The problems of the presence of passenger and freight trains in the same track and their impact on the profitability of the railway companies

Prof Christos Pyrgidis, Evangelos Christogiannis, Msc Civil engineer
Aristotle University of Thessaloniki, Greece

1. Introduction

The vast majority of railway networks worldwide practice mixed operation [1], [2], [3], [4]. Passenger and freight trains share the same track. This was the basic rule in the railway sector for many years. This practice on one hand seems to achieve economies of scale, as more trains make use of the same railway infrastructure, on the other hand however it causes problems in the network operation and maintenance as trains with different axle load and cinematic characteristics circulate on the same track. Many features of the freight wagons/trains differ substantially from those of the passenger coaches/trains. As a result, sharing the same track affects directly or indirectly the design, construction, operation and maintenance of a railway system.

The evolution in the transport volume and the viability of the various railway companies worldwide shows that there is prosperity in corridors or networks in general, where a dedicated operation scheme is applied, with either passenger or freight trains. Freight networks/corridors, in particular, are profitable, in constant growth and need no financial subsidy [5].

Railway infrastructure managers are aware of the problem and are trying to address it. Several countries are considering developing new railway infrastructures for dedicated operation while the World Bank recommends that railway organizations in distress should proceed to separate their passenger and freight transportation activities [6], [7], [8], [9].

This paper attempts to answer a question which is a matter of concern to many railway companies. Which is financially more efficient? Having both passenger and freight trains routed on one railway network/corridor at the same time (mixed operation) or separating passenger from freight traffic (dedicated operation)? [10]

In this context, this paper:

- Develops and proposes a methodology to classify railway networks and corridors based on traffic composition
- Correlates, considering a specific sample of networks, the traffic composition with the financial performance of the railway system, drawing conclusions
- Records the features of the freight wagons/trains that differ significantly from those of the passenger coaches/trains and identifies among them the ones that affect directly or indirectly the construction, operation and maintenance of a railway system, depending on whether it is intended for dedicated or mixed train operation
- Evaluates qualitatively and quantitatively the effect of some of the above features on the constituents and elements of the railway system

The field of application of this work is limited to the conventional speed interurban networks.

This paper constitutes a first approach of an overall research currently under way in the Transportation Department of Aristotle University of Thessaloniki. This research aims at investigating the effects of mixed train traffic in the efficiency of a railway system and at creating mathematical models, which could serve as decision support tools for the railway infrastructure managers, concerning the operational scheme to be adopted for a given rail corridor (dedicated or mixed operation).
2. Traffic composition and financial performance of a railway system

2.1. Terms and Definitions

“Mixed train operation” is understood as the routing of passenger and freight trains on the same track.[11]

“Dedicated passenger or freight train operation” is understood as the exclusive routing of either passenger or freight trains on a track. In this case, the infrastructure serves uniquely one train type and the task of managing the services provided by the network operator is greatly simplified. [11]

“Traffic composition” is understood as the percent traffic share of each train category out of all trains using the same railway infrastructure. It may also be defined as the percentage of the overall track capacity occupied by each of the various train categories.

The “efficiency” of a railway transportation system is a function of three parameters [11]:

- the level of services provided to the users of the system
- the financial profitability for the system operator, resulting from all system-related activities
- the impact (positive and negative) incurred by the system along its write- of- way as well as in the wider environment.

As “financial profitability” of a railway network/corridor is defined its capacity to produce significant transport volume, compared to other competitive transportation means and to be financially robust, i.e. to show profit rather than deficits and debts.

As “viability index” of a railway company is defined the ratio of the operational revenues to the operational expenses.

“Earnings Before Interest and Taxes (EBIT)” is the financial index denoting the profitability of a railway company in the year referred to in the balance sheet, without considering any interest and before the profits are taxed.

2.2. Classification of railway networks based on traffic composition

Classification categories and criteria

Based on their traffic composition, railway networks may be classified in the following five (5) categories:

1. Dedicated freight operation network
2. Partially mixed freight operation network
3. Mixed operation network
4. Partially mixed passenger operation network
5. Dedicated passenger operation network

For this classification, quantifiable operational features are used that affect or characterize, either directly or indirectly:

- The type and quantity of the transport volume carried over the network
- The track capacity of the railway infrastructure
- The required amount of track maintenance work
- The length of the available railway infrastructure and the degree of track capacity occupancy by passenger and freight trains, respectively

As such quantifiable features are usually considered:

- Passengers carried per year (p)
- Goods carried per year (t)
- Passenger-kilometers traveled per year (pkm)
- Ton-kilometers of goods traveled per year (tkm)
- Number of passenger and freight trains circulating daily
- Daily traffic load of passenger and freight trains
Challenge C: Increasing Freight capacity and services

- The number of trailer passenger coaches and freight wagons constituting the rolling stock fleet of the network in question
- The train-kilometers traveled in the network by either train type (overall distance traveled by passenger/freight trains)

The above classification may refer to an entire railway network or to a specific railway corridor.

Based on the above, five (5) criteria have been identified in order to classify a network into one of the five aforementioned categories:

CRITERION I: The ratio of the trailer passenger coaches or freight wagons in operation to the total fleet of a railway network.

CRITERION II: The ratio of the daily passenger traffic load to the respective freight traffic load.

CRITERION III: The ratio of the passenger trains to the freight trains circulating in the network.

CRITERION IV: The ratio of the train-kilometers traveled per year by passenger trains to the respective train-kilometers traveled by freight trains.

CRITERION V: The ratio of the passenger-kilometers of passenger trains to the ton-kilometers of freight trains.

Selection of network sample to be classified

The network sample has been selected, so as to ensure the following:

- All continents are covered
- Countries with the most extensive railway networks are included
- Countries, where transport volumes are particular in terms of traffic composition (e.g. mainly passenger, mainly freight, balanced composition) are also included
- Membership of the International Railway Union (UIC), so that valid data can be retrieved [4]

The sample comprises the 20 countries listed in the second column of table 1.

Multi-criteria classification of the sample networks based on the traffic composition

Every network has been initially classified into one of the five defined categories, based on each individual criterion. To this end, classification ranges have been defined within each criterion. E.g. for criterion II, networks with a ratio of daily passenger traffic load to the respective freight traffic load between 0-0.1 have been classified into category 1, networks with a ratio between 0.1-1 into category 2, networks with a ratio between 1-6 into category 3, networks with a ratio between 6-100 into category 4 and finally, networks with a ratio >100 into category 5.

Furthermore, it is considered that the five presented criteria do not have all the same impact to the determination of the traffic composition of a network and the associated network classification based on traffic composition. In this context, each criterion was assigned a different weight, considering the degree to which its mathematical expression is related to the operational characteristics affected by the traffic composition. In particular, in table 2, a very significant correlation between a criterion's mathematical expression and an operational characteristic was qualitatively rated with (xxxx) while a rather insignificant one was rated with (x). The weighing factor of each criterion is measured as a percent fraction of one and results from the overall qualitative rating of every criterion through an appropriate extrapolation.

In this way, China is classified in traffic composition category 2, based on criteria I, II and III, and in category 3, based on criteria IV and V. Therefore, China will belong to either category 2 or category 3.

Based on the weighing factors, category 2 dominates since it is rated at 0.57 (0.10+0.20+0.27 = 0.57), outranking category 3 rated at 0.43 (0.23+0.20=0.43).
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<table>
<thead>
<tr>
<th>No</th>
<th>COUNTRY</th>
<th>NETWORK CATEGORY</th>
<th>RAILWAY COMPANY</th>
<th>EBIT [2007] [ x10^8 €]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>USA</td>
<td>1</td>
<td>AMTRAK (passengers) CLASS I (freight)</td>
<td>-698.63</td>
</tr>
<tr>
<td>(2)</td>
<td></td>
<td></td>
<td></td>
<td>4,625.85</td>
</tr>
<tr>
<td>(3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Canada</td>
<td>1</td>
<td>CN,CP,VR, etc (freight)</td>
<td>1,736.11</td>
</tr>
<tr>
<td>2</td>
<td>Lithuania</td>
<td>1</td>
<td>Lietuvos geležinkelių AB</td>
<td>347.80</td>
</tr>
<tr>
<td>3</td>
<td>Australia</td>
<td>2</td>
<td>QR Group (freight) Rail Corp. NSW (passengers)</td>
<td>335.89</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>-1,116.14</td>
</tr>
<tr>
<td>5</td>
<td>Estonia</td>
<td>2</td>
<td>EESTI RAUDTEE</td>
<td>17.64</td>
</tr>
<tr>
<td>6</td>
<td>Latvia</td>
<td>2</td>
<td>BE</td>
<td>41.30</td>
</tr>
<tr>
<td>7</td>
<td>Russia</td>
<td>2</td>
<td>RZD</td>
<td>3,082.89</td>
</tr>
<tr>
<td>8</td>
<td>China</td>
<td>2</td>
<td>CR</td>
<td>6.42</td>
</tr>
<tr>
<td>9</td>
<td>Ukraine</td>
<td>2</td>
<td>UKRALIZNYTSIA</td>
<td>110.03</td>
</tr>
<tr>
<td>10</td>
<td>S. Africa</td>
<td>3</td>
<td>TRANSNET</td>
<td>879.60</td>
</tr>
<tr>
<td>11</td>
<td>Poland</td>
<td>3</td>
<td>PKP</td>
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</tr>
<tr>
<td>12</td>
<td>Austria</td>
<td>3</td>
<td>ÖBB</td>
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<td>13</td>
<td>Romania</td>
<td>3</td>
<td>CFR</td>
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<tr>
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<td>Germany</td>
<td>3</td>
<td>DB</td>
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<tr>
<td>15</td>
<td>Spain</td>
<td>3</td>
<td>RENFE</td>
<td>-141.60</td>
</tr>
<tr>
<td>16</td>
<td>India</td>
<td>4</td>
<td>IR</td>
<td>249.06</td>
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<tr>
<td>17</td>
<td>France</td>
<td>4</td>
<td>SNCF</td>
<td>856.00</td>
</tr>
<tr>
<td>18</td>
<td>Italy</td>
<td>4</td>
<td>FS</td>
<td>201.00</td>
</tr>
<tr>
<td>19</td>
<td>Un. Kingdom</td>
<td>4</td>
<td>ARRIVA</td>
<td>121.62</td>
</tr>
<tr>
<td>20</td>
<td>Japan</td>
<td>5</td>
<td>JR EAST (passengers)</td>
<td>2,094.00</td>
</tr>
</tbody>
</table>

Table 1: Results of multi-criterion assessment of networks based on traffic composition - Financial profitability of railway companies based on EBIT index

<table>
<thead>
<tr>
<th>CRITERION I</th>
<th>CRITERION II</th>
<th>CRITERION III</th>
<th>CRITERION IV</th>
<th>CRITERION V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport volume</td>
<td>x</td>
<td>xxx</td>
<td>xxx</td>
<td>xx</td>
</tr>
<tr>
<td>Track capacity</td>
<td>x</td>
<td>x</td>
<td>xxx</td>
<td>x</td>
</tr>
<tr>
<td>Amount of track maintenance</td>
<td>x</td>
<td>xxx</td>
<td>xxx</td>
<td>x</td>
</tr>
<tr>
<td>Infrastructure length / track capacity occupancy</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>xxx</td>
</tr>
<tr>
<td>Total ratings</td>
<td>4x</td>
<td>9x</td>
<td>11x</td>
<td>10x</td>
</tr>
<tr>
<td>Weighing factor</td>
<td>0.10</td>
<td>0.20</td>
<td>0.27</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Table 2: Assigning of weighing factors to the network classification criteria based on traffic composition
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Based on the five assessment criteria as well as the above multi-criterion approach, we deduce the final ranking of the network sample in the five traffic composition categories (column 3, table 1). The conclusions drawn from the network sample classification are the following:

- Most E.U. networks are classified in categories 3 and 4, the majority being in category 4, i.e. passenger transportation is predominant.
- The USA, Canada and Lithuania are classified in category 1, i.e. they are dedicated freight train networks.
- Japan network is the only category 5 network, i.e. dedicated passenger train network.
- Almost all east European networks are classified in categories 2 and 3, with the majority in category 2, i.e. emphasizing in freight transport.

2.3 Correlation between traffic composition and financial profitability of a railway system

As far as financial profitability is concerned it should be noted that:

- the sample networks have been evaluated based solely on the earnings before interest and taxes (EBIT). It would, however, be scientifically more accurate to also consider other measurable quantities or indexes as criteria, such as market share of the railway vis-à-vis the competitive means of transportation, transport volume growth in the recent years, railway companies’ debts etc.
- In this phase the correlation of traffic composition and financial profitability, at railway network level, has been investigated. Soon a further investigation at corridor level will be carried out. This second approach is considered essential for this research, however the retrieve of valid data concerning the financial profitability of specific railway corridors encounter difficulties.

In column 5 of table 1 is presented the classification of the sample networks by their financial profitability, based on the EBIT\(^1\) index. It is generally concluded that in dedicated operation networks, railway companies covering the dominant traffic are generally profitable and usually not state-subsidized. In the USA, for example, where the railway network is considered as dedicated freight in what concerns traffic composition, the companies covering the dominant traffic, i.e. freight, are in their majority particularly profitable, yet not subsidized by the state. Similarly in Japan, where traffic is dedicated passenger service, the three biggest railway companies carrying only passengers are also profitable, without any state subsidy. Mixed operation networks are less profitable or even loss-making.

![Figure 1: Correlation between traffic composition and EBIT of railway networks](image)

\(^{1}\) Data drawn from the Balance Sheets of railway companies for fiscal year 2007
The above are presented in the graph of figure 1, which has been drawn from the data of table 1 through polynomial regression. As shown, profits of railway companies are higher in dedicated operation networks, shrinking as traffic shifts towards mixed operation. If, on top of the data given above, we also consider taxes, interest expenses and state subsidies which affect their balance sheets, we can deduce that the majority of companies operating in mixed traffic networks are loss-making. [5]

3. Traffic composition and its impact to the construction and operation of a railway system

Table 3 shows the qualitative impact of the features, which differ substantially between freight and passenger vehicles/trains, to the constituents and elements of a railway system. [10], [11] Below is described the quantitative relationship between train features and railway system constituents and elements for some of these interfaces.

3.1 Impact of axle load to the railway system constituents and elements

Axle load – rail profile correlation
Based on formula (3.1) [12], it is deduced that axle loads of 20, 25 and 30t require rails of minimum weight 50, 60 and 70 kg/m respectively. A 25% increase in the axle load requires a 20% increase in the rail weight.

\[ B_o = 2.25Q + 3 \]  
(3.1)

Where: \( B_o \): rail weight per running meter (kg)  
\( Q \): axle load (t)

The choice of rail weight is also greatly conditioned by the track design speed and the daily traffic load.

Axle load – maintenance requirements correlation
Considering two railway tracks with axle load values of \( Q_1 = 16 \) t and \( Q_2 = 22.5 \) t, and assuming that speed is almost equal in both cases, it results [13],[14]:

\[ \frac{C_2}{C_1} = 1.406^\frac{\beta}{\alpha} \]  
(3.2)

Where: \( C_2, C_1 \) the relevant maintenance costs  
\( \alpha, \beta \) empirically determined coefficients [11], [12], which vary with the infrastructure element fault

The ratio \( C_2/C_1 \) is calculated between 1.41 and 2.78 (the ratio \( \beta/\alpha \) is calculated between 1 and 3.5), i.e. maintenance cost in the case of a track with \( Q_2 = 22.5 \) t is between 41% and 178% greater than that for a track with \( Q_1 = 16 \) t.

3.2 Impact of daily traffic load to the railway system components and elements

Daily traffic load – track bed thickness correlation
Based on the chart of figure 2 [15], for a track substructure with a CBR index of 15 and heavy daily traffic load, a 30 cm thick ballast layer is required. If traffic is light, a 15 cm thick ballast layer is adequate.

In UIC 5 and UIC 6 Class lines, track bed thickness is reduced by as much as 18% of the respective UIC 1 and UIC 2 Class lines track bed thickness. [16]
<table>
<thead>
<tr>
<th>Train/Vehicle characteristic – qualitative influence</th>
<th>Effects on the railway system constituents and elements - Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed (V) - Increase</strong>&lt;br&gt;Is greater in passenger trains (120-350km/h) than in freight trains (60-120km/h)</td>
<td><strong>Increase</strong>: Track design dynamic load, train braking distance, centrifugal effort in curves, aerodynamic resistance, track capacity, consequences in case of accident&lt;br&gt;&lt;br&gt;<strong>Requirements</strong>: Larger axial distance between tracks, higher curvature radius in the longitudinal and vertical alignment, higher track cant, greater length of transition curve in the horizontal alignment, continuously welded and heavier rails, concrete sleepers, elastic fasteners, thicker track bed, track fencing, electric signaling, longer signal spacing, electrification (for V&gt;160 km/h), specific rolling stock, slow train overtaking, increased safety measures along the track, bigger tunnel cross-section, higher maintenance needs.</td>
</tr>
<tr>
<td><strong>Axle load (Q) – Increase</strong>&lt;br&gt;Is lower in passenger trains (12-18t) than in freight trains (16-25t)</td>
<td><strong>Increase</strong>: Track design static load, train braking distance, track geometry defects deterioration rate, train running resistance&lt;br&gt;&lt;br&gt;<strong>Requirements</strong>: Less steep gradients, heavier rails, thicker track bed, longer signal spacing, greater traction power requirements, higher maintenance needs</td>
</tr>
<tr>
<td><strong>Train weight (B) - Increase</strong>&lt;br&gt;Is much smaller in passenger trains than in freight trains</td>
<td><strong>Increase</strong>: Braking weight, train running resistance&lt;br&gt;&lt;br&gt;<strong>Requirements</strong>: Less steep gradients, longer signal spacing, greater traction power requirements</td>
</tr>
<tr>
<td><strong>Train length (Lz) - Increase</strong>&lt;br&gt;Is much smaller in passenger trains</td>
<td><strong>Decrease</strong>: Track capacity&lt;br&gt;&lt;br&gt;<strong>Requirements</strong>: Longer tracks and platforms in stations</td>
</tr>
<tr>
<td><strong>Daily traffic load (Tf) - Increase</strong></td>
<td><strong>Increase</strong>: Track maintenance needs, track geometry defects deterioration rate&lt;br&gt;&lt;br&gt;<strong>Requirements</strong>: Heavier rails, thicker track bed, higher maintenance needs</td>
</tr>
<tr>
<td><strong>Dynamic passenger comfort</strong>&lt;br&gt;Concerns mainly the passenger coaches</td>
<td><strong>Requirements</strong>: In the case of passenger trains, lateral residual centrifugal acceleration &lt; 1.0 m/sec², greater curvature radius in the longitudinal and vertical alignment, higher track cant, greater length of transition curve in the horizontal alignment. In case of mixed traffic, adoption of track normal cant satisfying both train categories</td>
</tr>
<tr>
<td><strong>Punctuality</strong></td>
<td><strong>Requirements</strong>: Imperative for passenger trains - Desirable for freight trains</td>
</tr>
<tr>
<td><strong>Vehicle clearance gauge</strong></td>
<td><strong>Requirements</strong>: Differentiates depot and station dimensioning, axial distance between tracks, height clearance under structures</td>
</tr>
<tr>
<td><strong>Terminal Stations</strong></td>
<td><strong>Requirements</strong>: Totally different design and equipment in passenger and freight stations. Passenger trains stop much more frequently (every 60-100km) than freight trains (every 300-800km)</td>
</tr>
<tr>
<td><strong>Transported good</strong></td>
<td><strong>Requirements</strong>: Different safety measures required for the infrastructure and the rolling stock when transporting passengers compared to cargo. Special safety measures in tunnels when carrying passengers, special safety measures along the open track when carrying dangerous goods</td>
</tr>
</tbody>
</table>

Table 3: Qualitative impact of train characteristics to the constituents and elements of a railway system - Requirements
Challenge C: Increasing Freight capacity and services

3.3 Impact of train length to the railway system constituents and elements

**Train length – track capacity correlation**

In figure 3 is depicted the track capacity of a track of one direction of circulation with an intermediate block signal as a function of train length. [17], [18]. From this diagram we can deduce that track capacity decreases as train length increases. This is due to the fact that longer trains require longer time to release a block section, leading to longer minimum train headways. For example, an increase in train length from 500 to 1500m leads to a decrease of track capacity from 88 to 81 trains per day.

![Figure 3: Track capacity – train length variation diagram (double track)](image)

3.4 Impact of passenger dynamic comfort requirements to the railway system constituents and elements

**Lateral dynamic passenger comfort – horizontal curvature radius correlation**

In figure 4 is depicted for dedicated operation, the minimum permitted horizontal curvature radius $R_{c_{min}}$ as a function of the lateral residual centrifugal acceleration $\gamma_{nc_{max}}$, for maximum allowed normal cant $U_{max} = 160$ mm, $V_{max} = 200$ km/h and $120$ km/h.

Assuming three operation schemes:
1. Dedicated passenger train service with uniform speed $V_{\text{max}} = 200 \text{ km/h}$, $U_{\text{max}} = 160 \text{ mm}$, $\gamma_{\text{nc max}} = 0.6 \text{ m/s}^2$ (usual value for passenger trains), maximum permitted cant deficiency $I_{\text{max}} = 90 \text{ mm}$ (deriving from formula (3.3)) [15]

$$I_{\text{max}} = \frac{2e_0}{g} \gamma_{\text{nc max}}$$

(3.3)

Where $2e_0 = \text{track gauge} = 1500\text{mm}$, $g = \text{gravitational acceleration} = 10\text{m/sec}^2$

2. Dedicated freight train service with uniform speed $V_{\text{max}} = 120 \text{ km/h}$, $U_{\text{max}} = 160 \text{ mm}$, $\gamma_{\text{nc max}} = 1.0 \text{ m/s}^2$ (no dynamic lateral comfort issue in freight trains), $I_{\text{max}} = 150\text{mm}$ (deriving from formula (3.3))

3. Mixed train operation with $V_{\text{max}} = 200 \text{ km/h}$, $V_{\text{min}} = 120 \text{ km/h}$, $U_{\text{max}} = 160 \text{ mm}$, $\gamma_{\text{nc max}} = 0.6 \text{ m/s}^2$, $I_{\text{max}} = 90 \text{ mm}$, maximum allowed cant excess $E_{\text{max}} = 100 \text{ mm}$

we derive for them the following minimum horizontal curvature radii, respectively: $R_{\text{cmin}} = 1888 \text{ m}$, $R_{\text{cmin}} = 548 \text{ m}$, $R_{\text{cmin}} = 1589 \text{ m}$. We note that the fastest (passenger) trains determine the horizontal curvature radius [11],[16],[19]

![Figure 4](image)

**Figure 4:** Minimum horizontal curvature radius $R_{\text{cmin}}$ as a function of maximum permitted residual centrifugal acceleration $\gamma_{\text{nc max}}$

3.5 Impact of train speed to the railway system constituents and elements

Train speed – rail profile correlation

The diagram in figure 5 presents the rail profile requirements for axle loads of 16 and 22.5 t, as a function of train speed

Where

$k \quad \frac{W_d}{I_z}$

$I_z \quad \text{Rail moment of inertia [m}^4\text{]}$

$W_d \quad \text{Static moment of inertia relative to rail foot [m}^4\text{]}$

As can be seen from the diagram, a speed increase leads to a rail profile weight increase, for the same axle load.

The same rail weight is required for freight trains with 22.5 t axle load and $V=80 \text{ km/h}$ and for passenger trains with 16 t axle load and $V=200 \text{ km/h}$.

It must be stressed in this point that achieving high speeds relies heavily on ensuring retaining track geometry. To this end, high speed networks ($V > 200 \text{ km/h}$) are using only heavy rails (UIC 60 (60.3 kg/m)) as these limit rail vertical displacement to acceptable levels.
Challenge C: Increasing Freight capacity and services

Train speed – track capacity correlation
In figure 6a is depicted the track capacity of a single track of two directions of circulation as a function of time required to travel the critical track section by the trains. It is noted that an increase in travel time for all trains (resulting from proportional decrease of their speed) leads to a capacity reduction. As an example, doubling the travel time (i.e. reducing speed by half) results to track capacity reduced to half (from 62 to 32 trains/day).[18]

In figure 6b is depicted the capacity of a double track as a function of traffic composition (homogeneity). The mark “a” denotes a train travelling the critical section in a short time (in this example this is a=8min), “c” denotes a train travelling the critical section in a long time (c=12min), “b” denotes a train travelling the critical section in an average time (b=10min), while “m” denotes a train type travelling the critical section in a time equal to the weighted average of travel times of all trains (here m=11min). From figure 6b it can be concluded that in the case of an intermediate block signal in the critical track section, track capacity is maximized when trains are homogenous in terms of critical section travel time, and, accordingly, speed (90 trains / day – sequence “m-m-m-m-m-m”). If there are three train types, namely a, b, c, the sequence “a-b-c-a-b-c” leads to a capacity decrease to 85 trains /day.
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4. Conclusions

This paper is a first attempt to investigate whether the traffic composition of a railway network is related to its financial profitability. The motivation for this investigation was the fact that in recent years, most mixed operation networks show an important decline of their transport volume. On the contrary, dedicated freight networks are profitable, in constant growth and in no need of financial subsidy. [1],[2],[3].

The findings of this paper have shown that:

- In dedicated operation networks, railway companies can expect higher profits, which are shrinking as traffic shifts towards mixed operation. Dedicated freight networks are more profitable than dedicated passenger ones. If we also consider taxes, interest expenses and state subsidies which affect their balance sheets, we can deduce that the majority of companies operating in mixed traffic networks are loss-making.

- The need to have passenger and freight trains sharing the same track has significant impact to the design, construction and maintenance of a railway system. By way of indication, in the case of constructing a single or double track for mixed train operation:
  - The alignment is determined by the design speed defined for passenger trains
  - Superstructure is built based on passenger train speed and freight train axle load
  - Track maintenance policy considers the daily traffic load made up of all trains.
  - Train rooting schedule must include trains running at different speeds, with whichever consequence to the track capacity.

Mixed networks satisfy primarily passenger transportation. This priority usually leads to resource inadequacy for freight trains, which are further delayed in favor of passenger trains. The cargo transportation market needs differ from those of passenger transportation. This seems to enforce the progressive segregation of networks for passenger and freight transportation. [20]

References

[7] Anjali Goyal, Executive Director Finance (Budget), «Dedicated Freight Corridors & High Speed Rail India’s -Ultra Low Carbon Mega Rail Projects», Ministry of Railways, India
Challenge C: Increasing Freight capacity and services