Railway line capacity planning support model
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Abstract

The paper presents the model for analysis of investment options, and study report preparation for capacity increase of a single track railway line. The model calculations are based on a railway line time-table. Investment impacts are modelled for a range of options. The effect of each investment option can be expressed in tons or tons/investment value. Within the economic evaluation, the model can produce the output tables up to the internal rate of return and the sensitivity analysis tables for a pre-feasibility study. The tools and the final report text are linked, thus minimising the routine job and risk of errors.

Introduction

IRCIM - "Investment in Railway Capacity Increase Model" is a specific model, a set of interconnected tools, for the consultant support in pre-feasibility study elaboration. The model involves the calculations of technical effects based on a railway line time-table scheme, including the successive economic evaluations with all output tables up to the internal rate of return and within the sensitivity analysis. In addition, approx. 30 pages of a sample text, usually requested in a typical feasibility study report, is available. The model is in accordance with the bank viewpoint (Alston [1]) as well as with the investor viewpoint (Jelaska [2]).

The railway time-table is the operational representation of the passive railway infrastructure. The use of time-table model in capacity calculations helps to avoid generalisation through the use of “capacity”
formulas and to apply an exact method. This helps that the “keep it simple” principle can be respected.

The model has been developed after an exhaustive experience from two problem areas: railway line time-table models, and transport system planning models. In the early computerisation stage from 1973 to 1975 the railway line time-table elaboration, including the time-table diagram drawings on “co-ordinatograph”, also made its pioneer steps in Ljubljana, and relevant papers were published (Jelaska [3],[4]). The transportation modelling, as a part of the regional transport system planning (Reuschel [5]) demands for a compatible railway capacity sub-model, also applicable within the transport system study. If a multimodal transport system is modelled, the railway investment options are requested to be elaborated so flexible - like the road improvements are modelled - to be examined from the viewpoint of the whole (state or regional) transport system as well.

Data

Up to one hundred heterogeneous data items of fixed input data can be prepared to exploit the full benefits of the model, if various capacity improvement options should be elaborated. The input data set is consequently reduced for a partial analysis. The data set is also reduced for the technical evaluation if economic evaluation is not necessary, and only throughput in freight trains will satisfy. The details of a particular option should be prepared outside the model and relevant data can be introduced in the model as follows.

1. Fixed input data (data sets for station description, section description, traction and rolling stock, train traffic time intervals, yearly traffic, passenger trains impact, maintenance, reserve, peak traffic, bottlenecks, etc.).
2. Time-table parameters.
3. Coefficients within the calculation formulas.
4. Switches for the model procedure control (to define what has to be elaborated in the available calculations).
5. Changes of the model procedure statements (to define what has to be done to change some of the existing modules or to incorporate new ones, required by new problems).

The economic evaluation requires data about forecast flows, commodities, tariffs, parameters, rates, and other necessary data to cover cost/benefit calculations.

The sensitivity analysis part requires data about selected variations to examine impacts on the economic evaluation.
Procedure

The model elaboration procedure can be presented in a block diagram as in Figure 1. There are five main "parts" as in a usual feasibility study elaboration.

1. Inputs (fixed data about railway traffic and line characteristics, time-table and various coefficients, as well as switches enabling the control over the procedure and adaptations of the procedure).
2. Capacity and relevant partial cost calculations per each option.
3. Other inputs (forecast data, tariffs, rates, parameters, costs and benefits during the observed period, etc.).
4. Evaluation and sensitivity analysis, (economic costs, economic benefits, present value, net present value, internal rate of return, repeated calculations per each variation in the sensitivity analysis).
5. Report block (including sample text modifications, additional text elaboration, graph or table format changes, printing, etc.).

Various blocks imply one or more professional fields. If necessary, responsibilities in the elaboration may be shared among the experts from railways (fixed input data, time-table data, coefficients, etc.), computer modelling (selection by procedure control switches, adaptations by model changes, model running), transport system planning (data forecast, flows and limitations), economics (data about time structure and cost/benefit structure data, tariffs, parameters, delay data, rates) and common problems (running of the economic evaluation and sensitivity analysis, report text modifications, running report module, report completion).

Investment options and line throughput

Each investment option is evaluated by a cost/benefit analysis. Several indicators can be calculated, offering the comparison among the options (gross weight, net weight, number of trains, invested amount, net present value, internal rate of return). Costs depending on throughput are calculated simultaneously with the time-table calculations.

The following three main sources of benefits are prepared: less time per train (higher speed, shorter acceleration, shorter deceleration), more trains per line (more safety sections, modified section configuration, shorter train traffic time intervals, better uniformity, lower reserve), and more transported freight (with approx. the same or with a changed net/gross ratio). Each option may have an impact composed from different sources.
Figure 1. The model procedure block diagram

- **INPUTS**
  - FIXED INPUT DATA: data sets for stations, sections, traction, traffic, organisation, maintenance, train traffic time intervals, pass.traffic, peak traffic, bottlenecks, etc.
  - TIME-TABLE DATA
  - COEFFICIENTS
  - SELECTION BY SWITCHES
  - ADAPTATIONS BY MODEL CHANGES

- **CAPACITY**
  - RUN
    - CALCULATIONS OF THROUGHPUT AND COSTS PER INVESTMENT OPTION

- **OTHER INPUTS**
  - DATA FORECAST
  - LIMITS & FLOW DATA
  - DELAY DATA
  - TIME STRUCTURE & COST/BENEFIT

- **EVALUATION & SENSITIVITY ANALYSIS**
  - BENEFITS DYNAMICS
  - COSTS DYNAMICS
  - NPV & IRR
  - NET VALUES, PRESENT VALUE & IRR CALCULATIONS

- **REPORT**
  - TEXT MODIFICATIONS
  - RUN REPORT MODULE
  - REPORT TEXT, TABLES & GRAPHS

The diagram illustrates the flow of data and analysis through the model, starting with inputs and progressing through capacity, other inputs, evaluation, and finally reporting.
Table 1. List of basic investment options

<table>
<thead>
<tr>
<th>No.</th>
<th>Investment option</th>
<th>Impacts</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dispatcher radio</td>
<td>Lower disturbances</td>
<td>No time-table calculation</td>
</tr>
<tr>
<td>2.</td>
<td>Station interlocking equipment</td>
<td>Shorter train traffic intervals</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Remote computer traffic control</td>
<td>Lower disturbances</td>
<td>No time-table calculation</td>
</tr>
<tr>
<td>4.</td>
<td>Automatic block line equipment</td>
<td>A train pair may run per section</td>
<td>Next critical section on the unequipped part may appear</td>
</tr>
<tr>
<td>5.</td>
<td>New wagon structure</td>
<td>Better gross/net ratio</td>
<td>No time-table calculation</td>
</tr>
<tr>
<td>6.</td>
<td>New traction units</td>
<td>Shorter acc/decel. &amp; running times, heavier trains*</td>
<td>* If limited by traction parameters</td>
</tr>
<tr>
<td>7.</td>
<td>Longer sidings</td>
<td>Longer trains</td>
<td>If limited by sidings</td>
</tr>
<tr>
<td>8.</td>
<td>Track parameter improvement</td>
<td>Improved running times, heavier trains*</td>
<td>* If limited by track parameters</td>
</tr>
<tr>
<td>9.</td>
<td>Flying crossing of two opposite trains</td>
<td>Shorter running time, shorter acc/decel. time</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>New official posts construction</td>
<td>Shorter sections at bottleneck</td>
<td>Next critical section must be observed</td>
</tr>
<tr>
<td>11.</td>
<td>Electrification</td>
<td>Shorter acc/decel. &amp; running times, heavier trains*</td>
<td>* If limited by traction parameters</td>
</tr>
<tr>
<td>12.</td>
<td>Partial double track construction</td>
<td>Eliminated major bottlenecks</td>
<td>Next critical section must be observed</td>
</tr>
<tr>
<td>13.</td>
<td>Entire double track construction.</td>
<td>Full double track time-table diagram</td>
<td></td>
</tr>
</tbody>
</table>

Particular impacts of investment options are modelled (prepared) as is given in Table 1. Any permitted and meaningful combination of technical options can be examined. Even more, this is an open model and new options, added or partly combined, can be incorporated.

In the case of a new combined option the effect is not necessarily a sum of particular separate effects, but new values are calculated on the new time-table basis. It is important to understand the problem to make a proper and feasible selection by the control switches.

The station interlocking equipment can help since it reflects in shorter time intervals between two trains. Shorter intervals mean shorter waiting time per train, thus less non-productive time for the track. The share of productive time increases.

The automatic block (AB) equipment can help a lot. Without the AB equipment only one train may run on a single track section between two
neighbouring stations. With the AB equipment the same section is segmented so that the first train generates red light just immediately after itself, the yellow light one segment behind and the green light two segments behind, enabling to the successive train to run smoothly two steps behind. The effect, however, will be reduced if stations have no enough sidings to accept trains in "packages".

The computerised remote train traffic control system makes the entire traffic controllable from one centre. Either the train dispatcher or partly automated traffic monitoring system may take measures to timely correct various consequences of imperfect traffic operation. Especially in heavy conditions, or close to the saturation level, the disturbances may strongly affect the traffic throughput. A similar logic - elimination of disturbances - is applied for the despatching radio link effect calculations. In both cases there are no special calculations of the time-table.

In the case of a changed wagon structure, the net/gross ratio may be improved, with minor impact on the time-table, except if running characteristics or train masses change significantly.

Track parameters are improved by the increase of the curve radius, track quality and other elements enabling the higher speeds and/or axle loads. Improvements have to be designed separately, and the resultant values of train running times or increased train mass have to be inserted in the model.

The construction of new official posts has a similar effect of section segmentation and can be easily modelled. This option has lost its importance since the automatic block equipment provides similar functions.

The extension of station track sidings to enable the so called "flying" train crossing - a crossing of two trains running in the opposite directions without stopping - has a better effect if station sections are relatively short; thus the time saved in train detention, acceleration and deceleration has bigger share.

The introduction of more powerful traction units can affect the train mass and length, and train speed if there is enough reserve up to the existing speed limits. The electrification of traction can improve the transport work, due to more powerful traction units together with a complete power supply system. The model time-table calculations are of the same type in both cases. The key difference lies in additional costs of the power supply system.
The extension of station track sidings reflects in the acceptance of longer trains. This means longer trains, more tons and greater transport work. The model takes into account all sidings.

Partial double track construction can be tested on bottleneck sections with the rule of maximum gradient - until the throughput increment will be satisfactory. In the model, the rest of the single track portion is then observed, and calculations are performed for the next critical section.

This part of the model provides throughput expressed in trains per day, ton millions per year, etc. If the costs are applied, the relevant ratio can be calculated as additional tons versus invested amount (or all trains, additional trains, all tons, etc. can be used). An example of intermediate results for option comparison is shown in Figure 2. The ratio of the yearly transported additional freight in kilograms per each USD invested is provided for each investment option.

**The throughput calculation**

The throughput calculation finds throughput $w$ for each applied investment option $a$ from the set $\{A\}$.
All necessary data for the observed line and for investment options to be examined are:
\[ \{A\} = \{\{I\}, \{J\}, \{C\}, \{O\}\} \] (1)

For each applied investment option ‘a’ all necessary data have to be arranged in sets: \{I\} per stations, \{J\} fixed data per sections, traffic intervals and time-table scheme data, \{C\} for the calculation procedure control purposes, \{O\} for preliminary investment option data. Set \{O\} concerns section "Investment options and line throughput". Sets \{I\}, \{J\}, \{C\} concern section "Data".

Among all option throughputs \([w(a)]\) the maximum value can be chosen:
\[ w_{\text{max}} \text{ for } a \in A(\{I_a\}, \{J_a\}, \{C_a\}, \{O_a\}) \] (2)

The maximum throughput \(w_{\text{max}}\) indicates an option proposed for comparison, decision making (and stop the work with the model), or for further elaboration through the evaluation block.

If necessary, option ‘a’ may be based upon only one preliminary investment option from the set \{O\}, or it may be combined as a joined implementation of more than one preliminary investment options. An effect of two combined options \(o_m o_n\) may be observed if the combination has technical sense and the option sequencing is possible.

The complete data set \{A\} looks huge but many items need not to be duplicated. Most of preparation work can be done by the control switches included in the calculation procedure, and many data, invariant for several options, can be included efficiently by an adequate model design.

The switches and relevant data have to be adjusted in sets \{I\}, \{J\}, \{C\} and \{O\}. If any new type of special investment option has to be created, this can be done as an expansion of these sets.

Control data set \{C\} includes switches, average values, sums, indices, control variables, etc. Set \{C\} is prepared to handle the procedure, to ensure that the right data from \{I\}, \{J\} and \{O\} will be properly used.

The most important issues regarding the calculation procedure are running times, relevant traffic intervals, train lengths and weights, net weights, freight train traffic schemes for the observed option, passenger traffic elimination scheme, section reserve time and maintenance time. These must be available to determine the freight traffic.

Within a 24 hour period it is virtually possible to put a set \{K\} of freight trains on the line. Due to the passenger traffic (if any) the set \{k_E\} of freight trains is eliminated and due to maintenance or/and reserve time period the set \{k_S\} of freight trains is also eliminated.
Throughput $w$ is defined for the non-eliminated freight trains. Its value is calculated as a sum of net weights of freight trains from the set $\{k\}$ and returned by procedure $W$:

$$w = W(\{k\})$$

For each investment option the worst part of the line has to be detected. Procedure $W$ examines what is the worst part of the whole line as follows.

The worst part identification requires an adequate traffic scheme prepared in accordance with the applied investment, based on schemes from the simplest elementary train pair (or, if applicable, a scheme of two pairs of two successive trains, each pair running in the opposite directions) till the combined sections traffic scheme. The most typical schemes are prepared within set $\{J\}$. Special solutions can be inserted by expanding the set.

A "traditional" single critical section can be indicated with the maximum sum of times required for running two trains in the opposite direction plus the relevant time intervals. In most cases such section is the worst part of the line with throughput $w_j$. In some cases, several other neighbouring sections with tracks in adjacent stations, observed as a whole, can make ineffective combination with low throughput $w_2$. (e.g. if such traffic scheme includes three sections $j^*, j+1^*$ and $j+2^*$, four stations $i = j^*, i+1^*, i+2^*, i+3^*$, and their tracks are observed as a whole). The lowest $w$ value indicates the worst part of the line.

The check of lengths and sufficiency of station tracks has to be performed through the set $\{I\}$ for all stations. A reduction in time and train elimination are taken into account just before the procedure end. Now, the procedure returns value $w(a)$.

Repeated calculations for the whole set $\{A\}$ of applied investment options will give a vector of values $\{w(a)\}$. The vector can be used for decision making or for other purposes (See presentation in Fig. 1. combined with investment costs). One selected applied investment option can be elaborated further within the evaluation block.

**Economic effects**

The benefit in freight traffic means greater revenue due to greater transport work, and lower operating expenses of the new equipment, fewer accidents and less damage both to freight and transport means, savings in time (in
trains and in the queue due to insufficient capacity), and increased convenience (lower logistic costs).

The selection criteria for investment options may include various components: safety, economy, users benefit, environmental impact, relations to other modes, employment, energy, delays in transport, etc. The model deals only with operational effects. Other effects must be taken into account separately and linked to the model.

Each investment option has its own economic effect, calculated from the capacity, commodity structure, quantities and tariffs. The selected option is then elaborated within the alternative "to invest" or "to do nothing" and financial indicators calculated. The net present value (NPV) and the internal rate of return (IRR) are proposed as the main indicators.

**Sensitivity analysis**

A typical scheme with several separate negative impacts is prepared to support the sensitivity analysis. Most impacts are of the following types: higher costs, lower tariffs, lower productivity due to obstacles, and impact of project delays. The first type denotes a price rise at the international level, and cost increases due to investment project growth over the foreseen reserve limits. The next type denotes lower revenue due to tariff changes of due to a loss of freight flows. The third type denotes less transported freight due to unexpected traffic disturbances, occasional capacity constraints (delays due to misuse in the initial period, inefficient use of equipment during the first few years, unpredicted additional works, etc.). The fourth impact applies to losses due to project execution delay and can be simulated simply like a shift in the “benefit” data column. The final resulting set of NPV and IRR values can be arranged in a table.

**Basis for model validation**

Most requests necessary for a good model have been successfully met. The described model is transparent and it helps the investor to get a thorough and comparable view of the investment options. It is open, upgradeable and efficient, especially in the interaction with the consultant’s knowledge. The model can be expanded or linked to the transportation models, train movement simulation, marshalling yard job simulation, etc. It is realistic, because it reflects impacts on the line throughput via the time-table calculations. It is simple, readable, PC oriented and well balanced regarding the output result sensitivity. It
enables the task completion "within minutes". When the last problem is over and the last data typed, the rest of the routine preparatory work is almost completed, thus seriously shortening the study elaboration time. The present version is written in Microsoft Office for Windows'95, able to link data among various documents, spreadsheets and drawings.

The model can be used as the basis for discussion among various professions, railway, traffic, traction, civil engineering, transport planners, economists, managers, it can accelerate talks, negotiations or the designing process. It can improve human communications and diminish confusion. Further, it can help in job distribution among the team members, because the whole data structure is clear and tasks can be assigned to the members via a common list.

**Future actions**

At the present stage the model is in operational form as described, and for the future work at least three possible upgrades can be done:

The model can be improved to be more friendly and the nucleus can be equipped with more elegant graphic. This may be a stand-alone version for consultants’ work.

Additional modules can be developed, so that a sequence of investment steps may be examined. This can be useful if a long-term flow growth is examined, or for a long term planning of capacity increase.

Additional interfaces to another models (e.g. to the multimodal network model) can contribute to a better regional transportation planning. Even more, an optimisation version can be designed.

**Conclusion**

An open, simple and transparent model is presented, a friendly support for consultants, with many incorporated investment options, known from feasibility studies. The given short description of the model, data and procedure can help to understand its potentials. Its first role is to bring new power to consultant’s work.

The model can integrate the work of railway, economy, transportation and computer experts. It may offer an efficient way to bring together (often) diverse perceptions of a complex problem. As an integrated tool, it can also contribute help to better understanding among investors and providers.
It can be used in various ways. The first part of the model alone can be used for comparison of technical solutions. If costs are calculated, a relative comparison among the options is possible. If effects are calculated, the economic evaluation can be performed, thus offering a support to the feasibility study elaboration. It covers many technical calculations for a set of investment options and the back-bone of feasibility study for “with or without investment option” alternative.

The model can also be used in the joint transportation planning for railways and roads. It can be applied in the model of transport system multimodal network, and tested in an iterative job for the best solution on the network. The main advantage is that each version can be tested through the operational time-table calculations. Further research and development of the model is also possible.

References


