Vol 2, No.3 (2022)

International TVET Academic and Research Symposium ITARS (2022)

ITARS 2022

Excellence in TVET and Entrepreneurship

Organiser:

PUSPANITA CAWANGAN KECIL JPPKK

Co-organiser and Publisher:

PERSATUAN KEDOKTORAN TEKNIKAL MALAYSIA
MALAYSIAN TECHNICAL DOCTORATE ASSOCIATION

e ISBN 978-967-18231-1-8

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ISBN 978-967-18231-1-8 (e-book)
Front cover image by PKTM
e-book design by PKTM

First e-book edition July 2020
Second e-book edition April 2022

Persatuan Kedoktoran Teknikal Malaysia (PKTM)
No 64, Persiaran Wira Jaya Barat 40,
Taman Ipoh Jaya Timur 1, 31350 Ipoh,
Perak.
http://www.pktm.org

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A CONCEPTUAL DESIGN OF AN EXTENDABLE AIRCRAFT PASSENGER ARMREST USING THE TECHNIQUE OF ORDER PREFERENCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS)

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Abstract

Nowadays air transportation mode become more accessible to most people around the globe due to the affordability of purchasing flight ticket at cheaper price. The penetration of the low-cost carrier airline into the aviation industry sector has becoming more competitive in order to cater more passengers onboard per flight on the designated route. Consequently, most of the airliners has taken a proactive approach to modify the cabin space configuration by installing more passenger seats in order to cater the increasing number of passengers. Thus, this has led to discomfort travel experience due to the uncomfortable aircraft passenger seat on the economy class cabin. Speaking of which, one of the elements that contribute towards this negative feedback is due to the unpleasant feeling of sharing the aircraft passenger armrest with the adjacent passengers on the economy class cabin. Having said that, this paper enlightens on the conceptual design of the aircraft passenger armrest which incorporate important features such as a middle separator, width and length extension and height parameters to resolve the issue pertaining passenger comfort, privacy and personal space. Furthermore, throughout this paper, a formulation of design concepts that comprises of several stages which involved design requirements, design concepts generation and lastly an evaluation and development of the design concepts. In relation to this, few selected design tools such as a questionnaire survey, Pareto Diagram, Quality Functional Deployment (QFD), Morphological Matrices, Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) and Sketch-up Software has been utilized and explained throughout this paper. Following the evaluation process using TOPSIS, a third design model out of 5 design concepts generated has been chosen based on its TOPSIS Closeness Rating Value = 0.850 as the most optimum design solution and hopefully this design will elevate passenger comfort level of economy class cabin.

Keywords: Aircraft armrest, ergonomic design, Quality Functional Deployment (QFD), Morphological Matrices, Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

1. Introduction

International Air Transport Association (IATA) throughout its annual report review in 2019, the number of scheduled air passengers has been tremendously increased starting from year 2000 with approximately 1.5 billion air passenger per year up to nearly 4.5 billion air passengers in year 2018. Additionally, this positive increment in air transportation demand over the years witnessed the frequency of subsequent flight trip has significantly increased and number of months before next trip is halved of that in year 2000. Furthermore, according to the survey conducted by World Air Transportation Statistics (WATS) in 2019, the key factors that contribute to this positive scenario is due to cheapest air fare that is being introduced by the low-cost carrier airline in this recent year. Furthermore, the flexibility of direct flight that offered by the airline has attracted more passengers to take this advantage and save their time of travelling.

1.1 Problem statement

Liu, Yu, Chu and Gou (2017) summarise with the increasing demand in air transportation, aviation industry has becoming more competitive in order to accommodate and fulfill passenger's expectation while offering such affordable flight ticket at cheaper price. Most of the international airline around the globe has significantly increased a total number of aircraft passenger seats for the same designated aircraft. Conclusively, on average, most of the airlines had taken initiative to increase the capacity of aircraft passenger seats per cabin up to 11.5% in 2015 than that of year 2009 for the same type of aircraft. Following the increment of the aircraft passenger seats that cramped in the economy class cabin, the aircraft passenger seats must be modified accordingly which include the reduction in size of seat pitch, seat width, aisle width and armrest width (Vanessa, 2014). The reduction of aircraft passenger seat particularly on the economy class cabin has significantly introduced discomfort travelling experience as mentioned by Global Passenger Survey (GPS) throughout their survey conducted in 2018 pertaining traveler's biggest complaints about air travel. Particularly, Divya (2016) highlights that one of the elements which contribute to this negative feedback is the shrinkage of the armrest width despite the uncomfortable feeling of sharing the same armrest with the adjacent passengers.

1.2 Project objectives

i. To obtain the design requirements of the Extendable Aircraft Passenger Armrest determined by the commercial aircraft passengers throughout survey questionnaire.
ii. To formulate the conceptual designs of the Extendable Aircraft Passenger Armrest that meet customer's expectation.
iii. To evaluate the optimum design and develop the model of the selected design using the appropriate engineering design tools.

2. Literature review

2.1 Prior art search

Table 1: A list of armrest designs.

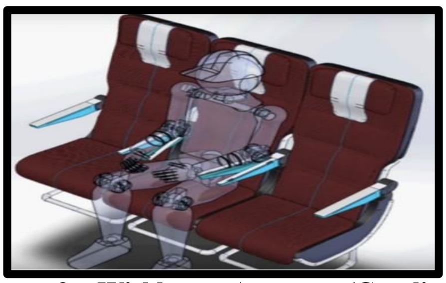
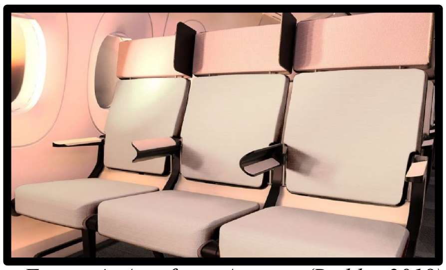
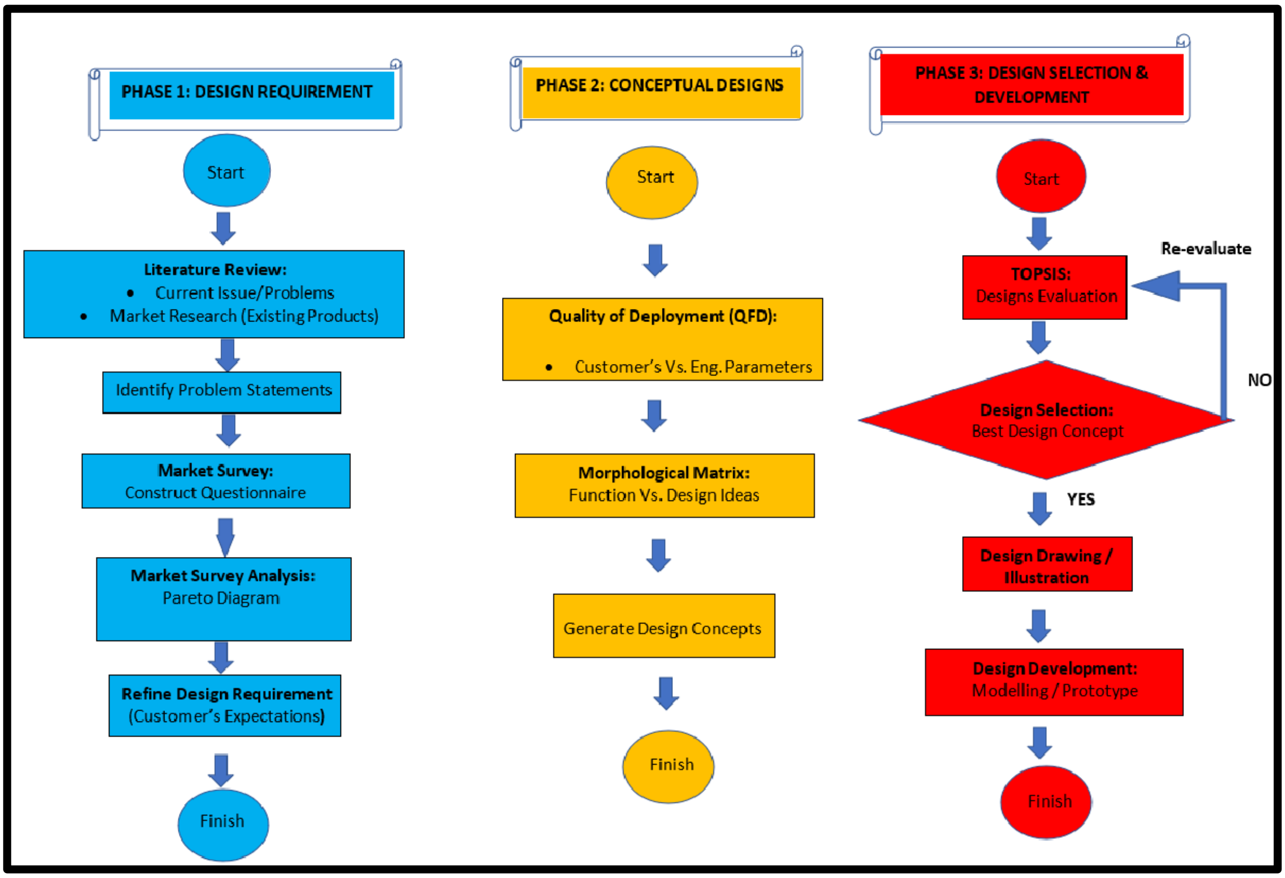
No.	Multiple design of aircraft passenger seat armrest.	
1.	 **Figure 1: Soarigami Armrest (Barry N., 2014).**	**An award-winning armrest design so called as Soarigami invented by Grace Chang and Arthur Chang in 2016 incorporates a paper plane soarigami model. This elegant and portable armrest design is made from 100% recyclable material to support eco-friendly element on its innovation. This look-alike paper plane armrest design incorporates two features mechanism such as expansion and retraction of its side "wings" in order to increase the armrest width and supported by the existing armrest underneath. Furthermore, this simple and elegant design of the armrest comes with the middle separator in between to increase the privacy and personal space between adjacent passengers.**
2.	 **Figure 2: Paper Clip (Alex D., 2014).**	**An elegant and sleek design of the armrest called Paper Clip is invented by James Lee in 2015. As the name implies, the armrest design is being inspired as simple as a standard paper clip design used in a stationery work. It is constructed with two different staggering level of the armrest, which the lower section has a longer armrest length in comparison to the upper section that has shorter armrest length. This innovative armrest design can be incorporated to the aircraft passenger seat assembly and passenger does not have to bother to bring this along onboard while travelling on the aircraft.**
3.	 **Figure 3: Wishbone Armrest (Caroline K., 2016).**	**Wishbone armrest design which inspired by Michael Cummins in 2016 incorporates extension and retraction mechanism of the armrest. Wishbone design featuring an armrest that can be extended and split inwards into two parts. At this position, the passenger has the flexibility to adjust the angle of extension of the armrest to suit with personal preference and comfort level.**

Table 1: A list of armrest designs (continue)

No.	*Multiple design of aircraft passenger seat armrest.*	
4.	 *Figure 4: Aerofoam Armrest (Reddit, 2018).*	*CSM Aerofoam company has successfully conceptualised their armrest design in 2018 so called as Aerofoam armrest. The sleek design of the armrest incorporates two different shapes which are concave and convex shape onto its armrest handle. This unique and sleek design allows adjacent passengers to lay down their arms on the upper and lower section of the armrest at certain tilting angles. As the name implies, Aerofoam armrest has been furnished with extra cushioning on its upper surface in order to increase the comfort level of the passenger.*

3. Methodology

Figure 5: Overall project flowchart.

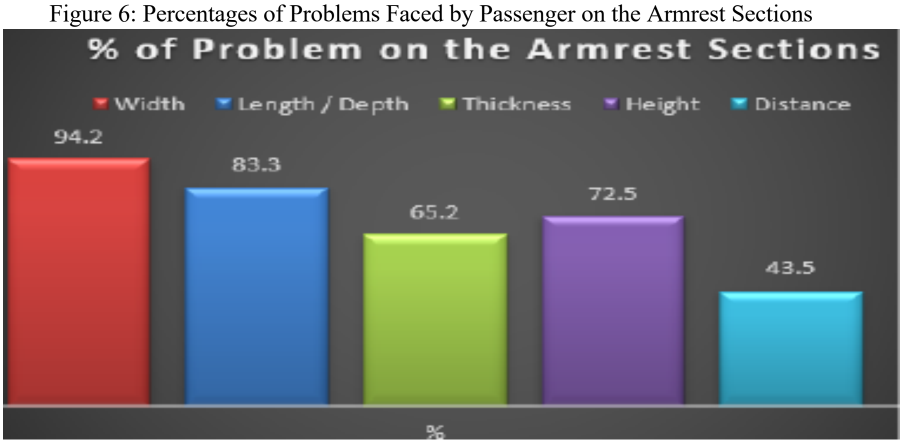


As depicted in Figure 5, a conceptual design process of the armrest comprises of three (3) distinct important stages which includes Phase 1: Design Requirement Analysis, followed by Phase 2: Formulation of Conceptual Design, Phase 3: Design Concept Evaluation and Design Concept Development. At initial stage of the process, design requirement will involve literature review pertaining to aircraft passenger armrest issues and latest innovative related products, establishment of the problem statement clearly, construction of a questionnaire survey and distribution to a targeted group of respondents and construction of a Pareto Diagram. Subsequently, the formulation of the conceptual design for the armrest includes a translation of customer's requirement into engineering parameter using Quality Function Deployment. Once set of engineering parameters has been established, a Morphological Matrices will be constructed to generate various ideas and possible design concepts of the armrest. At final stage, design evaluation incorporates method of selection of the design concepts using Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) approach and a conceptual design based on the selected concepts will be illustrated using appropriate tools.

4. Finding and analysis

4.1 Questionnaire survey

Figure 6: Percentages of Problems Faced by Passenger on the Armrest Sections



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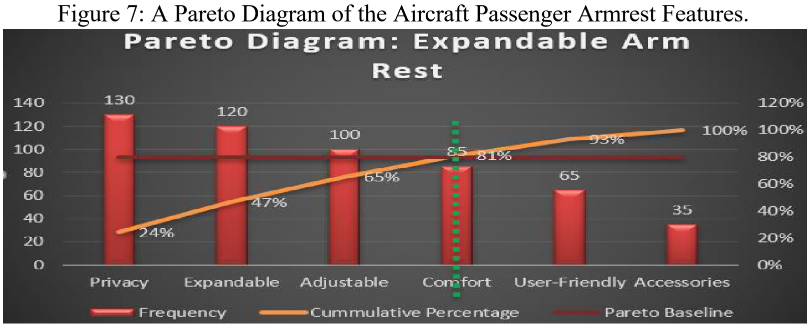
In order to really understand the problem faced by the aircraft passenger particularly who boarding on the economy class cabin, a set of questionnaire survey can be used to reach targeted respondent and collect required data to identify design requirement of the armrest. A questionnaire survey comprises of four (4) different sections has been constructed and disseminated to a targeted user which had experience flown on the economy class cabin previously. The first section of the questionnaire comprises of respondent's demographic, second section involved user's flying experience, third section is critical since it identify and measures a real problem faced by the passenger when using the armrest and final section of the questionnaire involved product features development on the existing armrest. As depicted in Figure 6, most of the passengers had a major problem on the armrest width with 94.2%, followed by the armrest length or depth with 83.3% and as much as 72.5% agreed that they had problem on armrest height. Obviously, it can be interpreted that only 43.5% who had a minor problem on the armrest separation distance.

4.2 Pareto diagram

Figure 7: A Pareto Diagram of the Aircraft Passenger Armrest Features.



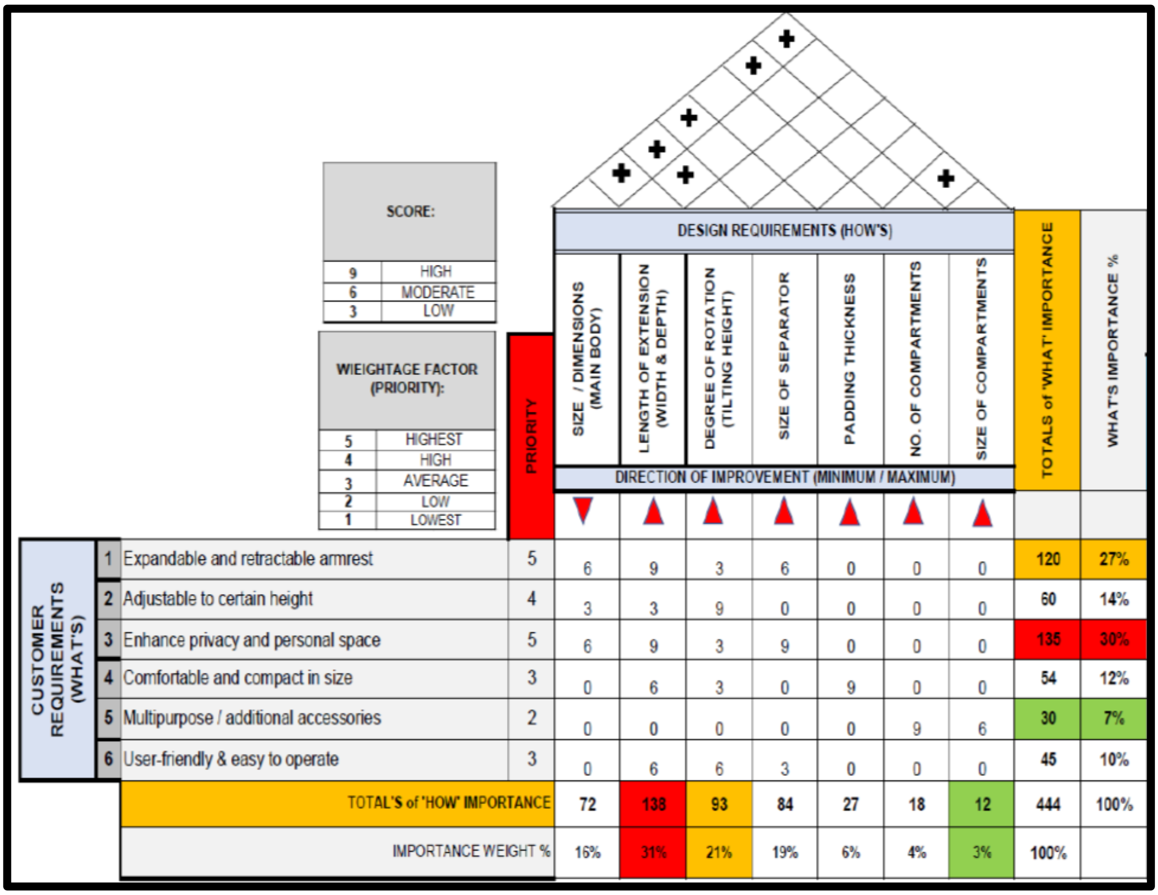
Clearly as depicted in Figure 7, a Pareto Diagram has been constructed following a data collection from a questionnaire survey previously. In relation to the questionnaire conducted previously, the frequency of the armrest features has been arranged in descending order which privacy became the highest frequency, subsequently followed by expandable, adjustable, comfort, user-friendly and lastly accessories. As referred to the Pareto

Diagram, Privacy feature has become the top priority of concern since it has the maximum score of its frequency, 130 out of 535 cumulative score. A Pareto baseline which intersected the line graph at 80% which dictate the following features such as privacy, expandable, adjustable and comfort to be priority features in design concept generation at later stage.

4.3 Quality Function Deployment (QFD)

Quality Function Deployment or simply known as House of Quality (HoQ) has been utilised which translate customer's requirement into corresponding engineering parameters. It highlights the importance of the design requirement by introducing a proper weightage and correlate those requirements to a set of corresponding technical parameters that are identifiable and measurable. Based on the QFD diagram, related design requirements or engineering parameters which is measurable have been assigned accordingly in relation to the attributes or features defined by the customers. They were seven (7) measurable design parameters that have been included such as size/dimension of the main body, length of extension, degree of rotation, size of the separator, thickness of the padding, number of compartments and the last one is size of the compartments. Significantly, the length of extension of the armrest with its score of 31% is the most important design parameter that must be considered for the design concept of the armrest. Subsequently, degree of rotation or height adjustment of the armrest seems to be quite significant with its score of 21%. Furthermore, the size of the main body and the size of the separator were quite important to be considered as well in design phase later since their percentage score were approximately half of the score for the maximum one. All in all, most of the customer's requirements is strongly influenced by these two parameters which is the length of the extension and the degree of rotation, hence, these two design parameters were quite significant and must be included later in a design phase.

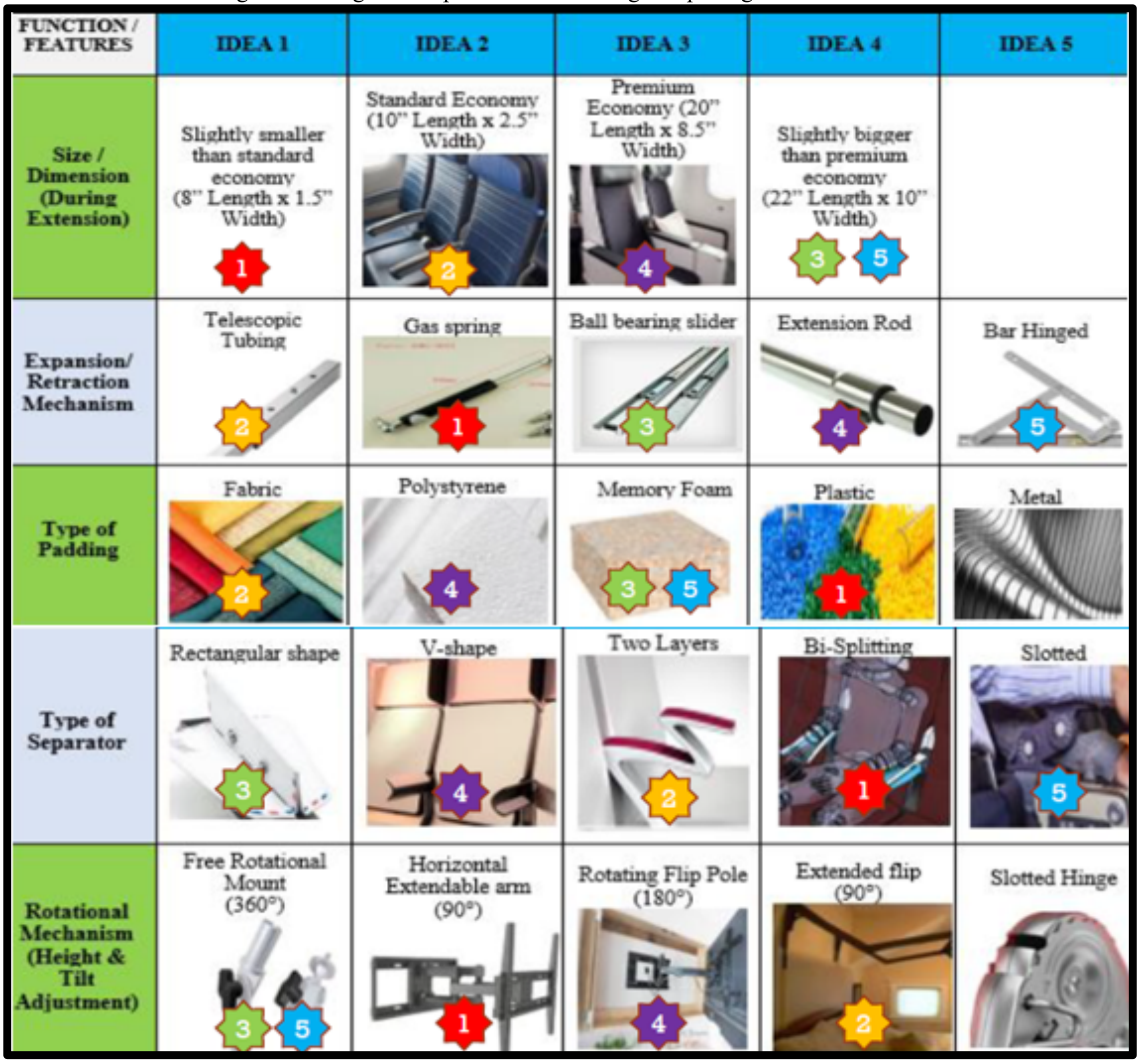
Figure 8: A Pareto diagram of the aircraft passenger armrest feature.



4.4 Morphological Matrices

Following a Quality Function Deployment constructed at previous stage, selected and prioritised customer's requirement and engineering parameters will be included in a Morphological Matrices. This tool is used to aid in design concept generation which various ideas of design solution for each parameter will be arranged in a matrix form and the combination of the ideas are randomly mixed up to produce at least five (5) relevant or alternative design concepts that matches the design solutions (Derek, 2020).

Figure 9: Design Concepts Generation using Morphological Matrices.



4.5 TOPSIS evaluation

TOPSIS is one of the decision-making aid tools that works on the mathematical model or quantitative approach which emphasizes on the shortest or longest geometrical distance towards either positive or negative ideal solution (Zeynep, 2018). It consists of few designated steps starting from a construction of decision matrix up to a calculation of the separation distance which lead to the ranking of the possible alternative ideal solution. At this final stage, TOPSIS evaluation is used to filter and assess five (5) design concepts that exhibit optimum alternative design solutions which has a potential to be brought forward for the final design concept of the armrest. The selection of the design concept must incorporate important parameters or attributes that have been highlighted in the Morphological Matrices previously and meet customer's requirement or expectation as mentioned in the matrix-correlation of a previous QFD. As depicted in Table 2, a step-by-step procedure on how the TOPSIS evaluation is being carried out towards the selection of the most optimum designs of the armrest.

Table 2: TOPSIS evaluation process.

Step 1: Decision matrix

CONCEPT/CRITERION	Size	Mechanism	Comfort	Privacy	Flexibility	Multifunction	Ease of Use
Concept 1	1	1	2	2	2	3	2
Concept 2	2	2	2	2	2	2	2
Concept 3	3	3	3	3	3	2	3
Concept 4	2	3	2	3	2	3	2
Concept 5	3	2	3	2	3	2	3

Step 2: Quantify qualitative dimension

CONCEPT/CRITERION	Size	Mechanism	Comfort	Privacy	Flexibility	Multifunction	Ease of Use
Concept 1	3	3	6	6	6	9	6
Concept 2	6	6	6	6	6	6	6
Concept 3	9	9	9	9	9	6	9
Concept 4	6	9	6	9	6	9	6
Concept 5	9	6	9	6	9	6	9

Step 3: Normalise dimension

CONCEPT/CRITERION	Size	Mechanism	Comfort	Privacy	Flexibility	Multifunction	Ease of Use
Concept 1	0.19245009	0.19245009	0.365148372	0.365148372	0.365148372	0.547722558	0.365148372
Concept 2	0.384900179	0.384900179	0.365148372	0.365148372	0.365148372	0.365148372	0.365148372
Concept 3	0.577350269	0.577350269	0.547722558	0.547722558	0.547722558	0.365148372	0.547722558
Concept 4	0.384900179	0.577350269	0.365148372	0.547722558	0.365148372	0.547722558	0.365148372
Concept 5	0.577350269	0.384900179	0.547722558	0.365148372	0.547722558	0.365148372	0.547722558

Step 4: Weightage factors

Weightage	0.20	0.1	0.10	0.2	0.2	0.10	0.10
	Size	Mechanism	Comfort	Privacy	Flexibility	Multifunction	Ease of Use
Concept 1	0.038490018	0.019245009	0.036514837	0.073029674	0.073029674	0.054772256	0.036514837
Concept 2	0.076980036	0.038490018	0.036514837	0.073029674	0.073029674	0.036514837	0.036514837
Concept 3	0.115470054	0.057735027	0.054772256	0.109544512	0.109544512	0.036514837	0.054772256
Concept 4	0.076980036	0.057735027	0.036514837	0.109544512	0.073029674	0.054772256	0.036514837
Concept 5	0.115470054	0.038490018	0.054772256	0.073029674	0.109544512	0.036514837	0.054772256

Step 5: Positive & negative ideal solution

	+ve	+ve	+ve	+ve	+ve	+ve	+ve
	Size	Mechanism	Comfort	Privacy	Flexibility	Multifunction	Ease of Use
Positive ideal solution	0.115470054	0.057735027	0.054772256	0.109544512	0.109544512	0.054772256	0.054772256
Negative ideal solution	0.038490018	0.019245009	0.036514837	0.073029674	0.073029674	0.036514837	0.036514837

Step 6: Separation distance

S1 (positive) =	0.103637545	S1 (negative) =	0.018257419
S2 (positive) =	0.074286732	S2 (negative) =	0.043033148
S3 (positive) =	0.018257419	S3 (negative) =	0.103637545
S4 (positive) =	0.059004080	S4 (negative) =	0.068041382
S5 (positive) =	0.045133547	S5 (negative) =	0.091084007

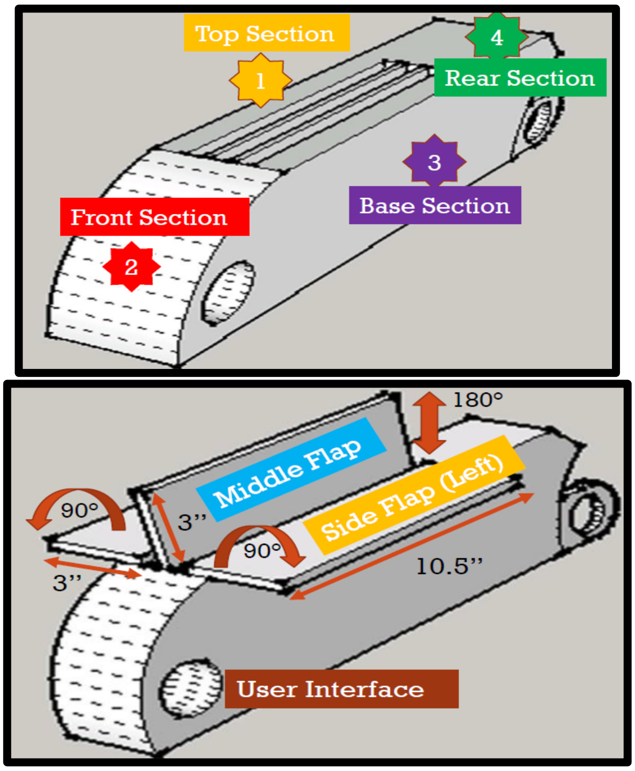
Step 7: Closeness rating & alternatives ranking

Concept 1	0.149779926	Concept 1	#5
Concept 2	0.366801844	Concept 2	#4
Concept 3	0.850220074	Concept 3	#1
Concept 4	0.535567195	Concept 4	#3
Concept 5	0.668665708	Concept 5	#2

Conclusively, from the TOPSIS evaluation, it can be clearly verified that Design Concept 3 out of 5 design concepts in total has a maximum value of Closeness Rating of 0.85022, followed by design concept 5, design concept 4, design concept 2 and lastly design concept 1 that obtained the minimum value of Closeness Rating of 0.14978. From here, it can be deduced that design concept 3 is the most optimum alternative design solution since its geometrical distance to the positive ideal solution is the closest and at the same time its geometrical distance to the negative ideal solution is the farthest in comparison to the other design concepts generated (Zlatko & Vederan, 2013). In relation to the project objectives stated, the Expandable Aircraft Passenger Armrest or design concept 3 addresses all customer's requirement in Pareto Diagram and QFD such as privacy, comfort, flexibility, adjustable and user-friendly. Furthermore, the design concept of the armrest incorporates ergonomic element which helps to elevate passenger comfort level and personal space especially when using the aircraft passenger seat of the economy class cabin (Jordi, Gonzalo, & Maria, 2019).

4.6 Conceptual design of the armres

Figure 10: An illustration of the extendable aircraft passenger armrest in stowage position (left) & fully extended position (right).



In order to come out with the conceptual design of the armrest, an illustration of the selected design concept 3 has been developed using Sketch-up Software in order to improve a level of understanding on the conceptual design of the selected concept (James, 2019). The Extendable Aircraft Passenger Armrest consists of four (4) main sections namely front, top, base and rear section. The armrest design incorporates most of the features highlighted in the Morphological Matrices and meet the passenger's requirement such as privacy, comfort, flexibility and ease of use. The top section of the armrest consists of three (3) different slots which is a stowage compartment of the middle flap and two side flaps. The middle flap is in the middle slot on the top section of the armrest meanwhile the side flaps are located left and right section to the middle flap. The main function of the middle flap is to create a barrier of partition in between adjacent passengers and thus improve the privacy of the passenger. It can be lifted upwards 180 degrees and being extended as much as three (3) inches vertically upwards from the top surface of the armrest. Passenger can simply lock its position and push it downwards for easy storage back into its slot.
Furthermore, two side flaps, left and right position can be individually extended from its stowage compartment ninety degrees from the middle flap. In extension mode, side flap can be fully deployed as much as three (3) inches from its original position to give extra space for supporting passenger's elbow and forearms comfortably. Moreover, the side flap can be extended in length up to 10.5 inches in order to fully support the length of the forearm up to wrist section of the passenger. Besides that, a rotational mount which support 360 degrees of rotation is installed on the side flap to improve flexibility and allow height adjustment of the side flap to support passenger preference with different anthropometric dimension (Kirk & Corlett, 1978).

5. Conclusion

Throughout this paper, a conceptual design of the Extendable Aircraft Passenger Armrest has been clearly established and developed using appropriate design tools. A conceptual design of the aircraft passenger armrest can be summarised as follows:

i. The first phase of the conceptual design involves design requirement analysis. Throughout this stage, three (3) important design tools initially used such as questionnaire survey, Pareto Diagram and QFD. At this initial stage, it is very important to really understand and investigate a root problem pertaining aircraft passenger armrest. Furthermore, the application of Pareto Diagram highlights the important features that need to be considered in a design stage. The application of QFD is undeniably important since it translate and correlate passenger's requirement into a measurable and attainable engineering or technical parameters.

ii. Following a detail analysis on the design requirement of the armrest, a Morphological Matrices has been fully constructed to generate various possible idea of solutions. Particularly, five (5) different of ideas has been successfully generated which related to each of the design attributes or parameters. Furthermore, in order to come out with a conceptual design of the armrest, five (5) different unique combinations of design concepts have been successfully generated using Morphological Matrices.

iii. Finally, at this final stage, all design concepts that have been generated previously using Morphological Matrices will be carefully filtered and evaluated using TOPSIS approach. It is important a set of criteria used in the TOPSIS closely related to the design attributes highlighted at previous stage. Throughout TOPSIS analysis, a design concept 3 appeared to be an optimum alternative solution of the armrest which incorporates features or attributes that is needed and development of the conceptual design of the armrest has been illustrated using Sketch-up Software.

Acknowledgement

In the name of Allah SWT, the Most Gracious and the Most Merciful. Special thanks to my colleagues from Politeknik Banting Selangor and collaborators from University Putra Malaysia for their effort and endless commitment to contribute in this research paper.

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