies. Based on the competitive environment of suppliers, these findings were interpreted as meaning that they always need to keep up with the state of the art, such as in the aviation industry. Because prospective suppliers are specialized and limited in certain disciplines, their R&D teams are always working to produce technologies in a way that enhances the technical performance of the end product, i.e., the system is being designed.

It is possible that some RETIs specifications are completely unknown to the design organization and require extensive verification and validation (V&V) after the integration process. And some RETIs make significant changes to the SOI, for example, a change in the configuration of the platform or recalculation of weight distribution in the aircraft design, but they are worthy of consideration.

As mentioned in this study, some researchers linked the technology pull with radical technologies, for example, Collopy [19] said that "Radical technologies and aircraft designs created in response to military capability needs (technology pull) have enabled the development of major advances in commercial aircraft technologies." On the other hand, technology push is more related to the incremental development of items or subsystems and needs an effort to be integrated into the SOI.

The interpretation of the theme of technology type findings agreed with some of Mr Schmidt [20] findings where he states that the "business has changed from a technology push to a technology pull for affordable technology. Newer technologies are emerging from the consumer electronics, communication, and information industries".

Despite this, there is no strong evidence that there is a link between the technology-push and incremental technology development; rather, the technology pull is linked to radical technological shifts.

Summary of the technology-type theme:

a) 62% of RETIs were requested by the suppliers as technology-pull to be implemented in SOI. Furthermore, these technologies were usually requested as radical or novel technologies. This finding supports the screening process in selecting filtering questions suitable for adopting quick radical technology in the development phase. Screening also seeks to evaluate the maturity of this new technology to be integrated into the SOI.
b) 38% of RETIs were requested by the organization internal stakeholders and the regulatory bodies as part of a technology push. Although this technology push is more related to incremental technology, some of these technologies still emerge through the developmental phase and need to be considered for essential reasons.

4.0 CONCLUSION

The respondents' experiences in a variety of fields related to system design within well-established organizations support the validity of the collected data, and perspectives on the answers substantiate the findings' reliability. Due to the adoption of RETIs in the developmental phase, the design organization is confronted with issues such as re-defining requirements, re-verifying and re-validating the SOI. Generally, the results indicated an increase in the complexity of the design processes, the pre-defined schedule, and the allocated cost as a result of adopting RETIs in the developmental phase.

Furthermore, several reasons, including better technical performance, strengthening the safety of the end product, and sustaining the competitive advantages of the design organization encourage the stakeholders to consider RETIs for use in the system being designed during the development phase.

To ensure that RETIs are adopted effectively during the developmental phase, interventions are required throughout the development phase. These interventions could be in terms of developing a single source of truth for exchanging reliable information and establishing a proper screening method to ensure the maturity of the RETIs and that they could effectively be adopted into the system being designed.

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