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**INLAND TRANSPORT COMMITTEE**

Working Party on Rail Transport  
(Fifty-sixth session, 16-18 October 2002,  
agenda item 5)

**PRODUCTIVITY IN RAIL TRANSPORT**

Note by the secretariat

Note: As requested by the Working Party at its fifty-fourth session in 2000 (TRANS/SC.2/194), the secretariat has prepared the attached note for consideration by the Working Party.

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## I. Background

In order to have an appropriate basis for drawing certain conclusions from productivity indexes, the Working Party on Rail Transport, at its fifty-first session in 1997 (TRANS/SC.2/188, paras.17-18), had underlined the importance of social, technical, economic and political framework for rail productivity. At its next session, the Working Party considered the data on rail productivity provided by the OSZhD and UIC. Commenting on the differences in the value of productivity indicators between countries, it reiterated its observation that the technical, economic, political, geographic, etc. framework of each country was reflected, to a considerable extent, in productivity measurements. The Working Party underlined the fact that the principal difficulty in such comparisons was to ensure that one was comparing like with like.

In order to pursue further discussion of this item, the Working Party asked the representative of UIC and the OSZhD to provide data of their member railways on the eight productivity criteria also indicating the growth rates for the individual criteria.

The indicators were as follows:

(a) Labour productivity: (distinguishing between high-speed and conventional rail transport)	employees/km of network in use net ton-km + passenger-km/employee
(b) Productivity of freight transport:	per km: - gross ton-km/km of network - net ton-km/km of network per employee: - gross ton-km/employee - net ton-km/employee
(c) Productivity of passenger transport: (distinguishing between high-speed and conventional rail transport)	per km: passenger-km/km of network per employee: passenger-km/employee
(d) Productivity of traffic: (distinguishing between high-speed and conventional rail transport)	net ton-km + passenger-km/km of network
(e) Productivity of locomotives: (distinguishing between high-speed and conventional rail transport)	gross ton-km/locomotive
(f) Productivity of wagons:	net ton-km/wagon
(g) Productivity of lines: (where necessary only on railway lines to be determined)	passenger train-km + freight train-km /km of network
(h) Energy consumption (for traction power):	MJ/1000 gross ton-km

In reply to the Working Party's request to the UIC to analyse the social, technical, economic and political framework which has an impact on rail productivity, the representative of that organization had submitted a note on a review of productivity figures for rail transport. Based on this note, the interaction between the various factors influencing rail productivity was explained in great detail. In order to continue the search for more meaningful productivity figures, the Working Party asked experts participating in its sessions to provide comments on the explanations given in the UIC note.

At its fifty-fourth session in 2000 (TRANS/SC.2/194), the Working Party again examined the productivity figures provided by UIC, OSZhD and the TER PCO, and agreed that the indicators available should be completed by qualitative indicators. It also asked the secretariat to prepare a proposal in this sense, together with the UN/TER project Central Office and in cooperation with the UIC and OSZhD and to present it at its session in 2002 together with productivity figures from all UNECE countries.

The secretariat received some suggestions about possible additions to the indicators:

- In order to calculate the average trip/haul:
  - number of passengers
  - number of net-tons transported
- In order to calculate passengers/train and net-tons/train,
  - separate figures for passenger and freight train km
- In order to compare the cost structures:
  - labour costs to total costs of operation;
  - train km to total cost of operation;
  - train km to labour costs.

As a measure of labour productivity a ratio of total adjusted ton-kilometres (the sum of the number of ton-kilometres and twice the number of passenger-kilometres) divided by the total number of freight and passenger transport employees was also proposed.

## II. The World Bank productivity indicators for railways

The World Bank railway database provides information on scale, output and performance for over 90 railways worldwide permitting comparisons of performance and facilitating target setting by individual railways. Over the years, the database has been expanded and improved and now contains data files on over 90 railways, representing more than 80 countries and covering the years 1980 to 2000.

*Scale and output measures* include: line kilometres, rolling stock (locomotives, electric or diesel multiple-unit cars – MUs, freight wagons, passenger coaches), freight activity (tonnes and tonne-kilometres), passenger service (passengers and passenger-kilometres), and employees. Where totals were disaggregated, employees are defined as rail staff and do not include construction, medical, education, or other non-transport workers. This distinction is considered critical when examining labour productivity in some countries where only about 50 per cent of the “railway” workers are designated rail staff, with the remaining employed in clearly non-rail activities.

Another set of data provides *standard performance indicators* that attempt to measure the productivity, effectiveness and asset utilization of the railway. Average length of passenger trip is defined as total passenger-kilometres divided by total passengers; average length of freight haul, total tonne-kilometres divided by total tonnes.

**Asset utilization measures** include traffic units (TU- the sum of passenger- and tonne-kilometres) per line kilometre, TU per locomotive, tonne-kilometres per freight wagon, and passenger-kilometres per passenger coach. When calculating total passenger handling capacity, both locomotive-hauled and MU coaches are included to adjust for railways where most passenger trains are formed of electric or diesel multiple-units stock. The productivity of tractive equipment was estimated by dividing traffic units by the sum of locomotives plus MUs divided by the average length of MU trains. Some countries have a sufficiently large proportion of their fleet as MU equipment that dividing traffic units by locomotives alone significantly distorts output per locomotive.

**Labour productivity** is typically measured in traffic units per rail staff. Examining staff costs (wages plus benefits) as a per cent of total operating revenues reveals that in a number of railways, staff costs alone exceed total revenues from users and are often the largest single cost category. Employees' effectiveness provides a useful illustration to highlight the danger in relying on a single measure to support any particular judgment.

The ratio of passenger fares to freight rates is a rough measure of the likely extent of cross-subsidy of passenger losses from freight income. Average passenger fare (or freight rate) is estimated by dividing total passenger (freight) revenue by total passenger (tonne)- kilometre.

The World Bank productivity indicators for railways are as follows:

- Diesel locomotive availability (%)
- Operating ratio with normalization
- Operating ratio without normalization
- Average lead, freight (km)
- Average lead, passenger (km)
- Freight tonne-km per wagon (000)
- Employee productivity
- Employee per km of line
- Total wages per total revenues
- Ratio of passenger fares to freight rates
- Traffic density (000 of TU per km)
- Passenger wagons productivity (000 of pkm per wagon +MU)
- Locomotive productivity (000 of TU per locomotive +MU/MU factor)
- Freight wagon productivity (000 of ton-km per wagon)
- PPP passenger revenue per pass-km (ICP)
- PPP freight revenue per ton-km (ICP)
- Official exchange dollars passenger revenue per pass-km
- Official exchange dollars freight revenue per ton-km
- PPP passenger adjustment factor
- Adjusted PPP passenger revenue per pass-km (ICP)
- PPP freight adjustment factor
- Adjusted PPP freight revenue per ton-km (ICP)

The World Bank railway database uses the following productivity and employee productivity ratios:

<b>Productivity Ratios</b>	<b>Employee Productivity</b>
Freight revenue per net tonne-km <ul style="list-style-type: none"> <li>○ current local currency</li> <li>○ constant local currency</li> <li>○ constant dollars</li> </ul>	Staff (total number of employees) <ul style="list-style-type: none"> <li>- permanent</li> <li>- temporary</li> <li>- total</li> </ul>
Freight system traffic density <ul style="list-style-type: none"> <li>○ tonne-km/km (000 000)</li> </ul>	Estimated non-rail employees
Passenger system traffic density <ul style="list-style-type: none"> <li>○ passenger-km/km (000 000)</li> </ul>	Freight (tkm/employee (000))
Wagon utilization <ul style="list-style-type: none"> <li>○ freight net tonne-km/total wagons (000)</li> </ul>	Passenger (pkm/employee (000))
Average freight train lead (net tonnes)	Traffic units /Employee (tkm + pkm/total employees (000) (tkm + pkm/total rail employees (000)
Average gross tonnes per wagon hauled	
Average gross tonnes per train operated	Total employees/Total km of line Total rail employees/Total km of line
Gross tonne-km/freight train (000)	
Fuel consumption (litres) (000 000) <ul style="list-style-type: none"> <li>○ total consumption on main line and in yards</li> <li>○ others (rail diesel cars)</li> </ul>	Revenue and Cost (current and constant local currency and constant \$) - Total wages (000 000)  - Total wages/employee - Total wages/total revenues - Total wages/traffic units

The most important caveat, according to the World Bank is “that railways are inherently non-comparable for many reasons which are not easily compressed into any set of statistics. These differences include topography, traffic mix, industrial location, access to modern technology, international flow disruptions, civil unrest, and many others. Basic measures such as tonne-kilometres and passenger-kilometres are, more often than not, estimates based on tonnes or passengers multiplied by average length of haul or trip. This difficulty in calculating passenger kilometres is exacerbated on railways with large numbers of urban commuters. Particular caution should be used with all financial measures as accounting definitions and procedures vary from country to country.”

### **III. Theoretical approaches**

The recent paper<sup>1</sup> surveyed alternative methodologies for measuring and comparing the productivity and efficiency of railways, and the empirical findings of applied studies. Empirical studies revealed trends and differences among railways and time periods. Authors noted that since 1945, railways in most countries have experienced a declining market share, rising input prices, and increasing competition from other transport modes. They believe that the success of

<sup>1</sup> A Survey of Productivity and Efficiency Measurement in Rail Transport, Tae Hoon Oum, W. G. Waters II and Chunyan Yu, Journal of Transport Economics and Policy, Volume 33, Part 1, pp. 9-42, January 1999.

individual railways, as well as the industry as a whole, depends on improving their productive performance. In order for Governments to design proper public and regulatory policies concerning the rail industry, and for railroad companies to set appropriate strategies to improve productivity, it is important to understand the determinants of productivity.

Authors note that railways are multi-product enterprises, and their outputs have a spatial dimension as well as quality attributes. A number of methodologies have been used to assess the productivity performance of railways. Different methodologies, along with data and computational differences, lead to different empirical results and interpretations.

One of the *main objectives of productivity measurement* is to make inferences about the efficiency of a firm, an organization, or an industry. However, productivity variation can arise from *different sources*: differences in efficiency, economies of scale, differences in network characteristics, and other exogenous factors that affect performance (for example, average length of haul, composition of traffic, market size, quality of service, weather, or terrain conditions) and/or technological changes. Therefore, to make inferences about productive efficiency, one must remove the effect on productivity caused by the differences in operating environment and other exogenous factors.

Authors distinguish the following theoretical approaches to measuring productivity:

- *index number procedures* for productivity and efficiency measurement;
  - o partial factor productivity (PFP) and performance ratios;
  - o total factor productivity (TFP);
  - o data envelopment analysis (DEA);
- *conventional econometric methods*;
- *frontier econometric measures*.

Index number procedures generally construct a ratio-type productivity/efficiency measure, without the need for statistical estimation of a production or cost function. They distinguish three general categories of index number procedures: *partial productivity measures*, *total factor productivity (TFP)*, and the *data envelopment analysis method (DEA)*.

Partial (factor) productivity measures generally relate a firm's output to a single input factor. For example, revenue tonne-kilometres per employee is a labour-based partial productivity measure. A large variety of "performance ratios" are in use in practically every industry, and tracking one or more output or intermediate activities relative to one or more input or other intermediate activity categories, can create almost an endless list of potential measures (trains despatched per hour, number of trains per kilometre of track, loaded to empty locomotive or wagon-kilometres, etc.). These types of measures are easy to compute, require only limited data, and are intuitively easy to understand. They have been widely used by both academics and industry analysts. Table 1 below lists some examples of commonly used partial productivity measures in the rail industry. It is important to note that productivity of one input depends on the level of other inputs being used; high productivity performance in one input may come at the expense of low productivity of other inputs.

Another common problem is an inadequate output measure. A single output measure, whether it is gross tonne-kilometres, revenue tonne-kilometres, locomotive-kilometres,

passenger-kilometres or train-kilometres, is not a comprehensive measure of the true total economic output. Although each of these measures reflects an important dimension of railway outputs, use of a single output measure could bias performance comparisons. A better approach is to combine passenger, freight, express freight, and other service outputs, to form a total output index as suggested in the total factor productivity measurement. In order to alleviate problems of using partial factor productivity ratios some general or “system” measures of productivity have been suggested. These measures, although still partial in nature, employ a combination of a number of partial factor productivity measures.

Despite their shortcomings, *partial productivity measures can provide useful insights to causes of high or low productivity, and thus provide practical guidance for identifying productivity problems.* Partial measures are useful in comparison or performance across firms operating in similar operating environments, or over time within a firm when operating environment and input prices remain relatively stable.

**Table 1.** *Most commonly used partial indicators of rail productivity*

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**General Operations**

1. Average train speed (train-kilometres divided by train-hours)
2. Average number of wagons per train (wagon-kilometres divided by train-kilometres)
3. Average haul (revenue tonne-kilometres divided by revenue tonnes)
4. Gross and revenue tonnes per train (gross tonne-kilometres divided by train-kilometres, revenue tonne-kilometres divided by train-kilometres)
5. Train-switching-hours and train-switching-kilometres as percentages of total train-kilometres and train-hours
6. Revenues and expenses per train-kilometre, per revenue tonne-kilometre
7. Ratio of revenue tonne-kilometre to gross tonne-kilometre
8. Gross tonne-kilometre per tonne or litre of fuel
9. Ratio of expenses to revenues
10. Ratio of loaded to total wagon-kilometres

**Locomotives**

1. Locomotive unit-kilometres (road, train-switching, and yard-switching)
2. Locomotive switching-unit-kilometres as a percentage of total locomotive unit-kilometres
3. Locomotive unit-kilometres or locomotive-hours per serviceable locomotive-day
4. Gross and revenue tonne-kilometres per serviceable locomotive
5. Average number of wagons per locomotive (wagon-kilometres divided by locomotive road-unit-kilometres)
6. Gross tonne-kilometres per locomotive road-unit-kilometres

**Wagons**

1. Ratio of revenue ton-kilometres to wagon-loadings or per ton of wagon capacity
2. Revenues and expenses per ton of wagon capacity
3. Average wagon-load (revenue ton-kilometres divided by loaded wagon-kilometres)
4. Wagon-kilometres (or revenue ton-kilometres) per serviceable wagon-day
5. Revenue tons carried per wagon
6. Wagon cycle time or number of wagon-loads per wagon per year
7. Wagon-hours in road movement per serviceable wagon-day
8. Average time in shipper's hands, in terminals, in trains, etc.
9. Revenue and expenses per wagon
10. Wagon-kilometres (loaded and empty)

**Track**

1. Number of kilometres of track
2. Revenue ton-kilometres per kilometre of track
3. Wagon-loads per kilometre of track
4. Revenue per kilometre of track
5. Maintenance expenses per kilometre of track

**Capital**

1. Net investment per employee
2. Dollars of revenue per dollar of net investment
3. Revenue ton-kilometres per dollar of net investment
4. Investment per ton of capacity

**Labour**

1. Revenue and gross ton-kilometres per employee or per man-hour paid
2. Professional, clerical, and general: man-hour per wagon-load
3. Maintenance of way and structures: man hours per million gross ton-kilometres
4. Maintenance of equipment and stores: man-hours per thousand locomotive-kilometres and wagon-kilometres
5. Transport (train and engine services): man-hours per thousand train-kilometres and train hours

A total factor productivity index (TFP) is the ratio of a total (aggregate) output quantity index to a total (aggregate) input quantity index. Output and input quantity indices recognize the multi-output multi-input nature of the rail industry. Because of the aggregation problem inherent in multiple output production, different productivity measures lead to differences in measured results. Some inputs are generally measured in physical quantities, for example, litres of fuel consumed or the energy equivalent. Labour inputs may be measured by the number of employees or employee-hours. Employee hours may distinguish between hours worked versus "hours paid for". It is preferable to disaggregate labour categories according to wage/skill levels.

The aggregate input quantity index is the weighted sum of the respective indices (weighted by cost shares), with each index set at unity for some common data point. More specifically, the growth in aggregate inputs is the weighted sum of the growth rates of the individual input quantity indices. An aggregate output quantity index is the weighted sum of the output categories. The weights are usually revenue shares for the respective outputs, although cost elasticity weights are the preferred measure. Ideally, a high level of disaggregation is



sought, but most productivity studies use only a few output categories. Many use just two: freight ton-kilometres and passenger-kilometres.

The total factor productivity indices do not distinguish among sources of productivity growth. Furthermore, by using input cost shares for aggregation of inputs, it is assumed that input prices are “correct”: that is, there is no change in allocative inefficiency. Similarly, aggregation of outputs using revenue shares as weights assumes that relative prices of multiple outputs are proportional to their respective marginal costs. In practice, both of these input and output aggregation conditions are likely to be violated, but to some extent they can be corrected for via decomposition analysis.

Data Envelopment Analysis (DEA) is a non-parametric approach for measuring efficiency. It involves an application of linear programming (LP) to observed data to form a production frontier, against which to evaluate the efficiency of each firm or organization. DEA utilizes a sequence of linear programs, one for each observation to construct a piecewise linear production frontier, and to compute an efficiency index for each observation relative to the frontier. Observations that lie on the production frontier are deemed efficient, while those not on the frontier are regarded as being inefficient.

Similar to the TFP index, the DEA index is a “gross” efficiency indicator, which reflects both productive efficiency and the effects of operating environments.

Econometric methods involve estimation of a production or cost function. The estimated production or cost function can then be used to identify changes in productivity or productive efficiency.

Frontier econometric measures are used for estimation of frontier production or cost functions of firms that may not be on the efficient frontier. Depending on the value (deterministic/stochastic) of inefficiency term used in calculating error terms of the production/cost function the method is called a “deterministic” or a “stochastic” frontier method.

## **Conclusions**

Productivity comparisons by any methodology are difficult to make with precision. There are conceptual and practical issues in identifying the number and diversity of outputs and inputs and their level of aggregation. Then there are data problems including unavailability, errors of interpretation and measurement, and the need for proxies when desired data do not exist. The computation or estimation procedures can make a difference. Even a simple measure of growth over time can vary substantially, depending on the choice of beginning and terminating year. Although managers and policy-makers would like to measure productivity growth to a tenth of a percentage point, the real accuracy is probably an order of magnitude lower. Comparisons across studies are probably not reliable unless restricted only to broad comparisons.

More data provides greater confidence. Productivity growth is best measured as a long-term trend, because the measure can fluctuate substantially from year to year. The development and use of various gross productivity measures (combining cross-section and time-series data, DEA) have become more widespread but they do not distinguish between sources of productivity change, which could reflect changes in the degree of technical inefficiency, changes in scale of

operations, and underlying changes in traffic mix including geographical shifts, differences in service quality or operating practices, as well as actual changes in productive efficiency (technological change).

In future research, it will be important to recognize and incorporate quality changes into the analysis. Reviewed productivity studies implicitly assume that quality of inputs and output are constant. But an increasing emphasis on “quality” has been stressed by probably every railway manager in the world. Improving quality absorbs increased inputs, and the output produced is not homogenous with what was produced before. There is a need to develop comprehensive quality measures that can be explicitly introduced into the analysis. Many partial performance measures are used (for example, percentage of on-time performance) but these are not sufficient for comprehensive efficiency measures. Quality must be expressed in a way that can be valued relative to traditional output and input quantity measures. Development of comprehensive quality measures both for outputs and inputs, and incorporating them into performance measurement, should be a high priority in future research.

#### IV. Possible quality indicators

As suggested in the Working Party’s reports and elsewhere in literature, the search for quality indicators of productivity of railways should continue. Bearing in mind limitations intrinsic to various theoretical and practical approaches, quality indicators of productivity should supplement those as defined by the Working Party, and enhance the quality of international comparisons of railway productivity indicators.

In this connection, the following list represents an attempt to address the issue, and suggest possible indicators that, in combination with the quantitative indicators as defined by the Working Party, may indeed bring comparison of individual railways’ productivity closer to realistic and more reliable results.

Indicator	Measure	Best practice*
Efficient service delivery	Price (US\$ per freight ton km)	< 2 ¢
	Price (US\$ per passenger km)	
Service quality	Average train speed (km/h) (urban, local, intercity, etc.)	
	% of arrivals less than 15 min. late	95 %
Safety	Train accidents (per million train km)	
Accessibility	Network density (route km/km <sup>2</sup> )	
	Freight ton km /US\$ GDP (P. P. Parity)	
	Rail share of rail + truck ton km	
	Rail passenger km as % of passenger km + ton km (%)	
Environment quality	Kj of energy per converted ton km	
Financial sustainability	% of costs covered from internal cash generation Real return on total gross assets (%)	> 100 USA
Capital	Track operated under slow orders on track and structures - route km - % total km	
	km travelled per available locomotive/day	
Management	Ratio of average passenger tariff to average freight tariff (based on US\$ per km) (%)	> 2.0 Europe
	Locomotive availability (%)	90 USA
	Freight and passenger wagon availability (%)	>90USA/Europe

Notes:

*Efficient service delivery*

Tariff is only part of the perceived cost to the user; this indicator gives a broad measure of efficiency of resources used in delivering the main service of railways.

*Service quality*

- average train speed – average scheduled speed should be distinguished by category of service (urban, local, intercity, freight, passenger, shuttle, etc.)
- per cent of arrivals less than 15 minutes late – this indicator shows schedule reliability; poor service reliability adds to the user's logistics costs.

*Safety*

Train accidents per million train kilometres – if this indicator is to be significant and used, it is important to define uniformly what constitutes a “train accident”.

*Accessibility*

- network density – this indicator represents a rough overall measure of accessibility of rail services;
- freight ton km per unit of GDP – this indicator represent a crude measure of the role of railways in the spatial and industrial structure of the economy;

*Environment quality*

Kj of energy per converted ton-km – this indicator might be used either as the absolute rate of fuel usage or the rate of change; it is crudely related to emissions and useful for comparisons.

*Financial sustainability*

- per cent of costs covered from internal cash generation – this is a rough indicator of financial health of the enterprise.
- real return on total gross assets – this indicator is rarely available in published statistics and requires asset valuation; it might therefore be difficult to obtain but is a good indicator of financial sustainability;

*Capital*

- track operated under slow orders on track and structures – indicates the extent of overdue maintenance for track, bridges and other structures; although rarely readily available, it is very useful in a time series;
- kilometres travelled per available locomotive/day – indicates absolute physical measure of asset utilization to facilitate international comparisons

*Management*

- ratio of average passenger tariff to average freight tariff – it is a crude general indicator of the extent to which freight services subsidize passenger service;
- locomotive availability – indicates the degree of overdue and deferred maintenance;
- freight and passenger wagon availability – indicates quality of rolling stock maintenance and availability of spare parts.

The third column in the above table could give levels on any specific indicator and should not be interpreted as an unqualified “target”. Some values in the column are presented only for illustration purposes.

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