Prevention of Fall and Safer Boarding in Trains-Automatic Vehicle Based Ramp

Dr. Richa Pandey[1], Shashwat Aditya[2], Pranjal Mahajan[3], Nishant Mishra[4]

[1]Professor, Mechanical Engineering, Birla Institute of Technology, Mesra Ranchi Jharkhand 835215, India
richapandey[at]bitmesra.ac.in

[2]Mechanical Engineering, Birla Institute of Technology, Mesra Ranchi Jharkhand 835215, India
jerryaditya06[at]gmail.com

[3]Mechanical Engineering, Birla Institute of Technology, Mesra Ranchi Jharkhand 835215, India
pmpranji[at]gmail.com

[4]Mechanical Engineering, Birla Institute of Technology, Mesra Ranchi Jharkhand 835215, India
nk.111.nm[at]gmail.com

Abstract: ***Boarding and disembarking trains for passengers while travelling via Indian Railway is not fool proof system yet because of the gaps and steep stairs. For ensuring safety to passengers, a ramp attached in coach can be installed for entry and exit near door. This will also help people to move conveniently along with heavy luggage. As the halt time of train is usually very less so the response time of the mechanism should be minimal. To achieve less opening and closing time, high rpm motor is needed. Light weight main ramp with enough strength is to be designed so that supporting ramp can pull it up using power from motor.***

Keyword: Analytical Hierarchy Process, Boarding and Alighting, Miss-stepping, Ramp

1. Introduction

The idea is to develop a solution for the safety of passengers while boarding and disembarking trains of Indian Railways. As there has to be a sufficient gap between train body and platform because trains at high speed tend to move sideways with the lateral movement of coach. Generally horizontal gap between platform and coaches' stairs is wider than 8 inches which even increases to 12 inches in case of curved platforms. A little carelessness may lead to a passenger's tripping over the platform which can result in potentially hazardous injuries. The Indian Railways should maintain the highest degree of care to minimize the cases of accidents associated with their operations.

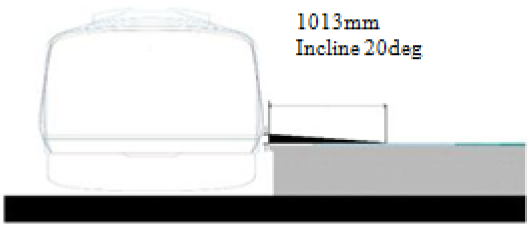

Figure 1: Schematic Diagram

2. Analytical Hierarchy Process

When there are several options to solve a given problem, it is sometimes tough to decide which one is the best possible option. For organising and analysing complex cases, several decision making tools are used. Analytical Hierarchy Process (AHP) is one of them. When there are several option to solve a particular option, and every option has its own advantages over other, AHP helps to decide which one is the best alternative. In this process a decision problem is divided into many sub problems and each sub problem is analysed independently.

2.1 Problem Statement

In most of the trains in India the floor level of train coach is much higher than platform level and also there is substantial horizontal gap between platform and train coach staircase. Also, the stair cases are very steep. These reasons result in passengers miss-stepping and falling down in the gap.

2.2 Methodology

2.2.1 Deciding criteria on which alternatives are to be judged.

The idea is to develop a solution to make boarding and disembarking safer for passengers travelling via Indian Railway. All passenger falls begin with a slip or a trip and must be taken of seriously, as they can result in potentially fatal injuries. Therefore, Indian Railway must exercise the highest degree of care in reducing or eliminating the causes of falls associated with their operations. Safe walking requires perfect timing in the transfer of support and balance from one leg to the other. The slightest imbalance can result in a serious fall as the body continues to move forward.

Out of several criteria, following criteria are most important ones-

- Safety
- Low maintenance
- Installation Cost
- Feasibility

2.2.2 Comparing criteria pairwise using matrix to find weightage of each criterion.

Table for rating comparisons is made as follows-

Table 1 Pairwise Comparison

Criteria	Safety	Low Maintenance	Installation cost	Feasibility
Safety	1	3	5	1
Low Maintenance	1/3	1	2	1/7
Installation cost	1/5	½	1	1/6
Feasibility	1	7	6	1

The above table can be shown in the form of matrix like this-

$$A = a_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

While making the decision selection, a_{ij} indicates how much more important the *i*th objective is than the *j*th objective.

Once completed, sum up the entries in column *j* and use the sum to divide each entry in column *j* of pairwise comparison matrix A. A new matrix, A*w*, will form as follows:

$$Aw = \begin{bmatrix} \frac{a_{11}}{\sum a_{i1}} & \frac{a_{12}}{\sum a_{i2}} & \cdots & \frac{a_{1n}}{\sum a_{1n}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{a_{n1}}{\sum a_{i1}} & \frac{a_{n2}}{\sum a_{i2}} & \cdots & \frac{a_{nn}}{\sum a_{in}} \end{bmatrix}$$

$$Aw = \begin{bmatrix} .39 & .26 & .35 & .37 \\ .13 & .08 & .14 & .05 \\ .07 & .04 & .07 & .06 \\ .39 & .60 & .42 & .37 \end{bmatrix}$$

Compute the priority vector (PV) by summing the entries in row *i* and dividing numbers of objectives to form the column vector of PV.

$$PV = \frac{\frac{a_{n1}}{\sum a_{i1}} + \frac{a_{n2}}{\sum a_{i2}} + \cdots + \frac{a_{nn}}{\sum a_{in}}}{n}$$

$$PV = \begin{bmatrix} .34 \\ .10 \\ .06 \\ .44 \end{bmatrix}$$

The sum of entities in column vector of PV will be 1, where PV represents the relative degree of importance of the selected n objectives.

Implement the Eigen value method, calculate the Consistency Index (CI), and determine Consistency Ratio (CR).

Start the judgments consistency of the pairwise comparison matrix by following the sub-steps shown next:
(a). Compute matrix A with column vector of PV.

$$A.PV = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} PV_1 \\ PV_2 \\ \vdots \\ PV_n \end{bmatrix} = \begin{bmatrix} \chi_1 \\ \chi_2 \\ \vdots \\ \chi_n \end{bmatrix}$$

From Table 1, we get

$$A.PV = \begin{bmatrix} .39 & .26 & .35 & .37 \\ .13 & .08 & .14 & .05 \\ .07 & .04 & .07 & .06 \\ .39 & .60 & .42 & .37 \end{bmatrix} \begin{bmatrix} .34 \\ .10 \\ .06 \\ .44 \end{bmatrix} = \begin{bmatrix} 1.38 \\ 0.40 \\ 0.25 \\ 1.84 \end{bmatrix}$$

(b). Compute the Eigen Value (λ_{max})

$$\lambda_{max} = \frac{1}{n} \sum_{1}^{n} \frac{ith\ entry\ in\ A.PV}{ith\ entry\ in\ PV}$$

λ_{max}= 4.08

(c). Compute the Consistency Index (CI).

CI=(λ_{max}-n)/(n-1)

= (4.08-4)/(4-1) = 0.26

(d). Compare CI and RI

At this stage, Consistency Index (CI) is compared with Random Index (RI) with the appropriate value of n to ensure the satisfactory of consistency degree. Decision-maker may detect the consistency of his judgment on weighting estimation for various criteria, if the CI value is significantly smaller than RI value.

(e). Compute the Consistency Ratio (CR).

CR=CI/RI

= 0.026/0.9 =.029

2.2.3 Deciding alternatives to solve the given problem.

AHP is done mainly to decide best alternatives from a list of alternatives to solve a particular problem. To bridge the gap between train floor and platform floor, there are many possible methods. These alternatives are as follows:

1. Platform based ramp (PBR)
2. Automatic vehicle based ramp (AVBR)
3. Standardisation of platform height (SPH)
4. Manual vehicle based ramp (MVBR)

2.2.4 Comparing each alternative with all other alternatives pairwise on basis of every criterion.

As all the criteria and their weightages are known, comparison of each alternative is done pairwise on the basis of each criterion. Firstlytable of ratings on basis of safety is formed as below.

Table2 Safety

Safety	PBR	AVBR	SPH	MVBR
PBR	1	2	4	1
AVBR	½	1	3	½
SPH	¼	1/3	1	¼
MVBR	1	2	4	1

$$A=\begin{bmatrix}0.36 & 0.37 & 0.33 & 0.36\\ 0.18 & 0.18 & 0.25 & 0.18\\ 0.09 & 0.06 & 0.08 & 0.09\\ 0.36 & 0.37 & 0.33 & 0.36\end{bmatrix}\rightarrow \overbrace{\begin{bmatrix}0.35\\ 0.19\\ 0.08\\ 0.33\end{bmatrix}}^{x}$$

$Ax=\lambda_{max}x$

$$\begin{bmatrix}1.38\\ 0.77\\ 0.31\\ 1.38\end{bmatrix}=\lambda_{\max}\begin{bmatrix}0.35\\ 0.19\\ 0.08\\ 0.33\end{bmatrix}$$

λ_{max} = 4.01075
CI = (λ_{max} – n)/(n-1) = (4.01075-4)/(4-1) =0.03
RI=0.9
CR= CI/RI = 0.003/0.9 =.004 < 0.1

Table 3 Low Maintenance

Low Maintenance	PBR	AVBR	SPH	MVBR
PBR	1	2	1/5	1
AVBR	½	1	1/6	½
SPH	5	6	1	5
MVBR	1	2	1/5	1

$$A=\begin{bmatrix}0.133 & 0.18 & 0.13 & 0.133\\ 0.06 & 0.09 & 0.11 & 0.06\\ 0.66 & 0.54 & 0.64 & 0.66\\ 0.133 & 0.18 & 0.13 & 0.133\end{bmatrix}\rightarrow \overbrace{\begin{bmatrix}0.144\\ 0.052\\ 0.632\\ 0.144\end{bmatrix}}^{x}$$

$Ax=\lambda_{max}x$

$$\begin{bmatrix}1.08\\ 0.909\\ 0.985\\ 1.08\end{bmatrix}=\lambda_{\max}\begin{bmatrix}0.144\\ 0.052\\ 0.632\\ 0.144\end{bmatrix}$$

λ_{max}= 4.0556
CI = (λ_{max} – n)/(n-1) = (4.0556-4)/(4-1)
= 0.01854
RI=0.9
CR= CI/RI = 0.01854/0.9 =.02 < 0.1

Now on the basis on Low Installation Cost

Table 4 Low Installation Cost

Low Installation Cost	PBR	AVBR	SPH	MVBR
PBR	1	2	1/9	1
AVBR	½	1	1/8	½
SPH	9	8	1	9
MVBR	1	2	1/9	1

$$A=\begin{bmatrix}0.087 & 0.153 & 0.082 & 0.087\\ 0.043 & 0.077 & 0.093 & 0.043\\ 0.782 & 0.615 & 0.742 & 0.782\\ 0.087 & 0.153 & 0.083 & 0.087\end{bmatrix}\rightarrow \overbrace{\begin{bmatrix}0.103\\ 0.064\\ 0.731\\ 0.103\end{bmatrix}}^{x}$$

$Ax=\lambda_{max}x$

$$\begin{bmatrix}1.18\\ 0.834\\ 0.984\\ 1.179\end{bmatrix}=\lambda_{\max}\begin{bmatrix}0.103\\ 0.064\\ 0.731\\ 0.103\end{bmatrix}$$

λ_{max}= 4.177
CI = (λ_{max} – n)/(n-1) = (4.177-4)/(4-1)=.0591
RI = 0.9
CR= CI/RI = 0.0591/0.9 =.07 < 0.1

Table 5 Feasibility

Feasibility	PBR	AVBR	SPH	MVBR
PBR	1	2	4	1
AVBR	½	1	3	½
SPH	¼	1/3	1	¼
MVBR	1	2	4	1

$$A=\begin{bmatrix}0.1 & 0.104 & 0.083 & 0.091\\ 0.7 & 0.725 & 0.75 & 0.73\\ 0.1 & 0.08 & 0.083 & 0.09\\ 0.1 & 0.09 & 0.083 & 0.09\end{bmatrix}\rightarrow \overbrace{\begin{bmatrix}0.094\\ 0.726\\ 0.089\\ 0.091\end{bmatrix}}^{x}$$

$Ax=\lambda_{max}x$

$$\begin{bmatrix}0.944\\ 1\\ 1.064\\ 1.003\end{bmatrix}=\lambda_{\max}\begin{bmatrix}0.094\\ 0.726\\ 0.089\\ 0.091\end{bmatrix}$$

CI = (λ_{max} – n)/(n-1)
= (4.013-4)/(4-1) = 0.0043
RI =0.9
CR= CI/RI = 0.0043/0.9 =.004 < 0.1

Matrix 1 Consistency Ratio

$$\begin{matrix}PBR\\ AVBP\\ SPH\\ MVBR\end{matrix}\begin{bmatrix}0.35 & 0.144 & 0.102 & .094\\ 0.19 & 0.052 & .064 & .725\\ .08 & 0.631 & 0.716 & .088\\ 0.33 & 0.144 & 0.102 & .09\end{bmatrix}\begin{bmatrix}0.34\\ 0.10\\ 0.06\\ 0.44\end{bmatrix}=\begin{bmatrix}0.207\\ 0.427\\ 0.169\\ 0.197\end{bmatrix}$$

The maximum consistency ratio of 0.427 is obtained which is of Automatic Vehicle Based Ramp. So, this is the most comfortable and cost effective method which can be installed in Indian Rail coaches.

3. Components

3.1 Battery- 12 volts Lead Acid Battery. This battery will be enough to operate the motors with required torque and rpm. The battery will be connected to main power supply from which it will get recharged. Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, its ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio.

3.2 Wheel – There will be four driving wheels mounted on Secondary ramp and 2 non driving supporting wheels on main ramp. Diameter of the wheel is calculated according to torque required to pull the main ramp and availability of wheels in market. wheels with diameter 67mm is used.

3.3 DC Motor- 12V, 150RPM with maximum torque 35kg.cm. Torque needed at each wheel to pull the main ramp from the platform is 15.1kg.cm. High RPM motor operated using Arduino will make the opening and closing time very feasible according to less stoppage of trains on platform.

3.4 Arduino- The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The board can operate on an external supply of 6 to 20 volts. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. It will be used to alter the operation timing of ramp and reverse the motor shaft rotation after fixed time interval.

3.5 Ramps- There will be 2 ramps of mild steel of thickness 3mm. One is the main ramp through which passengers will board. The secondary ramp will be used as supporting ramp which will help the primary ramp to move to and fro. The motor-wheel assembly will be mounted on Primary ramp with the help of casing. Width of the ramp is same as width of the doors in existing trains. Thickness of ramp is optimized by considering the worst case conditions and minimising the weight of ramp. Analysis is done on ANSYS Workbench16.0. The Main ramp will be padded with rubber material to eliminate the risk of sliding of luggage and passengers.

3.6 Guide Rail- Steel guide rails will be used to give directional stability to the 4 driving wheels and 2 supporting wheels. It will be mounted on the base of the train doors. Hatch design will be used to increase the friction between wheel and rail.

4. Mechanism

Firstly there will be an electric circuit which will have a switch to actuate 4 DC motors. The switch will be operated by on board railway staff. Energy source will be a lead acid battery. Relay between battery and switch will be installed for implying rotary motion of motors in both directions. These motors will be mounted on a supporting ramp which will push and pull the main ramp. Each motor will control a particular wheel.

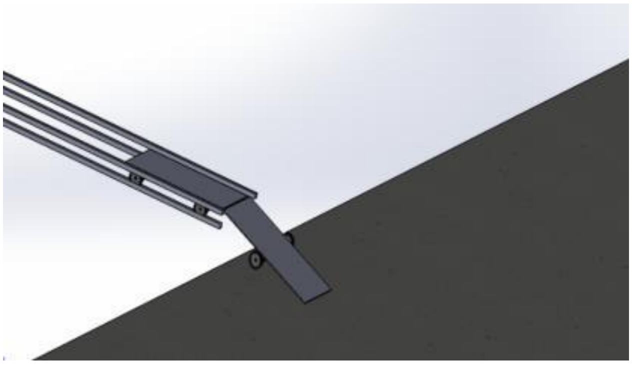

Figure 2 Ramp in open position

When we switch the circuit in 'on' position the power from battery goes to motors and all wheels start to rotate and move using friction from guide way. From here the opening of ramp starts. As wheel rotates the supporting ramp starts to move forward. As there will be a hinge joint connection between main ramp and supporting ramp, main ramp will get pushed.

Further, the supporting ramp will move on the guide way using wheels till the main ramps open due to gravity as there is hinge joint in between which will allow downward rotation. There will be a stopper to restrict the motion of supporting ramp. The movement of motors which are connected to wheels will be controlled by Arduino. Arduino will control the speed of wheels in such a way that impact between stopper and supporting ramp will not be severe.

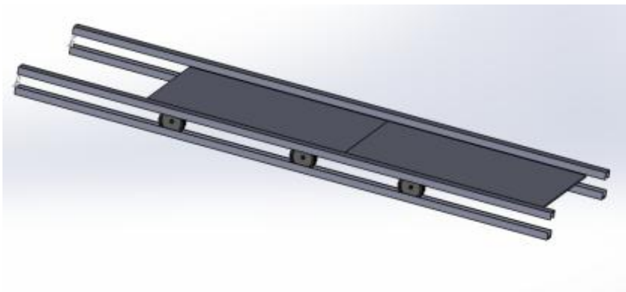

Figure 3 Ramp in closed position

For closing of ramp, reverse action will take place. The motors will rotate in reverse direction. And supporting ramp will pull the main ramp against gravity.

Table 6 Technical Data Sheet

CHARACTERISTICS	VALUE	COMMENT
Load carrying capacity	300kg	3 persons + Luggage
Minimum clear width of ramp platform	700 mm	Enough for 1 person and luggage
Ramp length	1100 mm	Optimize length according to incline angle
inclination	15 - 25 deg	Operational inclination range
Variation in height	284 – 464 mm	Cover most urban platforms
Horizontal speed of operation	0.15 m/s	Movement should be smooth
Manual operation possibility	Possible	Staff can manual close or open ramp
Motor torque	35 kg-cm	Enough for any operation load
Ramp platform thickness	3 mm	Calculated by ANSYS
Maximum deformation at maximum load	15 mm	Stress developed is below yield stress
Minimum manual force to operate the ramp	150 N	Low force required
Rubber padding provided on ramp	Yes	Ensure no slip and maximum grip to passengers

5. Calculations

Weight of main ramp (W_1) =m_1g
=11*9.81 =107.91 N
Force needed to pull the ramp from fully open position (F)
= 1.25*weight of inclined ramp
F = 1.25*107.91 =134.88 N
Weight of supporting or pulling ramp(W_2) = m_2g
=11.4*9.81 =111.834 N
As we are using four motor to drive the wheel
Load on each motor wheel system (N_1) = W_2/4
=111.834/4 =27.9585 N
Coefficient of friction (μ) = 0.6
Friction Force = μ N_1
=0.6x27.9585 =16.7751 N
Pull force is to be added to the friction force
Total pull force (F_3) = Friction Force + F/4
= 16.7751 + 107.91/4
= 43.7526 N
Radius of motor wheel (r) =33 mm =0.033 m
Torque required (T) = F_3r
= 43.7526x0.033
= 1.4438 Nm
Suitable motor which is available in market is 150 rpm motor with 35kg-cm torque.

Velocity and acceleration:

RPM of motor = 150
We will reduce the rpm and time-rotation control via L293D motor driver IC according to our need.
Horizontal velocity = 0.15 m/s
Opening time = 10 sec

6. Finite Element Analysis

A design is said to be perfect if the dimensions and weight are optimized. Ramp in fully opened position has to be capable of carrying 300 kg load. 300kg of load is considered assuming 3 persons of average weight of 70 kg each and total luggage weight of 90 kg are standing on the ramp.

Initial consideration:
1. Load = 300kg
2. Load is uniformly distributed over its surface.
3. Ramp act like simply supported beam.
4. Transverse deformation is negligible.

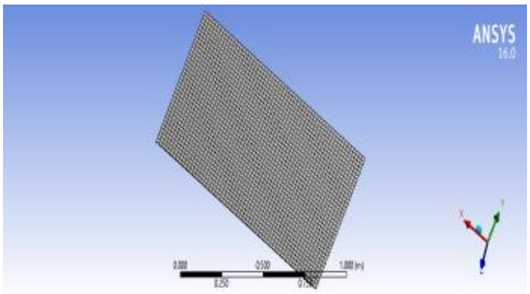

Figure 4 Meshed Ramp in Ansys

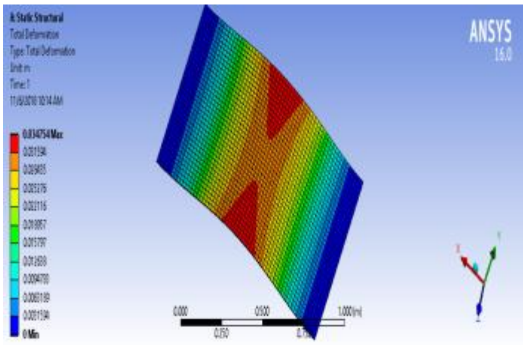

Figure 5 Deformation in Ansys

Material specifications:

1. Material : mild steel
2. Density : 7.87 gm/cc
3. Ultimate tensile strength : 440 MPa
4. Yield strength : 370 MPa
5. Young's modulus : 205 GPa
6. Poisson's ratio : 0.29

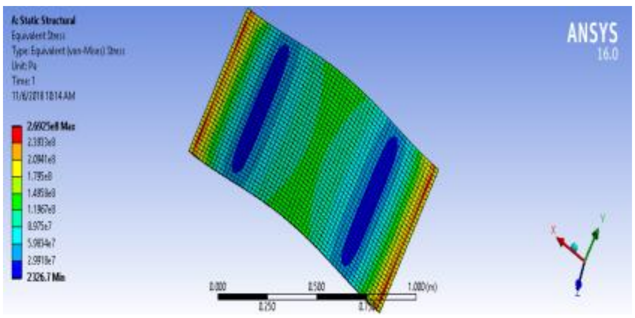

Figure 6 Stress in Ansys

Desired outcome:

1. Material must not get plastically deformed.
2. Generated stress does not cross yield stress.
3. Factor of safety must be greater than or equal to 1.5

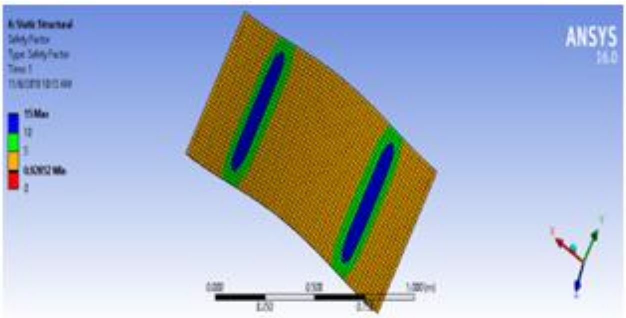

Figure 7 Factor of Safety of Ramp

7. Conclusion

As many new technical advancements are taking place in trains of Indian Railways, automatic vehicle based ramp can be next step to ensure safety to passengers. Recently Train 18 was launched with sliding footstep, but it solves the purpose only to some extent. It bridges only the horizontal gap, but with the use of Automatic Vehicle Based Ramp both horizontal and Vertical gap can be bridged and also passengers get to roll up their luggage instead of lifting. The mechanism can be installed just below the gates of already manufactured coaches of Indian-Railways.

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