transport capacity; seating; standing seats; commuter; train interior; train design

Conor O'NEILL*, Marcus WAKE, Lin FU, Christopher SAMUEL-HORSFALL
NewRail – Centre for Railway Research, Newcastle University
School of Mechanical and Systems Engineering
Stephenson Building, Newcastle upon Tyne NE1 7RU, United Kingdom
Evrim KOR
Yıldız Teknik Üniversitesi
Yıldız Mh., Istanbul, Turkey
João VIEIRA
Instítuto Superior Técnico, Universidade de Lisboa
Av. Rovisco Pais, 1049-001 Lisboa, Portugal
Yang DONG FANG
Ghent University
Sint-Pietersnieuwstraat 25, B - 9000 Ghent, Belgium
**Corresponding author*. E-mail: conor.oneill@ncl.ac.uk

STANDING SEATS FOR HIGH-CAPACITY TRAINS

Summary. This paper details the design and potential implementation of standing seats in a commuter rail vehicle for the purposes of maximising capacity and revenue. The vehicle interior design is suited to the "Commuter Class" – a subset of travellers who travel primarily within the commuter belt and frequently utilise rail networks on a daily basis but require little additional space for luggage or peripherals. The concept delivers capacity increases in excess of 50% whilst still offering passengers a greater degree of personal space when compared with standing in aisles or gangways. The impact on vehicle stability and supporting intelligent systems are also discussed, delivering a unique design tailored specifically to meet the needs of the commuter class passenger.

STOJĄCE MIEJSCA DLA POCIĄGÓW O DUŻEJ POJEMNOŚCI

Streszczenie. Artykuł opisuje szczegółowo projekt stojących miejsc siedzących i potencjał ich wprowadzenia, w podmiejskim pojeździe kolejowym, w celu maksymalizacji wydajności i dochodów z przejazdu. Wnętrze takiego pojazdu jest dostosowane do ludzi przemieszczających się głównie w okręgu miejskim, podróżujących codziennie i wymagających odrobinę miejsca dla mniejszych bagaży czy urządzeń peryferyjnych. Koncepcja zapewnia wzrost pojemności o ponad 50%, dodatkowo oferując pasażerom jeszcze większy stopień osobistej przestrzeni w porównaniu ze staniem w korytarzach lub przejściach. Wpływ na stabilność pojazdu i wspieranie inteligentnych systemów są także uwzględnione, dostarczając tym samym unikalną konstrukcję dostosowaną specjalnie do potrzeb pasażera pociągów podmiejskich.

1. INTRODUCTION

Traffic congestion is increasing in major cities, as with economic development there is usually an increase in mobility needs.

The massive use of private vehicles brings a deep urban crisis, caused by congestion, as the street network in cities has limited capacity and a huge demand. Therefore, there is a need for high capacity public transport systems as a way to reduce congestion on major cities.

This project focuses on the assessment of the potential for application of standing seats in commuter trains in order to increase passenger capacity and an appraisal on the benefits and blockers on its implementation.

In the first part of the paper, the motivation and need for increasing capacities in transportation is explained. Next, the design solution is studied and an assessment on the vehicle impacts is made, at the comfort, capacity and safety levels. Finally, we present an appraisal on the benefits of this solution and blockers to its implementation.

2. MOTIVATION

Railway transport is undoubtedly the transport mode with greatest capacity (Fig. 1), being particularly useful in cities with congestion problems. It is a safe, reliable and fast way of transportation and has a relatively large market share in major cities. For example, in London, the rail market share is larger than any other area in the UK. National Rail demand in London grew almost continuously from 1994 until the recession of 2009 and above all forecasts [1].

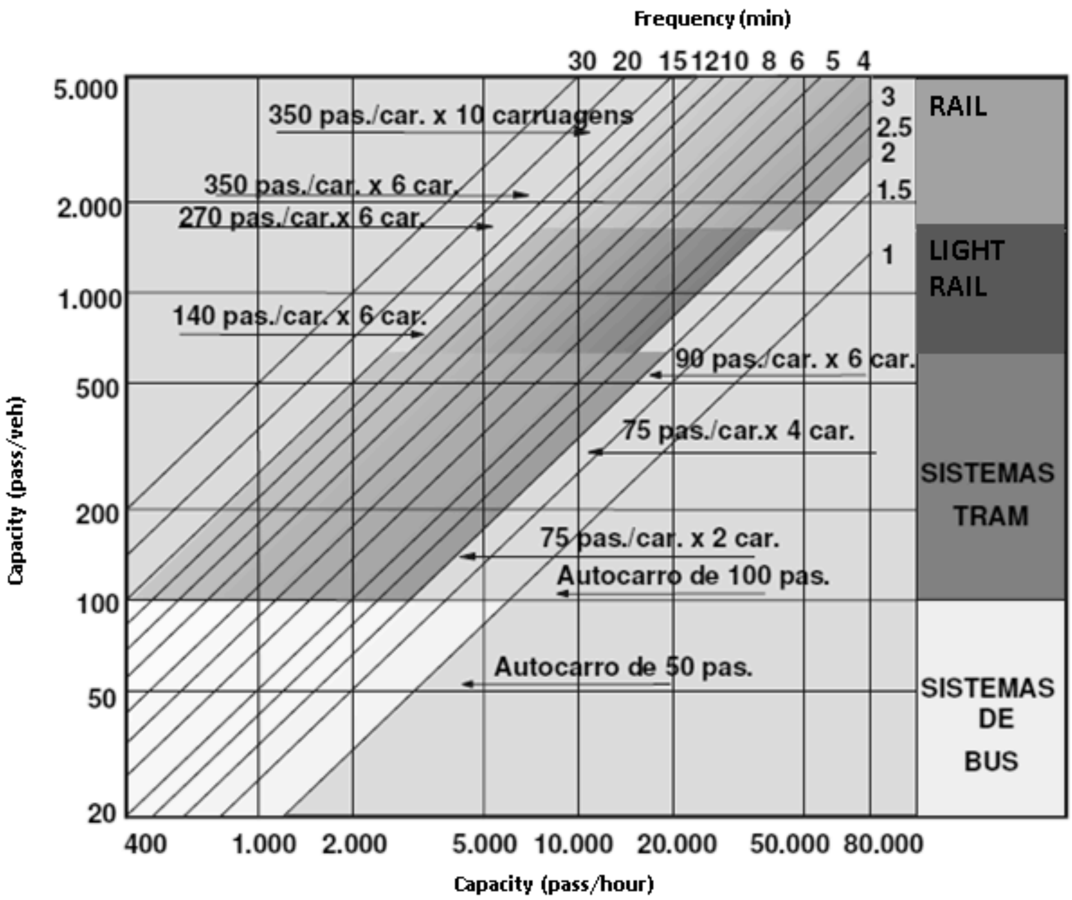

Fig. 1. Different modes of transport and their capacity
Rys. 1. Różne środki transport i ich pojemności

However, there are capacity limitations in railways due to several issues as for example signaling system inefficiencies, different types of railway services in the same infrastructure (high-speed, commuter, freight), poor rolling stock performance, train length limitations, etc.. In order to increase that capacity, there is the need of large capital investments, either in infrastructure or rolling stock, something that is not always financially achievable.

An increase of capacity in rolling stock may be achieved by increasing the density of passengers inside the vehicle. In a modern commuter train, the achievable density of seating passengers is approximately 2.5 to 3 passengers per square meter (pass/m^2) and the normal acceptable density for standing passengers is in the region of 4 to 5 pass/m^2. In Asian countries, this density can be as high as 8 pass/m^2. For new train designs in Hong Kong, a 10 pass/m^2 engineering load is specified and 8 pass/m^2 for passenger planning. In the US, a basic 5 pass/m^2 is considered the worst case allowable planning standard with 6 pass/m^2 or above for engineering requirements. Also, to calculate loads for engineering purposes, an individual weight per passenger is required. This may range from 70 to 75 kg per person and includes a luggage weight factor [2].

As the standing passenger density can almost double the seating passenger density, one possible measure towards this capacity increasing approach may be through exchanging existing seats for standing seats – a seat against which passengers can lean, offering some support in a semi-seated position, with armrests to better define the passenger's travel space.

3. THE DESIGN

3.1. Seat design

In order to design a comfortable standing seat we must take into consideration certain human factors and ergonomic concerns. As a unique scientific discipline, human factors and ergonomics systematically applies the knowledge of human abilities and limitations to the design of systems with the goal of optimizing the interaction between people and other system elements to enhance safety, performance, and satisfaction [3].

The starting point in this design process was the research on anthropometric data so we could make a usable, safe and comfortable seat that could fit the needs of the majority of the potential users. The most important data used in the seat design were measures of shoulder breadth (to assess seat width), body depth (longitudinal spacing between seats) and stature (seat height).

3.1.1. Seat Width

As the vehicle width is a very limiting design factor, we must have a compromise between the seat width and the shoulder breadth dimension percentile we must fit on the seat. In order to fit 95% of the British people, aged 18 to 65, we should need a 537 mm seat width. However, this dimension is larger than the majority of the normal train standard seats and can invalidate the possibility of having 5 seats (in a 3 + 2 arrangement) in a row.

If we relax this objective and we aim to fit only an average person, we need a 484 mm width. For the seat width we chose 500 mm so we could fit an average British male, with a small clearance, necessary because of clothing.

3.1.2. Spacing between seats

The limiting dimension in this issue would be the body depth. We found the 95 percentile of this dimension to be 340 mm, being the minimum value to allow the passenger fitting between seats. The final dimension chosen for the seat spacing was 530 mm, resulting in a free minimum passenger space of 415 mm. This was based on an acceptable clearance (190 mm) between the most front edge of the seat and the front seat to allow a fast and easy ingress and egress.

3.1.3. Seat Height

Due to a high variability of the human stature, particularly buttocks height, we aimed at making a height-adjustable seat so it can fit the majority of the potential users. Buttocks height varies between 691 and 919 mm for adults (male and female, 5 to 95 percentile). By having a height adjustment between 600 and 850 mm from the ground to the seating pad edge, we can cover the majority of the adult population needs.

3.1.4. Seat Inclination

In order to make the seat more comfortable for the passengers back, a back angle of 5^0 was agreed upon.

3.1.5. Armrests

Armrests are positioned to support an average person. The armrests retract automatically by the use of rotational springs and they are damped so they can return to the up position in a controlled manner.

3.2. Manufacturing

The manufacturing of the new seat will be carried out in much the same way that the current seat would be. That said, the specific dimensions of existing seats do not have much in common with the new design.

The head rest will be made of fire resistant foam, reinforced with a flexible plastic casing, likely to be injection moulded. The seat back will be made in similar way, but would require internal support, for example springs. Holding this up is the support, which would be made of a hollow steel pipe or composite equivalent. This would likely be extruded and cut to the correct length, then painted to avoid corrosion. Fig. 2 shows the final standing seat design.

3.3. Economic effect

With the final dimensions of the standing seat (500 mm width and 530mm of seat longitudinal spacing), the feasible passenger density is almost 4 pass/m^2. This is an intermediate value between the usual normal-seating density (2.5 to 3 pass/m^2) and the acceptable standing density in Europe (5 pass/m^2). Fig. 3 shows a typical rail vehicle interior layout using standing seats.

3.4. Seat Layout Study

3.4.1. Congestion Alleviation Layout

Our first design considers two access and egress points in the middle of carriage and set aside enough space near them, as is showed in Fig. 4.

Fig. 2. Standing seat design
Rys. 2. Projekt stojącego miejsca siedzącego

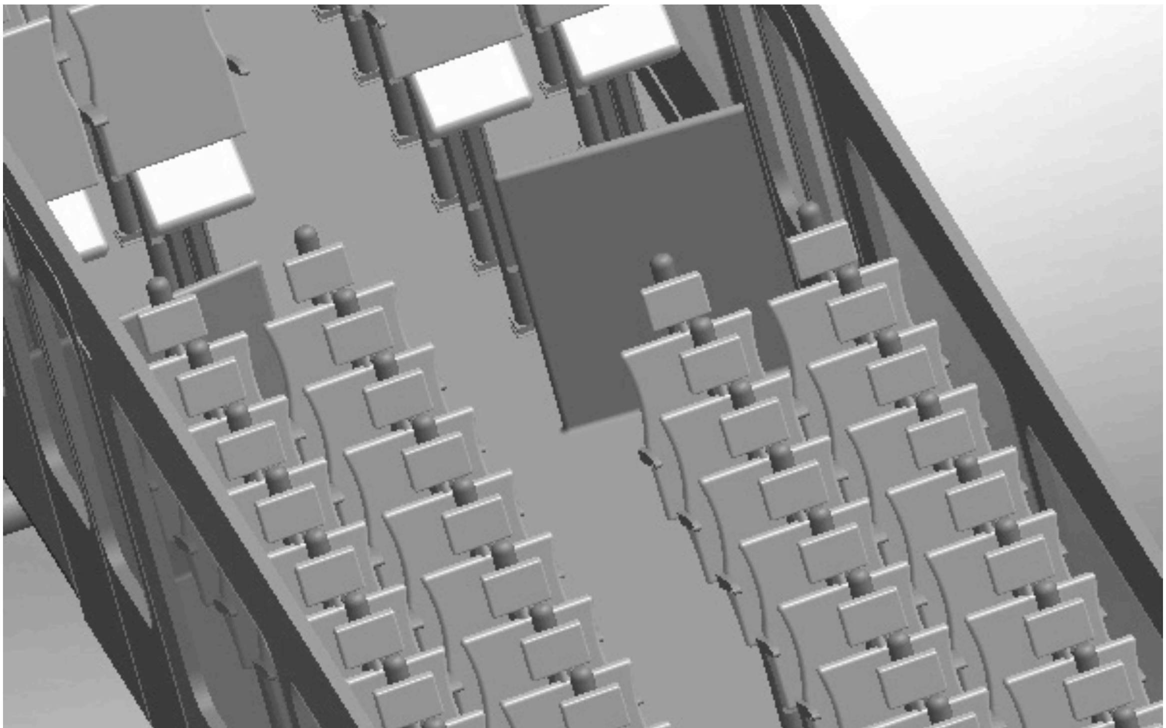

Fig. 3. Vehicle Density
Rys. 3. Ułożenie miejsc w pojeździe

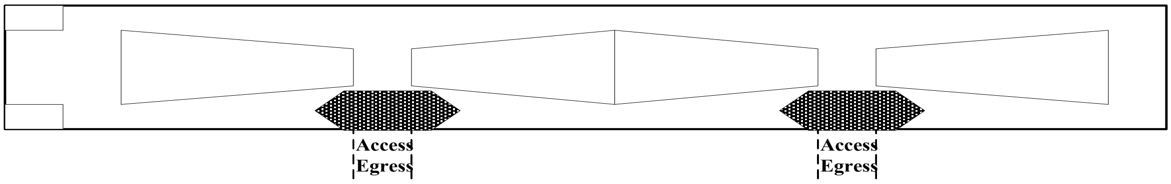

Fig. 4. The design of access and egress
Rys. 4. Projekt wsiadania i wysiadania

Inevitably, passengers keep moving after the train departs, and this kind of movement can be dangerous, so we must consider the factor of congestion when designing the seats.

In order to reduce the congestion, especially when high numbers of passengers get on and off the train at the same time, we designed the seats areas as trapezoids, shown in Fig. 5, where shaded parts represent seats.

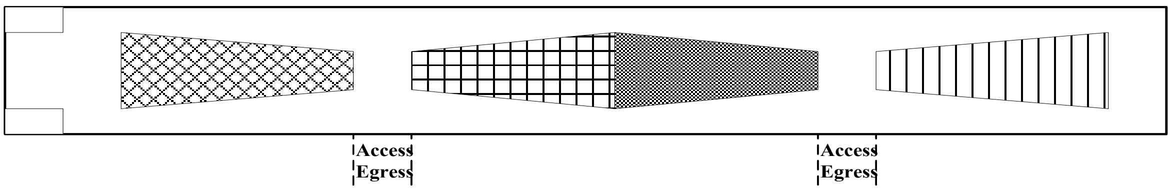

Fig. 5. The design of seats (trapezium section)
Rys. 5. Projekt miejsc siedzacych (sekcja trapezowa)

A design like this can reduce the congestion and make passengers move more easily within the train due to the trapezoid shape. This shape allows more room near the doors to allow for increased access. However, this layout compromises capacity and a more standard layout needed to be adopted.

3.4.2. Final Layout

We chose a more conventional seating plan, with 2 seat rows near each window and an aisle in the middle. There are two door positions located in the ¼ and ¾ length of the vehicle so the access and egress time can have a relatively small variability between the closest and the farthest seats from the doors.

In one end of the vehicle, a space for bigger luggage is also provided. There are a total of 108 standing seats in the final layout (Fig. 6). The free area for standing passengers is 11 m^2, allowing a standing capacity of 55 passengers. The total vehicle capacity is 108 passengers.

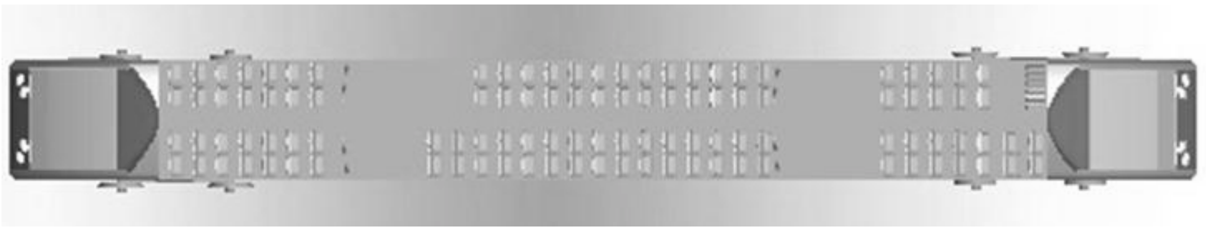

Fig. 6. Seating plan layout
Rys. 6. Układ miejsc siedzących

3.5. Design Conclusions

The layout of carriage is particularly relevant to the passenger's comfort and safety. On the basis of the analysis above, the trapezoid design has some advantages as it can provide enough room near the access points to make passengers get on and off quickly and thus increase comfort and passenger safety. However, that design (Fig. 5) does not fit in as many standing seats as would be fitted using a more conventional approach (Fig. 6). The reason for this is the need to have two aisles in the trapezoid layout, whereas less space is wasted when only using one.

4. HUMAN FACTORS DESIGN

It is a goal of this project to design a safe, efficient and comfortable rail vehicle in order to improve operational efficiency while minimizing the loss of comfort. As the standing seat is a trade-off between these two factors, there is the need to mitigate the utility loss sensation perceived by users due to this new design. In order to redress this loss, an improvement of other vehicle characteristics is deemed necessary to promote the acceptability of the standing-seats solution.

4.1. Vehicle stability and comfort

There are several factors affecting railway vehicles stability and thus affecting comfort and security. In order to assess the derailment potential of a high-capacity and standing-only passenger train we must consider some issues related to some major causes.

4.1.1. Flange climb

Wheel flange climb derailments occur when the wheel climbs onto the top of the railhead and then further runs over the rail. This usually happens when the outer wheel experiences a high lateral force against the high rail and the vertical force on that flanging wheel is reduced. The lateral force may be caused by centrifugal forces due to curvature at high speeds and the reduced vertical force may happen by poor bogie load equalization, track twist or when in presence of vehicle roll resonance.

4.1.2. Lateral Force

The main criteria for determining the maximum speed in curves are security against derailment, passenger comfort and maintenance issues. Usually, the passenger comfort is the most limiting factor of these, forcing the unbalanced acceleration (felt by passengers) to be no higher than 0.8 m/s^2. This reason derives from several tests made with the objective of assessing the threshold of passenger discomfort. In order to achieve good levels of comfort, standing passengers should not experience more than 1 m/s^2 of lateral acceleration in a continuous way. The unbalanced acceleration should be less than 1 m/s^2 because there are always some track defects that can increase, for short periods of time, the theoretical centrifugal acceleration attained in a perfect track. That is a possible reason for having different maximum tolerable cant deficiencies amongst different administrations, depending on the level of maintenance they provide to the infrastructure.

4.1.3. Impact of increased capacity in flange climbing

The weight increase due to higher passenger density should not be of great influence on probability of flange climbing occurrence. However, the suspension system must be correctly dimensioned to distribute the loads evenly between rails, both on empty and loaded carriages, without compromising vertical passenger comfort.

Also lateral comfort can possibly be affected if the suspension system is not carefully designed. When the train is heavily loaded, the passenger displacement towards the outside of the curve can increase the roll coefficient of the train, forcing to reduce the maximum speed in curve in order to maintain the comfort levels.

A particular attention should be paid when a loaded train has to stop in a high cant curve. The passenger mass displacement due to cant can shift the train's center of gravity towards the low rail and consequently making high vertical and lateral loads on this rail. This could cause some problems with train starting motion due to high flange-rail friction.

4.1.4. Impact of increased capacity in overturning

Being a standing-only carriage, the center of gravity of the vehicle would shift to a higher point above the rolling plane as well as shifting towards the outside of curves due to passenger displacement because of the centrifugal force.

With the usual maximum values of cant and cant deficiency, overturning problems are not expected. However, under strong side winds on open locations (no shielding) this might be problematic especially if in presence of poor aerodynamics and tall vehicles and combined with the lateral deflection of the center of gravity because of people displacement.

Therefore, a device limiting the lateral offset (hold-off-device), actuated automatically, will help to reduce the risk of overturning.

4.1.5. Vehicle Lateral Instability

On straight tracks, the wheelset generally oscillates around the track due to vehicle and track irregularities.

This self-centering capability is due to the conical shape of the wheels and the rail cant. At higher speeds, the lateral movement of the wheelset and vehicle, due to high wheel conicity and rail cant, can cause large amplitude and well-defined wavelength oscillations. These lateral movements are limited by flange contact and are called hunting [4].

Vehicle hunting can produce high lateral forces and it can severely damage track and cause derailments. As we are dealing with a standing-only passenger carriage, there's the possibility of the shifting masses of passengers can contribute to greater vehicle lateral instability. This problem can be mitigated with longer wheelbases and better bogie lateral displacement damping, increasing the critical velocity.

4.2. Air Conditioning and Ventilation

When in presence of a high-capacity vehicle, we must take in consideration some aspects of air quality and thermal comfort as the demand for fresh air and air conditioning power is higher than a regular vehicle.

The average value for fresh air needs to maintain an acceptable level of air quality is, according to the ANSI/ASHRAE Standard 62-2001, 8 litres per passenger per second. However, this value is calculated for an estimated maximum density of 1.5 pass/m^2. Given the expectable maximum density of the train being 4 pass/m^2, the demand for outdoor air may be even higher. The system must be dimensioned in order to provide the necessary volume of fresh air to meet the air quality standards at full capacity.

The demand for refrigerating and heating power may also be higher than in a regular train. The heat generated by a person varies according to his body area (as metabolism energy rate is strongly related to body area) and physical activity. For example, a normal value of generated energy (and thus environmental warming) for a seated person is 126W and for a standing person is 167W [5].

This makes necessary a stronger air-conditioning system than it would be necessary on a regular train in order to achieve a good level of comfort whether the train is empty or full, during summer and winter. The ISO 7730 standards of acceptable thermal comfort should be used in order to achieve a PPD (Predicted Percentage of Dissatisfied) of less than 10%. This means that the PMV (Predicted Mean Vote – a grade of coldness and heat sensation) should be always between -0.5 and 0.5, close to the neutral value of zero.

Air entrances and ducts must be dimensioned in a way that all this can be achieved with:

- Radiant temperature asymmetry between cold vertical surfaces (windows, etc.) and a point 0.6 m above the floor should be less than 10^{o}C;
- Air velocity should be less than 0.15 m/s in Winter (temperatures between 20^{o}C and 24^{o}C) and less than 0.25 m/s in Summer (temperatures between 23^{o}C and 26^{o}C);
- Floor temperature should be between 19^{o}C and 26^{o}C.

In order to control all these variables and provide an efficient system for thermal comfort, an Intelligent Transport System must be implemented to vary the system parameters in line with the passenger needs in real-time.

4.3. Emergency Requirements

In traditional trains, the access and egress are via the four doors on the side of the train, as well as at the two ends for during an emergency. It is also true that when it is busy and an accident happens, it may take the passengers a long time to get off. For this reason, for example, small hammers are located in every carriage of most trains; passengers can use them to break the window when some incident happens.

However, recent investigation by Rail Safety & Standards Board [6] built a train window risk model using a rich data source from 52 vehicles involved in accidents, to enable a comparison of two parameters crucial to the escape strategy as follows:

- the likely number of lives saved per year by preventing ejections through windows,
- the likely number of additional fatalities caused by reducing the scope for egress through windows

In none of the accidents investigated had any lives been obviously saved because people were able to escape through windows. Neither were any lives lost, nor would there have been any lost due to people being prevented from escaping through windows. The conclusion drawn during a risk workshop was that there would be an overwhelming net benefit in favour of preventing ejections by the fitting of stronger windows (RSSB, 2007).

That said, the emergency exits on the train are the four doors, with 2100 mm wide and 2000 mm tall and the windows should prevent breakage and induce passengers to stay in the train in case of accident, unless there are obvious safety risks in that option.

Emergency lights play a role in this, being necessary to provide a level of illumination, even in loss of the auxiliary battery feed, sufficient for passengers to evaluate their environment, to see other passengers and crew, administer first aid where essential, read emergency notices, move safely or encouraging them to stay on board if it is safer to do so, locate emergency exits and equipment and facilitate the safe use of exits during evacuation [7].

A whole data transmission system will be equipped in the train. This system includes emergency calls, data transmission as well as voice system within the train. Emergency calls can be of two types: automatic (in case of an accident) and manual. Data transmissions include all the required information such as position of the train, affected wagon and any form accidents. In-train voice system ensures the safety of the train by immediately contact.

4.4. ITS

Intelligent Transport Systems are means to enhance the operation of the transportation system, minimizing its impacts on the environment and improving its safety level and overall efficiency. Its key objectives are the improvement of safety, mobility, productivity, energy saving and customer satisfaction [6].

In this vehicle design, there is the need for systems of this kind in order to achieve better comfort and safety levels and thus improve the passenger's overall satisfaction.

4.4.1. People Counter

Railway companies have many methods to organise their train schedules for passengers whom use their trains every day. This scheduling is essential to optimise costs and increase the capacity of network lines. Therefore, service for passengers is also one of the critical issues which should be valued by service providers. Additionally the timetables, drivers, station staff, ticket prices and availability and other kinds of features must be at an optimal level. When the planners organize these systems, they usually use statics of passenger traffic using commuter trains.

The Passenger Count System (PCS) has a vital role in this case. Knowing the passenger movement and numbers in a network at all times makes planning work easier. Therefore, the information which the planner needs is the number of passenger and movement during the time period. The PCS gives information dynamically to planner and I.T. systems.

The PCS is based on simple image processing. Image processing is the analysis of a signal acquired from input images. Characteristic or parametric information of pixels which refers to the image can be measured by computers which analyse each pixel in turn. Video input can be considered as animated images, therefore video can also be processed.

If a simple camera (such as a webcam) is set above the vehicle doors, it can observe the path of passengers and detect their motions. At the same time, the software changes every image per second to grey pixels, otherwise each pixel will have 3 colours (RGB) making it harder to process. After the grey image is filtered, colour differences between neighbouring pixels can be understood easily. Therefore, the location of movement can be detected.

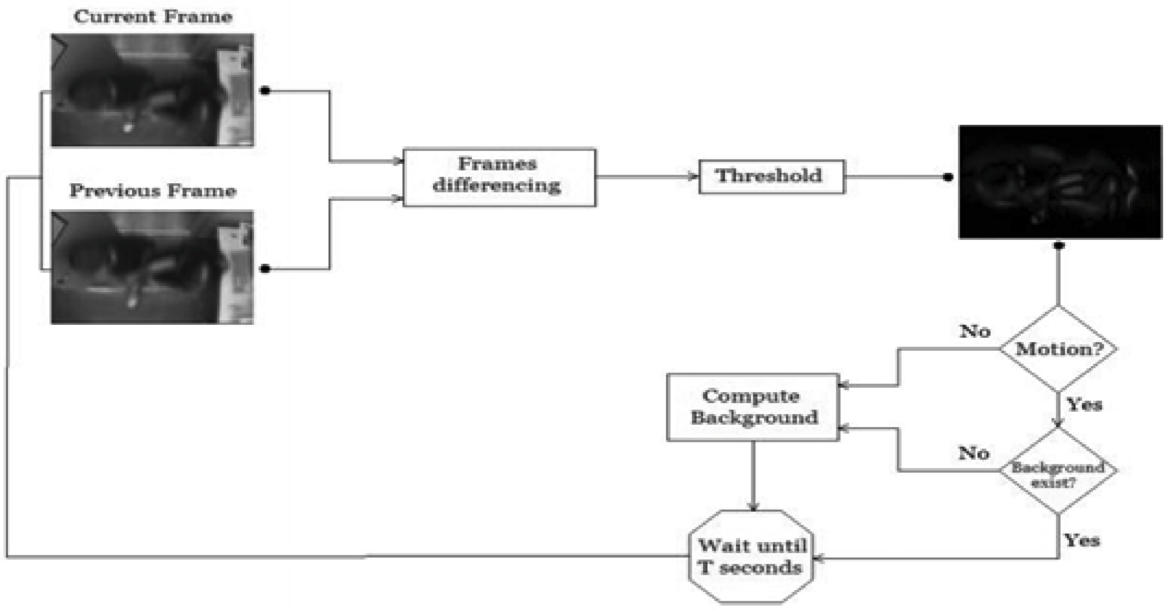

Fig. 7. Passenger Count System architecture
Rys. 7. Architektura systemu zliczania pasażerów

It is easy to implement these people counters to vehicles' doors and stations exits. The equipment required is basic and readily available. Cameras for each door are needed; however, one computer is needed to process the data. Intelligent Transport Systems (ITS) takes control here and collects data from each camera. After the system counts the passenger numbers, it will send data to a main computer on the train which controls the HVAC (Heating, Ventilation and Air Conditioning) and the suspension system.

Each train carriage will need different air conditioning power, ventilation and temperature based on the outside temperature and on the number of passengers on-board. The suspension system also has to be more flexible or stiff depending on the load of the vehicle. So, with a relatively inexpensive sensor system like the PCS, the necessary information can be provided to the vehicle's CPU which can adjust the necessary parameters.

5. CONCLUSIONS

Overall, the design detailed in this paper directly addresses the question of how to improve the capacity of European railways. It tackles the problem in one of the most important areas of rail design: increased capacity per vehicle and alleviation of rush-hour over-crowding.

This new design increases the sitting capacity of a coach from around 70 to 108. This is a 54% increase in passenger capacity. There is obviously less comfort achieved here than in a sitting carriage, but it is felt that if the ticket is cheaper, the journey relatively short (30 mins - 1 hour) and with proper design to provide good levels of thermal and spatial comfort, then commuters would not object to travelling in this way.

Furthermore, this concept may even increase the number of people choosing to travel by train, as it provides a cheaper way to travel. Demand elasticity of the rail transport varies between -0.51 on the short-run and -0.75 on the long-run and the cross-share elasticity between car travel cost and rail is almost 0.1 [9].

This competition with other transport modes can increase the stake that the rail service has, as it would benefit from the possibility of lowering rail fare prices and the fuel price uptrend that increases car travel cost.

In terms of safety, the standing seat offers a safer alternative to simply standing. The semi-seated position and armrests would allow passengers to maintain their position in the event of a collision.

References

1. Transport for London: Rail and Underground Panel. *“TFL’S Recommendations for the high level output specification for 2014 – 2019 (HLOS2)”*. 2011. P. 77.
2. Connor, P. *Railway Passenger Vehicle Capacity: An overview of the way railway vehicle capacity has evolved*. 2011. Available at: http://www.railway-technical.com/Infopaper%202%20Railway%20Passenger%20Vehicle%20Capacity%20v3.pdf
3. Shaver, E. & Braun, C. *What is Human Factors and Ergonomics?* Available at: http://www.benchmarkrs.com
4. Iwnicki, S. *Handbook of Railway Vehicle Dynamics*. CRC Press. Taylor & Francis Group. 2006. P. 552.
5. Águas, M.P.N. *Conforto Térmico*. 2000/01. Available at: http://in3.dem.ist.utl.pt/laboratories/pdf/emee_1.pdf
6. Rail Safety & Standards Board (RSSB). R*equirements for train windows in passenger rail vehicles*. 2007.
7. Rail Safety & Standards Board (RSSB). *Recommendation for rail vehicle-Emergency Lighting*. 2008.
8. Macário, R. *Gestão da Mobilidade Urbana*. 2011.
9. Litman, T. Transit Price Elasticities and Cross-Elasticities. *J. Public Transp.* 2004. Vol. 7. No. 2. P. 37–58.

Received 10.07.2014; accepted in revised form 08.10.2014