

## Passenger Seat Design and Analysis for Railway Executive Transportation

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### Abstract

The design of executive chairs for trains was carried out to improve safety, comfort and aesthetics of the train. Seat design innovation was made by prioritizing passenger comfort and paying attention to the S curve of the passenger's spine. This research carried out a redesign of the Indonesian railway executive chair with the added advantage of a chair that can be tilted up to 40° from the initial position of 10°. After the design concept is selected, a simulation will be done on three critical parts of the train seat including chair frame, footrest, and footrest frame. According to investigation, there are facilities tailored to user needs, starting from a folding table, middle arm rest, reclining seat 40°, rotate system 180°, and footrest. The mechanism used for reclining seats with the help of a gas spring to adjust the backrest and a rotate system mechanism with plate bearings. Thus, the seat can be adjusted to the direction of the train's advance. The final chair dimensions of 1101×1091×632 mm and material ASTM A36, polypropylene, rubber.

**Keywords:** executive chairs; innovation; reclining; rotate.

### 1. Introduction

Indonesia is the fourth most populous country in the world with a population reaching 270.20 million people in 2020 [1], [2]. With such a large population, adequate means of transportation are needed to be able to move people from one place to another quickly and safely. Community transportation modes other than private transportation are public transportation such as taxis, buses and trains [3].

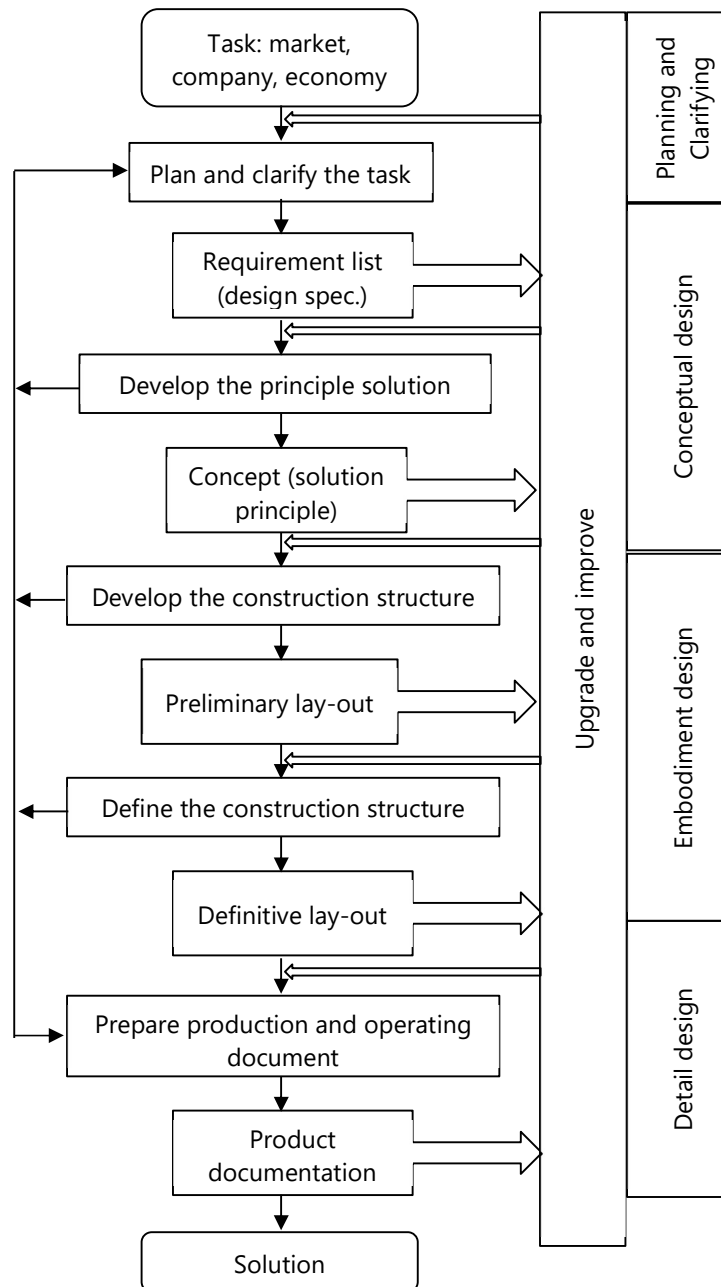
Going or commuting by train is one of the solutions people can choose. They choose train since it has series or carriages that are relatively large in size so that they can accommodate and transport passengers or goods on a large scale [4]. Trains are currently one of the favorite modes of transportation in Indonesia [5]. With relatively more affordable prices for long-distance modes of transportation, currently many Indonesians take trains as a mode of transportation.

The redesign method that has been achieved by Jazilah et al. [6] on the study using the ergonomic function deployment (EFD) method produces new measurements, to be precise: seat height 31 cm, seat depth 40 cm, seat width 51.2 cm, seat backrest height 54.8 cm, backrest angle 110°-130°, armrest height 24.6 cm, legroom 55.7 cm, seat pitch 110.7 cm. The method used in this study refers to the VD12221 standard. Moreover, the executive train seats above are a facility for the XYZ Train Service. The dimensions of the chair are 1165 x 1105 x 505 mm and have several advantages, including a chair that can be tilted up to 35° from the initial position of 10°, a portable table on the side and a middle armrest, and a chair that can be rotated 180°. The backrest settings can be adjusted by pressing the push button on the side of the chair. This chair is the kind of chair used for executive services at PT. XYZ to date.

This research has a purpose of redesigning the Indonesian railway executive chair with the added advantage of a chair that can be tilted up to 40° from the initial position of 10°. After the design concept is selected, a simulation will be completed on 3 critical parts of the train seat including chair frame, footrest, and footrest frame [7]. This research is limited by a problem limitation, in which the welding joints on the chair are not counted and are declared safe.

## 2. Experimental Methods

The design method used in designing executive chairs for trains is Pahl & Beitz [8] , [9]. Figure 1 shows a flow diagram of the research methods used to achieve the objectives of this research.



**Figure 1.** Flow chart research methodology

### a. Planning

At this stage, information is collected regarding user needs and an assessment of similar tools which is already on the market to produce a list of demands that must be met in this design.

b. Concept Design

The stages of concept design start from determining the function of chair parts, looking for alternative solutions needed, creating concept variations, assessing concept variations according to predetermined parameters and ending with the selected design concept of executive chairs for trains.

c. Detailed Design

At this stage, critical parts of the chair are determined for calculations to make it easier to determine the material and components of the chair. It was then followed by making a temporary 3D model of the tool. The end of this stage is an assessment of whether chairs have met the list of demands.

d. Documentation

In this final stage, a bill of materials and work drawing documentation are created. The final result of this stage is a complete design drawing with product specifications, which is called a product design document.

**3. Results and Discussion**

**3.1. Planning**

Based on the studies that have been accomplished, the list of demands can be formulated as follows.

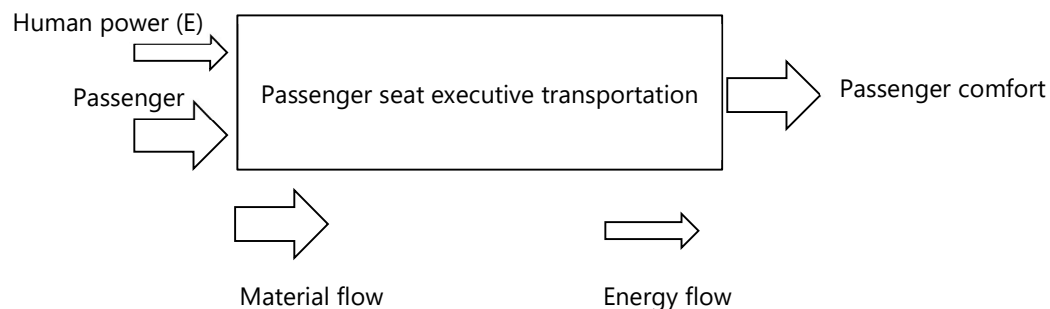
**Table 1.** Requirements list for executive railway chairs

No.	Parameter	Remark
1	Chair ability rotates	180°
2	Adjustable backrest	40°
3	Able to withstand maximum load	25 kg
4	Safety in operation is guaranteed	-
5	Ease of operation of all functions of the seat	-
6	Maximum dimensions of the seat	1165 × 1103 × 504 mm

**3.2. Concept Design**

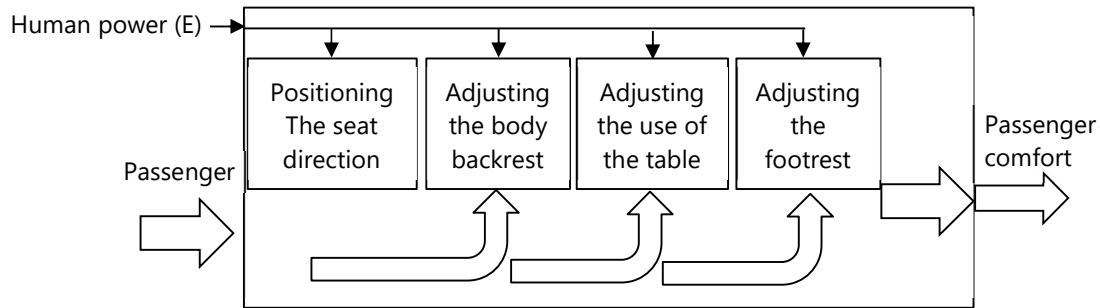
3.2.1 Description of Tool Functions and Sub-Functions

Before making the design, a black box and subfunction block diagram are made to determine the forces acting on the chair. The black box can be seen in Figure 2 and the sub function block diagram in Figure 3.



**Figure 2.** Black box











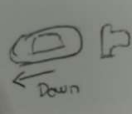
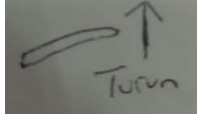
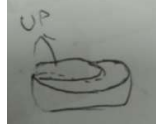



This black box explains about human labor and passengers who then sit on the executive seat which can then make them comfortable. In this black box, there is no electrical signal or sensor.



**Figure 3.** Sub function block diagram

### 3.2.2 Morphology

After determining the function diagram, we proceeded with creating a morphology schematic optional that has been adapted to the working principle of the tool as seen in Figure 4. Morphological schematic optional is a creative tool for generating ideas based on variations in the characteristics of a problem [10].

Solution		Subfunctions		
		1	2	3
A	Base	 Base frame	 Base solid	 Base solid portrait
B	Reclining	 Gas spring	 Reclining Seat	 3 steps wpecker recliner
C	Rotating regulation	 Handle	 Pedal	
D	Rotating plate	 90°	 180°	
E	Backup regulator	 Button	 Handle	 Button 2
F	Footrest	 One square back	 One elliptical backing	 Two backups





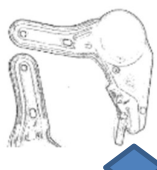

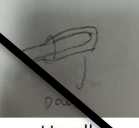

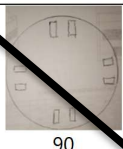
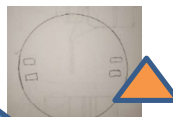
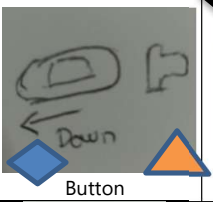
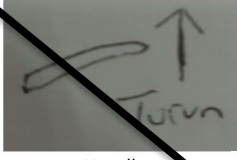



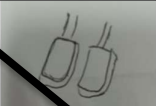
**Figure 4.** Morphology 1

3.2.3 Evaluation of Alternative Solutions

After preparing the morphology table, we continued with evaluating alternative solutions. The goal of alternative solutions as shown in Figure 5 is to select and adapt the work structure required for the overall function. This selection chart is used to help decision-making by presenting various options and related consequences. There are several criteria that must be selected for the best option. The value of + means that the solution must be pursued while the value of the value is the solution that must be eliminated.

		SELECTION CHART							
		for		<b>Railway Executive seat</b>					Page: 1
<b>SOLUTION VARIATIONS (SV):</b>	solution variants (SV) evaluated by				DECISION				
	SELECTION CRITERIA				Mark solution variations (SV)				
	(+ ) Yes				(+ ) pursue solution				
	(- ) No				(- ) Eliminate solution				
	? Lack of information				(? ) Collect Information				
	! Check requirements list				(re-evaluate solution)				
	Guaranteed compatibility				(!) Check requirements list for changes				
	Meet the demands of the list of requirements								
	It can be realized in principle								
	Expected costs								
Easy to Use									
Safety of use									
SV	A	B	C	D	E	F	G	Remarks (Indications, reasons)	DECISION
A1	1	+	+	+	-	+	-	realizable but user security lacks	-
A2	2	+	+	+	-	+	+	the base will be strong and secure	+
A3	3	+	+	+	-	+	+	base retracts vertical position relative to the seat	+
B1	4	+	+	+	-	+	+	effective in use but less affordable	+
B2	5	+	+	+	+	+	-	easy to use but lacking in security	+
B3	6	+	+	-	+	-	-	meets the demands but is not safe and easy to use	-
C1	7	+	+	+	+	-	-	can be used but not easy and safe	-
C2	8	+	+	+	+	+	+	according to the needs and safe in use	+
D1	9	+	+	+	+	+	-	meets demands but is not safe for se	-
D2	10	+	+	+	+	+	+	meet all the required demands list	+
E1	11	+	+	+	-	+	+	suitable solutions but quite high price	+
E2	12	+	+	+	+	-	-	the solution can be used but is not secure and easy to use	-
E3	13	+	+	+	+	-	-	solutions are not safe to use	-
F1	14	+	+	+	+	+	+	solutions meet the required demands	+
F2	15	+	+	+	+	+	+	the solution can be an option because it has met the demands	+
F3	16	+	+	+	+	-	-	solutions can be used but are not secure and easy to use	-
Date : 19 Oktober 2023									

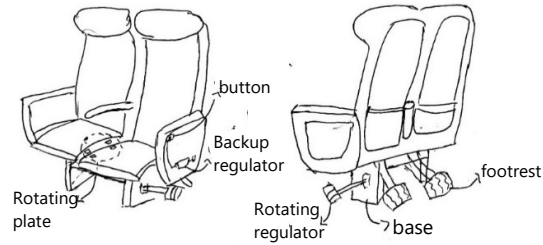
**Figure 5.** Evaluation of alternative solutions

Subfunctions		Solution		
		1	2	3
A	Base	 Base Frame	 Base Solid	 Base Solid Portrait
		 Gas Spring	 Reclining Seat	 3 steps wpecker recliner
C	Rotating regulation	 Handle	 Pedal	
		 90	 180	
E	Backup Regulator	 Button	 Handle	 Button 2
		 One square back	 One elliptical backing	 Two Backups
		Concept Variation 1	Concept Variation 2	

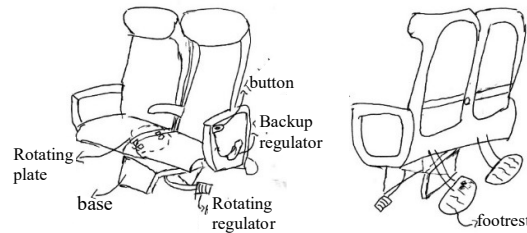
**Figure 6.** Morphology 2

### 3.2.4 Concept Variations

The results from Figure 6 morphology 2 are two variations of the chair concept which can be seen in Figure 7 for variation of concept 1 and Figure 8 for variation of concept 2.



**Figure 7.** Variation of concept 1



**Figure 8.** Variation of concept 2

### 3.2.5 Concept Variation Assessment

The next stage is formulating an assessment of two variations concept to determine the selected concept with the parameters that have been determined in each assessment (see Table 2). Technical criteria generally focus on efficiency and effectiveness, specifically minimizing the cost of producing the same amount of goods or maximizing production at the same cost. Meanwhile, technical criteria including efficiency, quality, cost, time, and safety are influenced by the selection of production processes, machine design, and resource management.

**Table 2.** Requirements list for executive railway chairs

No.	Economic criteria	Technical criteria
1	Ease of operation	Ease of manufacturing
2	Low material costs	Ease of assembly
3	Low component costs	Material availability
4	Manufacturing possibilities in a campus/corporate environment	Manufacturing costs
5	Aesthetic	Ease of maintenance

The assessment aspect parameters are then compared to each other to determine what will be prioritized in selecting the design concept. Comparisons are made by giving values 1 and 0, where a value of 1 means that the parameter is given more priority compared to parameters given a value of 0 (See Table 3 and 4).

$$\text{Weight} = \frac{\text{value}}{\text{total value}} \times 100\% \quad (1)$$

**Table 3.** Comparison of economic criteria aspect parameters

No.	Economic criteria	A	B	C	D	E	Subtotal	Weight	%
1	Ease of operation	1	1	1	0	1	3	0,3	30
2	Low material costs	0	1	1	1	0	2	0,2	20
3	Low component costs	0	0	1	1	0	1	0,1	10
4	Manufacturing possibilities in a campus/corporate environment	1	0	0	1	1	2	0,2	20
5	Aesthetic	0	1	1	0	1	2	0,2	20
<b>Total</b>							<b>10</b>	<b>1</b>	<b>100</b>

**Table 4.** Comparison of technical criteria aspect parameters

No.	Technical criteria	A	B	C	D	E	Sub total	Weight	%
1	Ease of manufacturing	1	0	1	0	0	2	0,2	20
2	Ease of assembly	0	1	0	1	1	2	0,2	20
3	Material availability	1	1	0	0	0	2	0,2	20
4	Manufacturing costs	0	0	1	1	0	1	0,1	10
5	Ease of maintenance	1	0	1	1	1	3	0,3	30
<b>Total</b>							<b>10</b>	<b>1</b>	<b>100</b>

Before assessing each concept variation, it is necessary to first know a clear scale for each assessment parameter. A scale of 1–4 is used to assess each concept variation (See Table 5 and 6).

**Table 5.** Weight of economic criteria

No.	Economic Criteria	Value	Assessment Criteria
1	Ease of operation	1	Very difficult (users require quite long training by experts)
		2	Difficult (Short training by the manufacturer is required)
		3	Easy (Just follow the user manual and practice a few times)
		4	Very easy (Simply follow the user manual and instructions on the tool)
2	Low material costs	1	Rp5,500,000 – Rp7,500,000
		2	Rp3,500,000 – Rp5,000,000
		3	Rp2,500,000 – Rp3,500,000
		4	Rp1,500,000 – Rp2,500,000
3	Low component costs	1	Rp4,500,000 – Rp6,000,000
		2	Rp3,000,000 – Rp4,500,000
		3	Rp2,000,000 – Rp3,000,000
		4	Rp1,000,000 – Rp2,000,000
4	Manufacturing possibilities in a campus/corporate environment	1	All components outside the campus/company
		2	>1/2 components outside the campus/company
		3	<1/2 off-campus components
		4	All components are on campus/business
5	Aesthetic	1	Less
		2	Enough
		3	Good
		4	Excellent

**Table 6.** Technical criteria weight

No.	Technical criteria	Value	Assessment criteria
1	Ease of manufacturing	1	Very difficult (requires expert services due to the entire complex component geometry)
		2	Difficult (all components have complex geometry but can still be made by yourself)
		3	Easy (some components have complex geometry and others have simple geometry)
		4	Very easy (all components have simple geometry)
2	Ease of assembly	1	Difficult (requires a lot of tools and assembly stages)
		2	Quite difficult (requires few tools but quite a lot of assembly stages)
		3	Easy (tools required and few assembly stages)
3	Material availability	4	Very easy (some parts can be done without the need for tools and others require tools with few steps)
		1	Rare (must do indents in specialized stores)
		2	Quite difficult to find (on average available in specialty stores that are rarely found)
		3	Available in most stores in the market
4	Manufacturing costs	4	Available in every store in the market
		1	Rp4,500,000 – Rp6,000,000
		2	Rp3,500,000 – Rp4,500,000
		3	Rp2,500,000 – Rp3,500,000
5	Ease of maintenance	4	Rp1,500,000 – Rp2,500,000
		1	Very difficult (need to take to the manufacturer as a special maintenance workshop)
		2	Difficult (need to call a special technician from manufacturer)
		3	Easy (just follow the user manual and a little consultation with the manufacturer via internet/telephone)
		4	Very easy (just follow the manual user only)

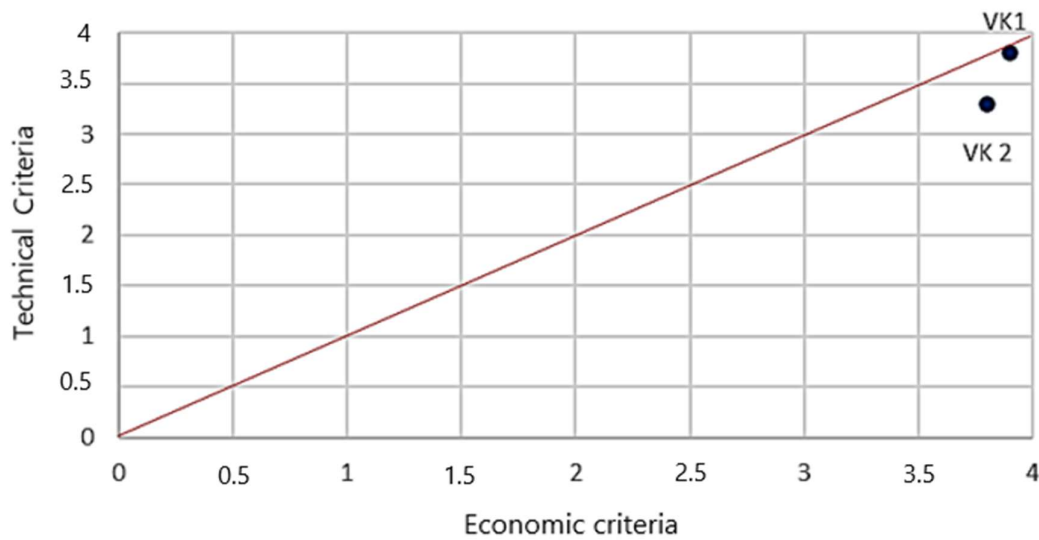
The final stage in assessing design concept variations is based on the parameters on a scale of 1-4 that have been explained (See Table 7 and 8).

**Table 7.** Assessment of concept variations in economic criteria aspects

No.	Economic criteria	Weight	Concept assessment (X)		Ideal value
		(W)	A	B	
1	Ease of operation	0.3	4	3	1.2
2	Low material costs	0.2	3	3	0.8
3	Low component costs	0.1	4	4	0.4
4	Possibility of manufacturing on campus/company	0.2	4	4	0.8
5	Aesthetic	0.2	4	3	0.8
Total (W×X)			<b>3.8</b>	<b>3.3</b>	<b>4</b>

**Table 8.** Assessment of concept variations in technical criteria aspects

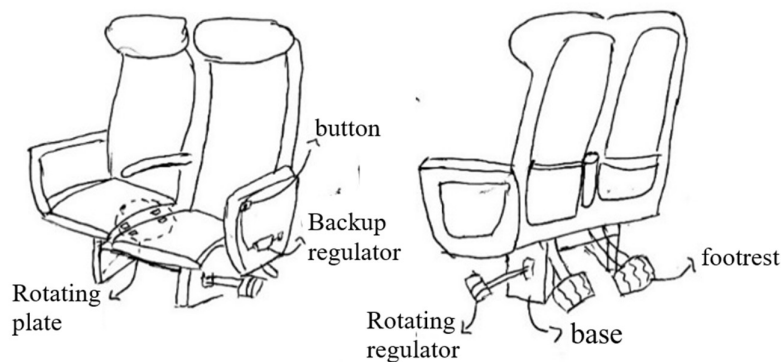
No.	Technical Criteria	Weight (W)	Concept assessment (X)		Ideal value
			A	B	
1	Ease of manufacturing	0.2	4	4	0.8
2	Ease of assembly	0.2	4	3	0.8
3	Material availability	0.2	4	4	0.8
4	Manufacturing costs	0.1	3	4	0.4
5	Ease of maintenance	0.3	4	4	1.2
<b>Total (W×X)</b>			<b>3.9</b>	<b>3.8</b>	<b>4</b>



**Figure 9.** Concept variation assessment chart

### 3.2.6 Selected Design Concepts

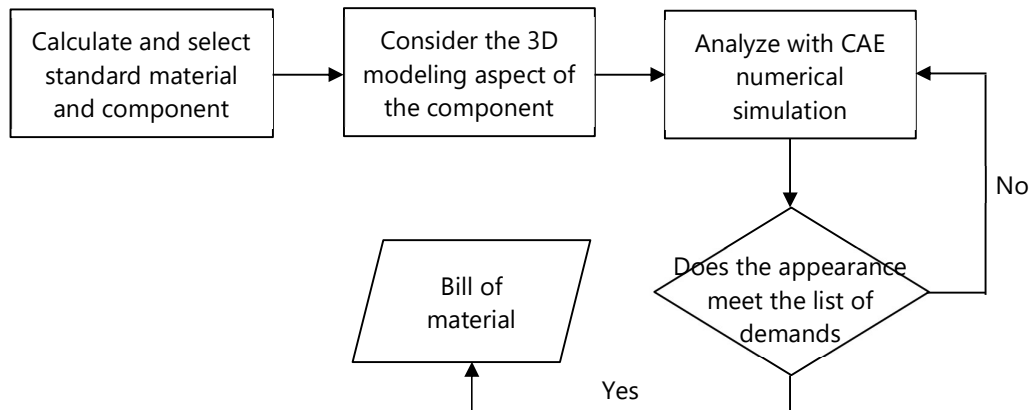
Based on the assessment and graph in Figure 9, it was found that the selected concept variation was variation 1 as seen in Figure 10.



**Figure 10.** Selected design concept

### 3.3. Actual Detailed Design

Detailed design is conducted to analyze calculations and simulate parts that intersect with other parts. The flow of detailed design can be seen in Figure 11.



**Figure 11.** Detailed design flowchart

### 3.3.1 Critical Part Calculation

In calculating critical parts, the load acting on the part is required. To support the calculations, an average load is obtained as in Table 9.

**Table 9.** Burden distribution

Load accepted	Mass (kg)	Weight (N)
03-Mar.	125	1225.83
03-Feb.	83.3	816.9
03-Jan.	41.6	406.97

a. Calculation of the force on the backrest

$$\frac{2}{3} W = 816.9 \text{ N}$$

$$L = 310 \text{ mm}$$

$$F = \cos 40^\circ \times 816.9 \tag{2}$$

$$F = 0.76 \times 816.9$$

$$F = 620.84 \text{ N}$$

A style that works on the pedestal 620.84 N

Moment calculation:

$$M = F \cdot L \tag{3}$$

$$M = 620.84 \times 310$$

$$M = 192460.4 \text{ Nmm}$$

Moment of inertia calculation:

$$I = \frac{\pi}{32} (D^3 \cdot d^3) \tag{4}$$

$$I = \frac{\pi}{32} (82.5^3 \times 70.81^3)$$

$$I = 20270 \text{ mm}^3$$

Where D is outer diameter (mm) and d is Inner Diameter (mm).

Bending stress calculation:

$$\sigma_{Max} = \frac{M}{I} \quad (5)$$
$$\sigma_{Max} = \frac{192460.4}{20270}$$

$$\sigma_{Max} = 9.5 \text{ MPa}$$

Where I is moment of Inertia ( $\text{mm}^3$ ) and M is Momen (Nmm).

Allowable stress calculation:

To ensure that the maximum voltage occurs can be held by the backrest, the calculation of the permitted voltage is continued. For stable data and the load occur can be calculated properly, the safety factor used is 2.

$$\sigma_{allowable} = \frac{\sigma_y}{Sf} \quad (6)$$
$$\sigma_{allowable} = \frac{250}{1.2} = 125 \text{ MPa}$$

With Conditions.  $\sigma_{max} < \sigma_{allowable}$

Where  $\sigma_a$  is allowable stress (MPa) and  $\sigma_y$  is material tensile stress (MPa).

b. Calculation of the force on the footrest

$$\begin{aligned} \frac{2}{3} W &= 816.9 \text{ N} \\ L &= 153 \text{ mm} \\ F &= 816.9 \times \cos \theta \end{aligned} \quad (7)$$

$$F = 816.9 \times 0.9$$

$$F = 465.21 \text{ N}$$

The force that works on the footrest 465.21 N

Moment calculation:

$$M = F \cdot L$$

$$M = 465.21 \times 153$$

$$M = 71160.3 \text{ Nmm}$$

Moment of inertia calculation:

$$L_x/y = \frac{bh^2}{6} \quad (8)$$
$$L_x/y = \frac{5.3^2}{6}$$
$$L_x/y = 75 \text{ mm}^3$$

Where b is wide (mm) and h is length (mm).

Bending stress calculation:

$$\sigma_{Max} = \frac{M}{L_x/y} \quad (9)$$

$$\sigma_{Max} = \frac{71160.3}{75}$$

$$\sigma_{Max} = 94.8 \text{ MPa}$$

Where  $L_x/y$  is moment of inertia ( $\text{mm}^3$ ) and M is moment (Nmm).

Allowable Stress Calculation

$$\sigma_{allowable} = \frac{\sigma_y}{Sf} \quad (10)$$

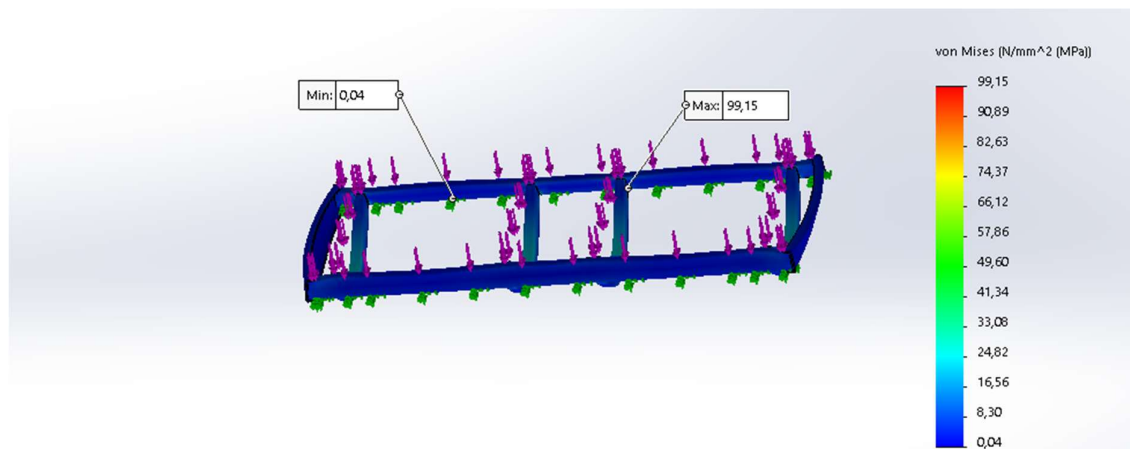
$$\sigma_{allowable} = \frac{250}{1.2} = 125 \text{ MPa}$$

With conditions  $\sigma_{max} < \sigma_{izin}$

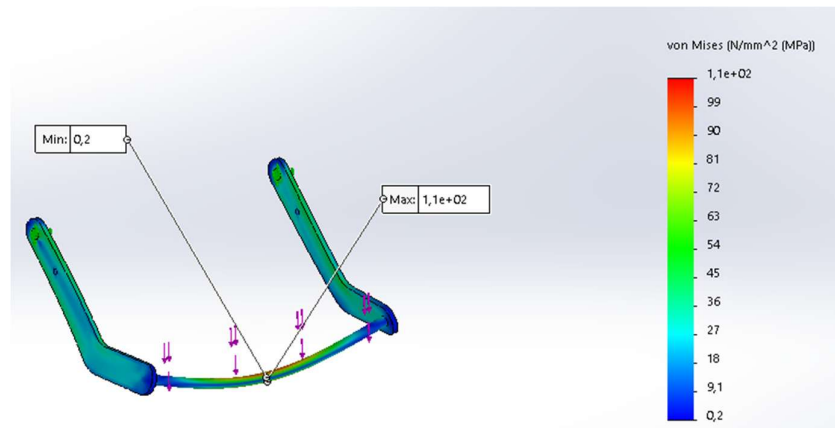
Where  $\sigma_a$  is allowable stress (MPa) and  $\sigma_y$  is material tensile stress (MPa).

### 3.3.2 Numerical Simulation

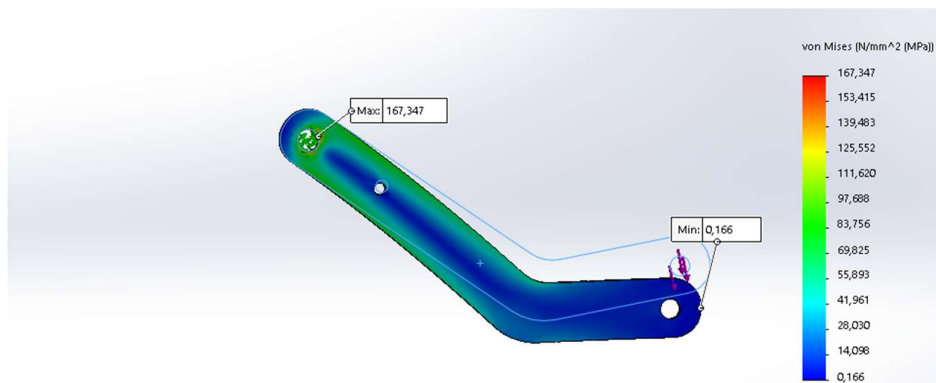
CAE numerical simulation was conducted on the frame components, footrests and footrest frames, where these components are critical parts of the train executive chair because they receive continuous loads [11] [12]. If the seat frame is damaged or fails, it will affect passenger safety.



**Figure 12.** Chair frame simulation results



**Figure 13.** Footrest simulation results

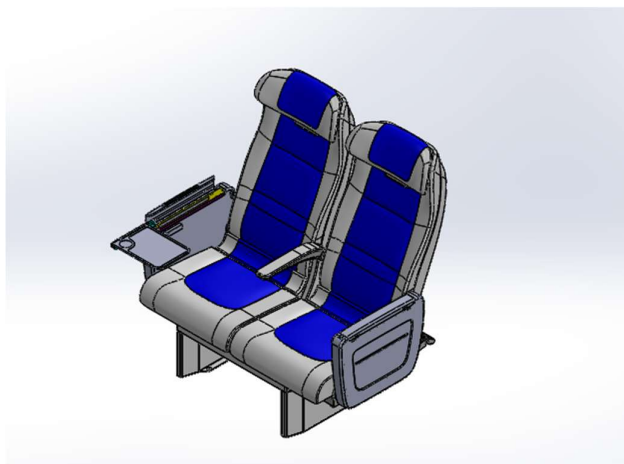
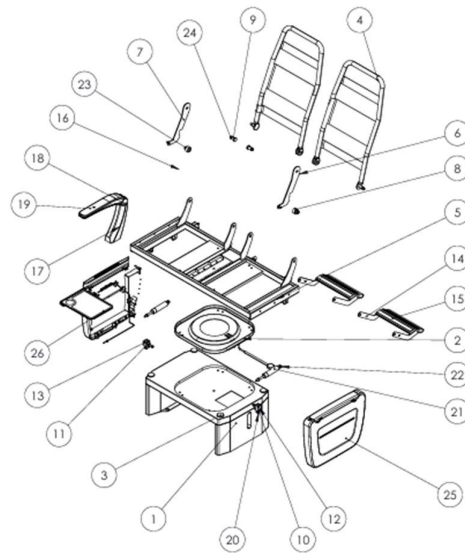


**Figure 14.** Footrest frame simulation results

Based on the three simulations above (Figure 12-14), each part with a load that has been adjusted to the part's function is declared safe. The stress that occurs is 167.347 MPa, this indicates that the stress is not more than the stress of ASTM A36 material, that is 250 MPa [13].

### 3.2.3 Tool Modeling Results

3D modeling of train executive chairs was carried out using SolidWorks 2018 software [14]. 3D modeling was completed according to the concept with several adjustments to various aspects made at the detailed design stage [15]. The following is the results of selected tool 3D modeling. Executive train seats generally have a tilt of up to 35° from the initial position of 10°. In this development, the seat can be tilted up to 40° from the initial position of 10°.



**Figure 15.** Tool modeling results

Sub assembly right arm rest and table	26
Sub assy left arm rest and table	25
NUT M12	24
NUT M10	23
NUT M8	22
Gas spring	21
Bolt M3×20	20
Middle arm rest	19
Hinge cover middle arm rest	18
Middle hand rest support	17
Hinge cover	16
Footrest	15
Frame of footrest	14
Gas spring pusher	13
Pin spring	12
Spring retainer right	11
Spring retainer left	10
Locking hinge bracket frame	9
Pin close hinge	8
Right back rest hinge	7
Left back rest hinge	6
Frame	5
Backrest frame	4
Frame mount	3
Rotating plate	2
Base	1

#### 4. Conclusion

Designing train executive chairs has been successfully conducted. The selected concept variation is concept 1 which has gone through an assessment stage adjusted to the existing parameters. The accomplished critical part calculations were declared safe because the bending stress occurred in the part was smaller than the allowable stress for the ASTM A36 material. Based on the CAE numerical simulation, it can be concluded that it is safe because the maximum stress that occurs is 167.347 MPa. This result does not exceed the permissible stress for ATSM A36 material of 250 MPa. The specifications of the equipment obtained are chair dimensions (1101×1091×632 mm), Material (ASTM A36, polypropylene, and rubber), and advantages (seat – rotate system 180°, side folding table, reclining seat 40° and footrest). The design of this train executive chair cannot be said to be optimal or not, therefore it is necessary to make a prototype or test to find out the weaknesses of the existing design so that it can become an optimal design.

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