IMPROVERAIL - Infrastructure Capacity and Resources Management

Modelling Long Term Infrastructure Capacity Evolution and Policy Assessment Regarding Infrastructure Maintenance and Renewal

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Abstract

IMPROVERAIL is a European project launched on July 1st, 2002. Besides several European academic institutes as well as consultants and stakeholders from the Railway industry, the project involves the Swiss Federal Railways, the Swiss Ministry of Transport, SMA-partners, Zürich, and EPFL, Lausanne.

The general aim of IMPROVERAIL is to support the establishment of railway infrastructure management in accordance with Directive 91/440 and following, by developing the necessary tools for the modelling of railway infrastructure and access management.

First of all, the paper briefly presents the main issues tackled by IMPROVERAIL, highlighting their relation to the railways infrastructure management. Then, the paper presents more in depth the work done within the first part of the work package 5 (WP5) of the project, encompassing three particular topics:

- Analysis and rough modelling of long-term infrastructure capacity evolution
- Analysis and rough modelling for the assessment of long-term policies regarding infrastructure maintenance and renewal
- Functionality of computer-based decision support system to deal with the long-term dependence between renewal/maintenance and capacity

The research results in the conceptualisation of a methodology dealing with the above-mentioned objectives, namely the simultaneous consideration of capacity needs (and investments) and strategic maintenance and renewal policies. In particular, two computer-based tools have been developed. The first tool assesses the capacity of a railway network and estimates the value of the capacity, which is related (among other things) to the saturation rate. The second tool simulates long-term policies for railway infrastructure maintenance and renewal.

Keywords

Strategic railways capacity evolution – Track possession for maintenance – Maintenance and Renewal policy for railways infrastructure – 3rd Swiss Transport Research Conference – STRC 2003 – Monte Verità

1. The IMPROVERAIL project

1.1 Introduction

IMPROVERAIL is an European project launched on July 1^{st}, 2002 and belonging to the 5^{th} framework program (Growth). The project is due to end in June 2003.

Besides several European academic institutes as well as consultants and stakeholders from the Railway industry, the project involves the Swiss Federal Railways, the Swiss Ministry of Transport, SMA-partners, Zürich, and EPFL, Lausanne. Swiss partners are financed by the Swiss Federal Office of Education and Science.

The paper mainly focuses on part of *work package 5 (WP5)* of IMPROVERAIL, dealing with *strategic capacity and resources management*. EPFL (WP-leader) and SMA (task-leader) were substantially involved in this WP.

1.2 Background

The 90s witnessed significant developments and implementations of important reforms in the railway sector. The major concerns behind the reform were the market share loss and the need for innovative sources of finance. The aim was to reach a more efficient and final user orientated railway industry. The efforts of the industry and the decision makers were focused on three areas of reform,

- Separation of service operations from infrastructure management
- Redefinition of the financing system of the industry towards contractual agreements
- Intensive efforts towards interoperability and integration of the TENs

This work tries to take railway research one step further by developing management tools for railway infrastructure managers, covering the different managerial aspects, from the organisational structure and functional procedures to the operational performance. For the first time, a project of these characteristics has the direct involvement of industry partners and authorities / decision-makers at the root of its development.

1.3 Objectives

The general aim of the IMPROVERAIL project is to support the establishment of railway infrastructure management in accordance with Directive 91/440 and other newly issued railway infrastructure directives, by developing the necessary tools for the modelling of railway infrastructure and access management. According to this aim, overall objectives of the project are,

- Provide improved methods for capacity and resource management.
- Improving the Life Cycle Costs calculating methods in every aspect covered by LCC methodology.
- Provide indicators for the performance of the railway infrastructure managers and re-engineering for the business processes.
- Improving data background in support of harmonised charging for use of railway infrastructure.

IMPROVERAIL focuses on heavily charged railways corridors, such as TEN's.

1.4 The consortium[1]

IMPROVERAIL consortium gathers the experience and expertise of well-known organisations all over Europe such as consultants, universities and research institutes, with a strong and wide experience in the railway sector. Additionally, the research work benefits from a continuous feedback from the 'real world' through the direct participation of representatives of authorities/decision makers, railway infrastructure managers and maintenance companies. Moreover, an Advisory Board with international organisation with direct interest in railway infrastructure management, rolling stock supplies and operators is assembled, gathering this way representatives of all the railway community in Europe.

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[1] TIS.PT (P) - Consultant in Transportation, ERASMUS (NL) - Research in Transportation, Infrastructure and Logistics, RIB (NL) : Railway Infrastructure Manager, ICSTM (UK)- Higher Education in Science, Technology and Medicine, FIT (I): Consultant in Transportation, NTUA (G): Research in Transport Planning and Engineering, CTC (BG) - Consultant in Infrastructure, Planning and Engineering, INCERTRANS (RO) : Research in Transportation, EPFL-LITEP (CH) - Transport Research, Education and Consulting, SBB-CFF-FFS (CH) : Railway Infrastructure Manager, TUB (D) : Research in Transportation, LET (F) : Research In Transportation Economics and Regional Planning, SMA (CH) : Consultant In Transportation Planning and Engineering, TOI(NO) : Research in Transportation and Development, CESUR (P) – Research in Transportation.

2. Objectives of WP5

Work package 5 objectives consist on a network based railway infrastructure capacity and resource management in the dual perspective of long and medium/short-term. From infrastructure managers' point of view, the railway network is a production unit, like a plant, which outputs feasible and practicable train paths. As for every business unit, managers have to deal with several views, covering short- to long-range objectives, concerns, and visions. Simply put:

- The long-range objectives aim to *steer development and future evolution* of the network according to economical, social, political, environmental, etc., needs.
- The short-range objectives aim to operate the network existing infrastructure in the most efficient manner.

Often, those objectives may be conflicting, and there is a need for the management to design and implement trade-offs. Thus, for instance, short-term optimisation may push towards reduced maintenance, in order to maximise available slots and sales of train-paths, while long-term vision should command for sufficient maintenance, in order to ensure infrastructure durability. In huge companies, conflicts may exacerbate due also to the task division, where different business units, that lack an overall vision, tend to optimise their own partial objectives; this process leads to partial optimisation (optimisation of sub-systems) that may hamper global optimisation.

Therefore, methods and tools to improve management of railway infrastructure (capacity and resources) should ideally address both hierarchical levels: a) the company level, to improve short- to medium-term operations and long-term development, and b) the managerial level, in order to achieve the best trade-offs between conflicting objectives. One could raw a first typology for methods and tools, along those lines: A first layer of methods and tools to help managers with

- long-term planning of infrastructure development
- short- to medium-term planning of operations

A second layer of methods and tools to help managers arbitrating conflicts among different business units, or resulting from differences in vision range

To steer *long-term network development* means to manage condition of infrastructures and their capacity to meet the volume and the quality of required train-paths. On the other hand, efficient short- to medium-term operations requires to ensure an acceptable RAMS (Reliability, Availability, Maintainability, Safety) level for the infrastructure, with respect to the operations scheduling (timetable).

Consequently, the first layer of methods and tools that need to be developed or improved are either:

- strategic, aiming to define the long-term maintenance and renewal policy able to guarantee the required condition of infrastructure, and which is tightly co-ordinated with the policy of developing future capacity, in order to minimise use of resources, or
- operational, aiming to define short- and medium-term scheduling of infrastructure maintenance and renewal works, which minimises use of resources needed for its implementation, while it ensures the availability for the required train-paths.

Long-term strategic approach is, by its nature, mainly economical. Operational approach involves both technical and economical aspects.

3. Strategic railway network management : capacity evolution versus maintenance and renewal needs

3.1 Long term capacity evolution of a railway network

The capacity of a network is the main product of the railway infrastructure. It is expressed as the maximal number of train-paths which can be set on a given infrastructure, during a certain laps of time. The quality of these train-paths is mainly characterised by the travel time and the timetable stability (train punctuality).

The infrastructure manager should adapt its production tool to meet the needs of the rail transport market. In other words, he should steer its network so as to be able to supply train paths that train operators or public authorities require. Thus, if there is not enough available capacity to deal with the demand, the infrastructure manager may start to plan network extensions. On the other hand, infrastructures supporting low traffic levels may be simplified or reduced in order to cut down maintenance costs. However, on most European corridors, infrastructure managers face capacity bottlenecks that hamper the growth of the market share of railways.

Thus, several European railway corridors require investments to increase their capacity. This raise then the question *where and when to invest*? These questions are crucial as railways construction costs are very high and the planning period of a railway link adds up to 20 years or even more. Therefore, any capacity investments project belongs to the strategic planning activities of network managers.

Strategic capacity planning includes four main steps : the estimation of the demand, the assignment of the demand on the network, the capacity analysis and, finally, the elaboration of capacity investments scenarios, the whole process being iterative. IMPROVERAIL focuses on the *demand assignment* and *the capacity analysis*. The demand estimation has been left out of scope because there are already many models dealing with it. As well, the capacity investment scenario elaboration isn't included in the project as it is rather hard to systematize that process. Investment scenarios are usually based on local situations and decisions variables vary from a case to the other. Moreover, there aren't many choices of investment scenarios for a capacity bottleneck.

3.2 Strategic maintenance and renewal (M&R) policy of a railway infrastructure

In order to ensure an acceptable RAMS, the infrastructure of a railway network must be maintained and renewed. The infrastructure system is characterized by a high inertia, that is to say that decisions made today may have an impact in five or ten years. Therefore, long term planning of the infrastructure system should be done conscientiously.

The objectives of a long term M&R policy is to provide a decision framework for the medium term M&R work planning. This framework consists of several rules that are guidelines leading the medium-term management to achieving a minimal infrastructure cost over the life cycle. Major rules that constitute decision guidelines should be:

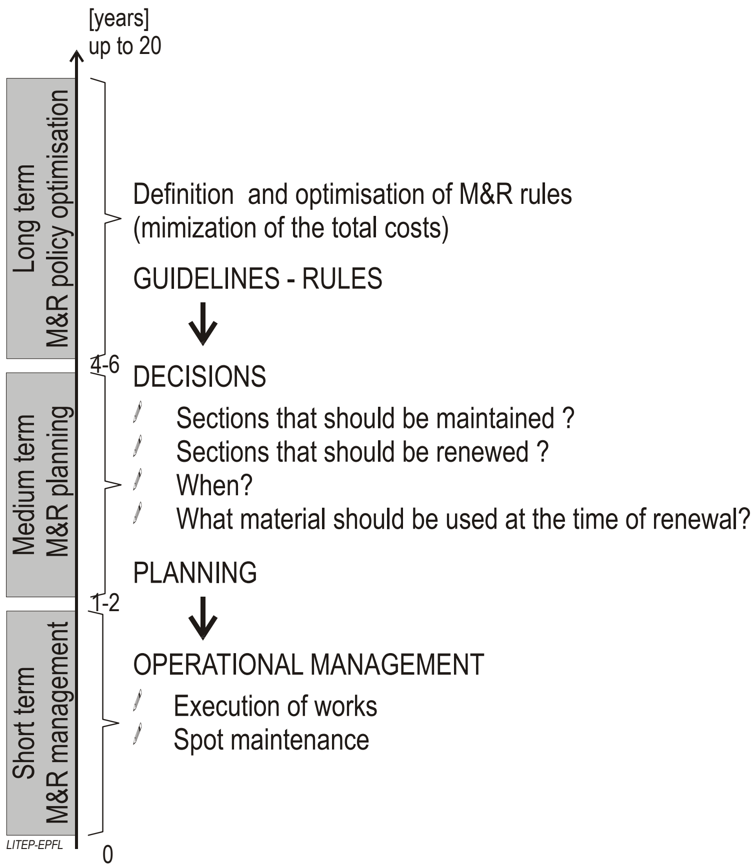
- annual ratio between renewal and maintenance (lengths and expenses),
- thresholds for renewal actions (age or accumulated load),
- type of material to use at the time of renewals,
- the quality level of infrastructure,…

These rules should either be defined by strategic business goals (e.g.: quality level of the infrastructure) or be adjusted through an optimisation process (e.g.: annual ratio between renewal and maintenance). The latter must be optimised on the long term so as to minimise the total cost of the infrastructure over its lifetime. The medium-term management can then rely on guidelines that ensure a coherent evolution of the quality[2] and the substance[3] of the network and a minimal cost of the infrastructure over its life cycle.

[2] Quality is concretised by the value of a set of indicators that mainly represent the geometry of the infrastructure.

[3] Substance is the remaining life time of the infrastructure. A network characterised by a poor substance has an old infrastructure which maintenance may become soon critical.

Figure 1: Role of a long-term M&R policy in the M&R process



The main objective of successful policy is to define maintenance and renewal rules leading to a sustainable balance between the magnitude of the three main decisive variables of infrastructure assets: the maintenance policy, the renewal policy and the available capacity.

The quality is mainly determined by the maintenance, whereas the substance of a railway network relates directly to its renewal cycle. What may occasionally be observed is the dangerous policy of increasing the traffic on the network, while the quality is kept at about the same level by more maintenance, because the budget for renewal is not sufficient and/or increased track possession time for these heavier works is not available due to increased traffic. The result is a dangerous loss in substance that unfortunately may become visible only in mid- or long-term range; the infrastructure lives on its substance. Considering the fact that after a certain age it is impossible to guarantee the quality of the infrastructure by a maintenance action, a renewal action has to be undertaken. An infrastructure living on its substance means that the average age of the infrastructure is constantly growing, leading to a point where an important part of the network should be renewed at the same time. This engenders budget problems, machines and manpower bottlenecks and, usually, as renewal actions can't be done quick enough, speed and traffic restrictions must be enforced. The system "rail" is then unstable.

This example gives evidence that certain basic decisions on the maintenance and renewal policy as the ratio between maintenance and renewal budgets have a decisive influence on the long-term network capacity. It is therefore crucial for any infrastructure managers to adapt a long-term M&R policy, integrating the evolution of capacity as well as maintenance and renewal needs. This is the point where the model for a long-term capacity and resource management of WP 5 comes in to support infrastructure managers.

3.3 Duality of the network capacity development and the infrastructure maintenance and renewal

As discussed above, the infrastructure manager should answer two major questions : *where and when shall I invest in capacity* and *how shall I maintain or renew my infrastructure*?

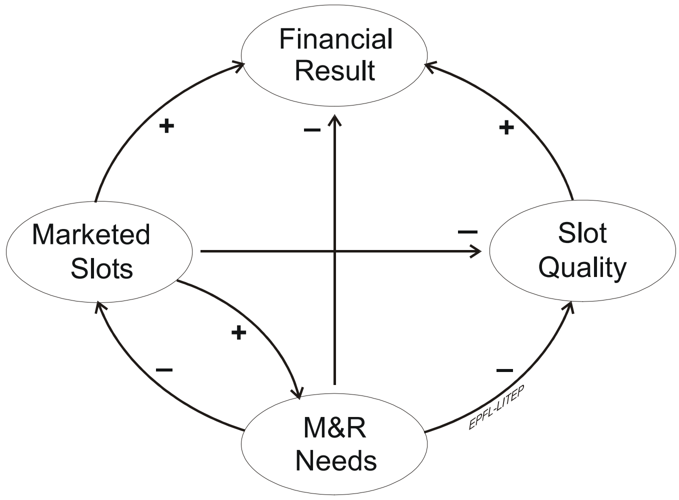
Thus, the infrastructure managers challenge to fulfil this objective is twofold:

- The capacity management aims at optimising network capacity in terms of future train-path demand. By anticipating future train-path demand based on traffic forecasts, the infrastructure manager has to identify and plan the necessary capacity extensions in order to meet the future demand. The optimisation task is complicated by the fact that capacity evolution occurs in leaps with typically a long time lag between identification and realisation, whereas the demand evolution is a rather continuous process. An optimum is reached if the available capacity follows the demand development as close as possible.

- The maintenance and renewal management defines and plans all the activities in order to maintain the infrastructure at a desired quality level (RAMS) with minimum total cost in the long-term view. The long-term M&R policy has to follow the strategic objectives of the infrastructure manager and the technological evolution as well as to determine the impact of M&R on the network capacity.

These two challenges are closely *interrelated and inherently contradictory*. The following figure shows the positive and negative effects of an improvement in one area of the infrastructure management to the other ones:

Figure 2: Interactions within the infrastructure management



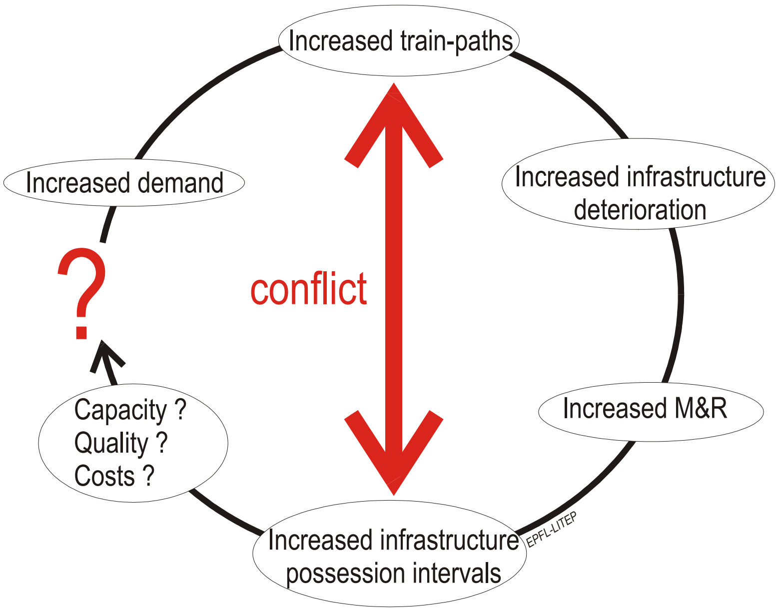
The most obvious conflict occurs between marketing and maintenance:

- The marketing department's goal is to sell as many slots as possible to satisfy customer demand. But the provision of additional train slots accelerates track deterioration and leads to more maintenance and renewal works. More maintenance consumes additional slots and thus reduces the number of marketable slots.

- The maintenance department's task on the other hand is to keep the infrastructure on a defined quality level. The maintenance work has to be carried out at the lowest possible costs, which implies the use of heavy machinery and work during the day. The resulting track possession intervals inherently consume capacity, hereby reducing the marketable train-paths.

The figure below outlines the contradiction.

Figure 3: Conflict between capacity development and M&R

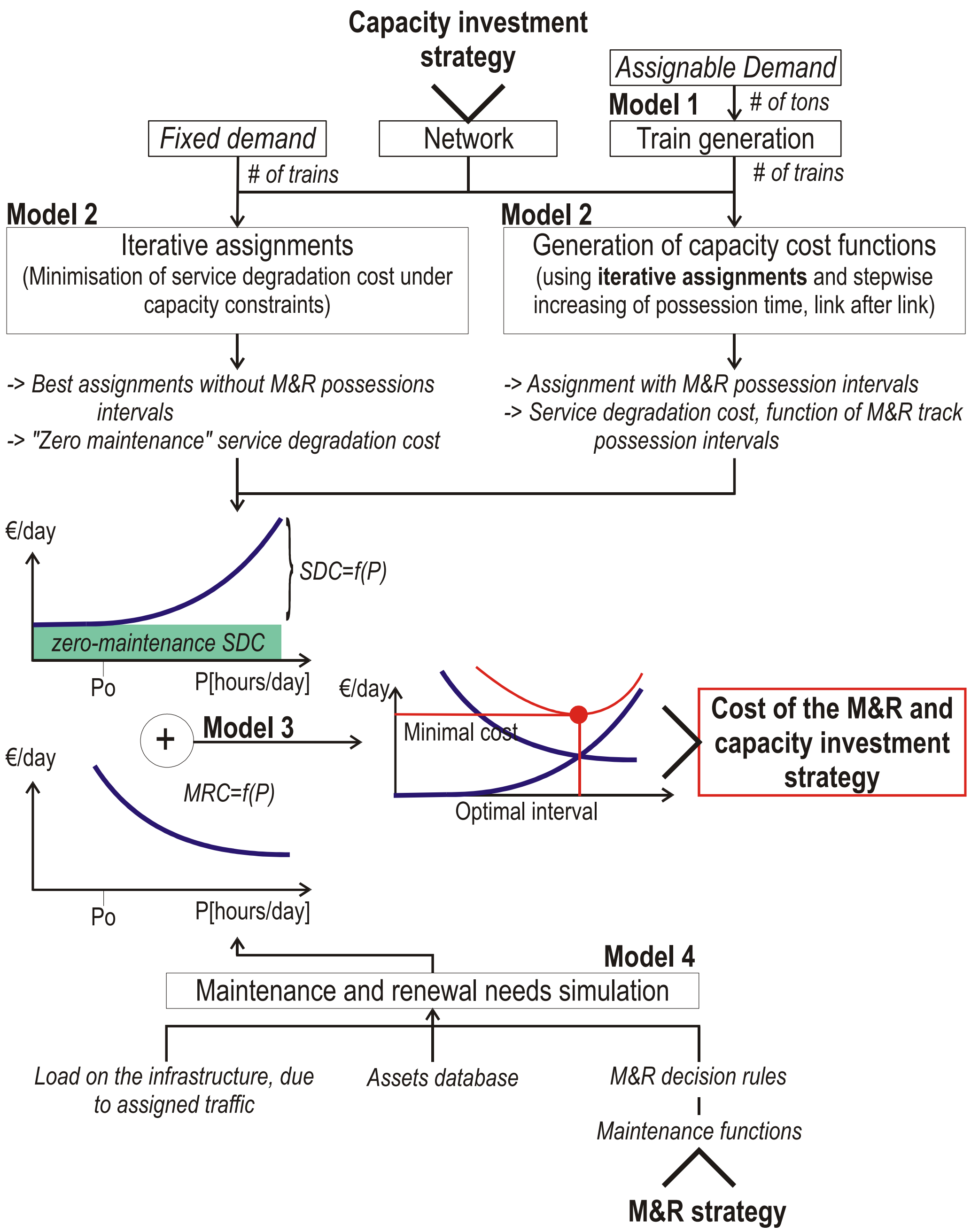


Thus, an infrastructure management seeking an optimal development of the network should tackle the dual approach, including both *capacity and M&R issues*.

4. Modelling

The following figure shows the overall approach that has been adopted for the project.

Figure 4: Modelling concept.



(SDC : Service degradation cost, MRC : M&R costs, P : track possession time)

4.1 Comments on the approach

The capacity evolution modelling first assigns the forecasted demand on the considered network. It provides the traffic (number of trains per category) on the links and information on the saturation of the network. In a second phase, new assignments are undertaken but with increasing possession intervals on a specific link. This step is repeated for each link and the whole process provides the costs of interval possession time over the network. These costs are composed of the cost of re-routing train, the cost of delays.

Costs of interval possession and traffic flows are then used by the maintenance and renewal policy modelling part. First of all, the M&R simulation model calculates the needs in infrastructure maintenance and renewal actions, by applying the forecasted traffic on the network. Then, it calculates, section by section, the optimal possession interval minimising unit costs of maintenance and renewal works, bringing thus to the infrastructure's engineering side the value of the capacity.

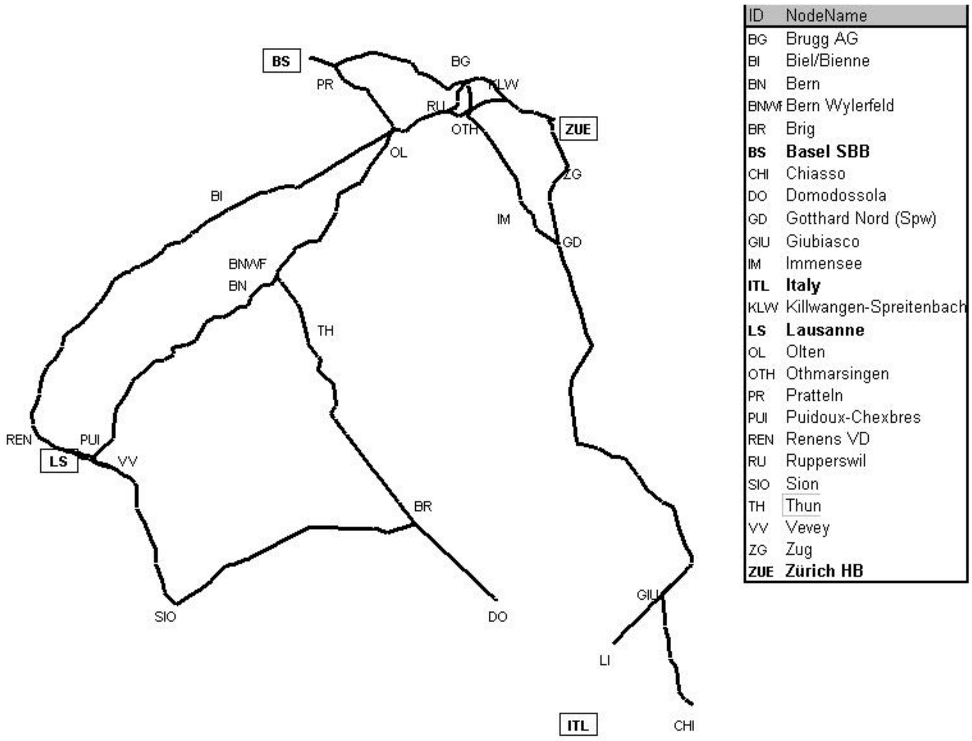
4.2 Modelling the network[4]

In the proposed approach, a network should be considered at two different levels of details.

The long term capacity evolution analysis requires an up-down network approach. The latter is split into sections according capacity parameters (number of tracks, number of overtaking facilities,…) and connections. Traffic generation nodes are defined as main stations, marshalling yards and border stations. The following figure shows the North – South network of Switzerland, defined for the real case illustration, with 349 sections forming 33 links.

[4] Moreira, al – Deliverable D6 - Task 5.1

Figure 5: Example of a network description (North-South corridors in Switzerland)



On the other hand, the M&R policy simulation tool requires an accurate description of the network and its infrastructure, a kind of down-up approach. Links are divided in homogeneous infrastructure sections, according the stability of the sub-soil, the layout of the line (curves and cants) and the type of material composing the track.

4.3 Modelling the demand

The model deals with two kinds of inputs : a *fixed demand* matrix and an *assignable demand* matrix. The first matrix contains trains that can't be rerouted, such as national and regional passenger services or local service freight trains. The assignable demand matrix includes all trains that can be assigned on the network on any routes leading from the origin to the destination (mainly national and international freight trains).

Fixed demand trains skip the assignment process and are directly affected to their respective links. *Assignable demand* is introduced in the model in the form of O/D matrices expressed in yearly tonnes by *market segment*.

The *freight market segmentation* follows an extended NST[5] (Standard Goods Classification for Transport Statistics) classification. The table 1 lists these market segments and provides, as example, their respective value of time as defined by Guglielminetti (2001). Values of time have been valued roughly on the basis of the average value of products and on the evaluations and indications given by shippers concerning requirements of service quality.

Passenger traffic segmentation is less questionable. The following segmentation is proposed :

- International traffic
- Long-distance national traffic
- Inter-regional traffic
- Urban and regional traffic

In the Swiss case illustration, the passenger traffic is seen as fixed demand and does not enter in the assignment process.

[5] See bibliography. This classification has been used by Paolo Guglielminetti in its thesis.

Table 1: value of transport time for the different demand segments (2000)

	Segments	*Time value* (*€ / tonne · hour)*
1	Land-based combined freight traffic	1.0 – 4.0
2	Maritime-based combined freight traffic	0.8 – 1.5
3	Agricultural Products (NST 0)	1.0 – 1.2
4	Foodstuffs And Animal Fodder (NST 1)	0.8 – 1.9
5	Solid Mineral Fuels (NST 2)	0.2 – 0.6
6	Petroleum Products (NST 3)	0.3 – 1.0
7	Ores and Metal Waste (NST 4)	0.1 – 0.6
8	Metal Products (NST 5)	0.7 – 1.8
9	Crude and Building Materials (NST 6)	0.1 – 0.5
10	Fertilizers (NST 7)	0.1 – 0.4
11	Chemicals (NST 8)	0.8 – 1.8
12	Manufactured Articles (NST 9)	1.0 – 4.0

Finally, O-D matrices that could be used for the presented modelling concept must be *aggregated* so as to coincide with the description of the network, that is to say, with the *traffic generator nodes*. For instance, the Swiss real case illustration uses 4 x 4 freight O-D matrices.

4.4 Model 1 : Train generation, from an O-D matrix to a number of train-paths[6]

As freight demand is usually expressed as tons per year (or similar values), related data should be transformed in terms of trains/day, especially for assignment and capacity assessment procedures. Passengers demand data could also require a similar transformation.

The model is a simple transformation method, relying on following parameters :

- Types of wagons : types of wagons determine how many tons can be loaded on them, and thus, the number of wagons that should be circulating, each year, between an origin an a destination, for each market segment.
- Maximal length of trains (i.e. maximal number of wagons) : the maximal length of trains determine the number of trains that should be circulating each year, between an origin an a destination, for each market segment. In fact, the tonnage and the maximum length of trains can vary strongly according to the chosen itinerary (plain track or mountainous,…). However, as this research relates to the long term, this dependence has been simplified and the model determines mean characteristics of trains, for each market segment.
- Empty wagons ratio : transport demand on a link may be imbalanced. This implies that empty wagons should be repatriated. Therefore, a empty wagons ratio weights values used for generating trains. This ratio may be determined from statistical data provided by operators or infrastructure managers.
- Day-period repartition factor : in certain case, freight trains leave marshalling yards or reach border stations at a specific period of the day. For instance, one could assume that the loading and unloading of ships occur during the day. Thus, freight trains related to shipping activities may reach the harbour early in the morning and leave it in the evening. A day-period factor takes into account this specificity.
- Year-period repartition factor : the demand may be varying regarding period of the year. Therefore, the number of trains should also reflect this fact. A year-period repartition factor adapts the mean value and outputs a more real figure of the generated traffic.

[6] Montfort, Danzer, al – Deliverable D6 - Task 5.1.

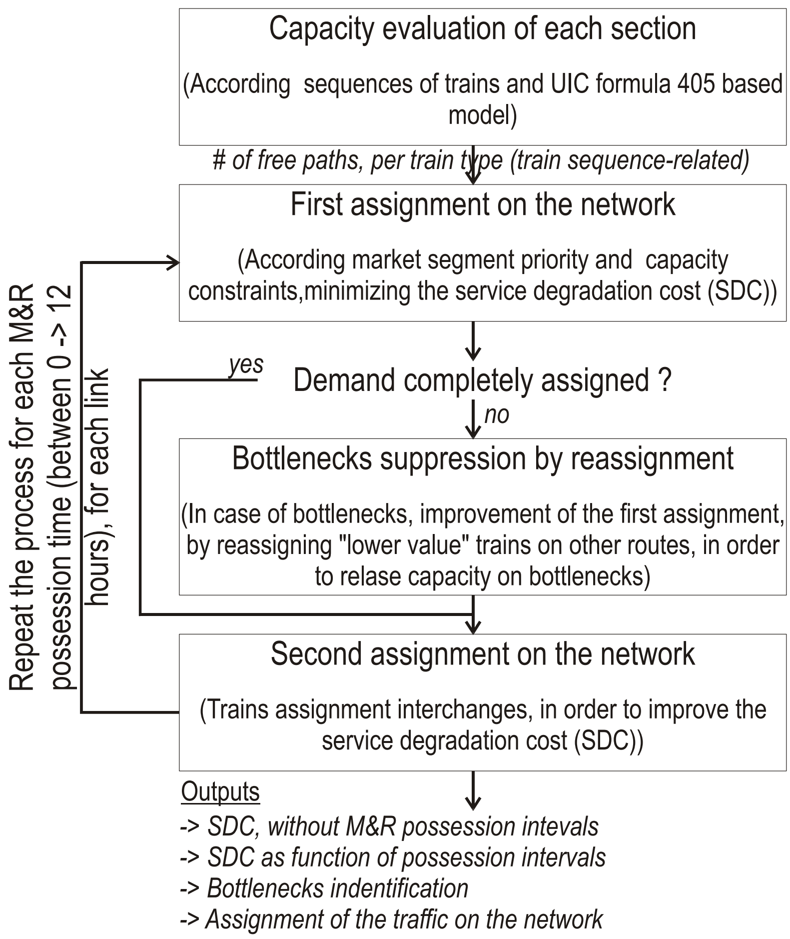
4.5 Model 2 : Capacity evolution[7]

4.5.1 Approach

The capacity evolution model provides three important results :

- identification of bottlenecks on the network,
- the assignment of the traffic on the network,
- the cost of service degradation, due to capacity insufficiency (including possession intervals).

Figure 6: Concept of the capacity evolution modelling



[7] Moreira, al – Deliverable D6 - Task 5.1

The model relies on two basic processes : the capacity analysis of the network and trains assignment on routes. In order to get more accurate results, the capacity analysis is made separately for three day periods : *day, night and peak hours*. The figure above shows the basic concept of the capacity evolution modelling.

4.5.2 Capacity analysis[8]

The capacity evaluation method relies on the UIC formula 405-R, which defines capacity as follows:

$$L_{[slots]} = \frac{T_{[\min]}}{\left(t_{fm} + t_r + t_{zu}\right)_{[\frac{\min}{slot}]}}$$

where:

- L capacity of a section in number of trains in the period T
- T considered time span
- t_{fm} average time span at minimal sequence of trains
- t_r running time margin
- t_{zu} added time

$t_{r[\frac{\min}{slot}]} = \alpha \cdot t_{frm}$ α determined by the maximal allowed use of the section;

The average time span, assuming saturation of the network, can be obtained by:

$$t_{fm[\frac{\min}{slot}]} = \frac{\sum\left(n_{ij} \cdot t_{fij}\right)}{\sum n_{ij}}$$

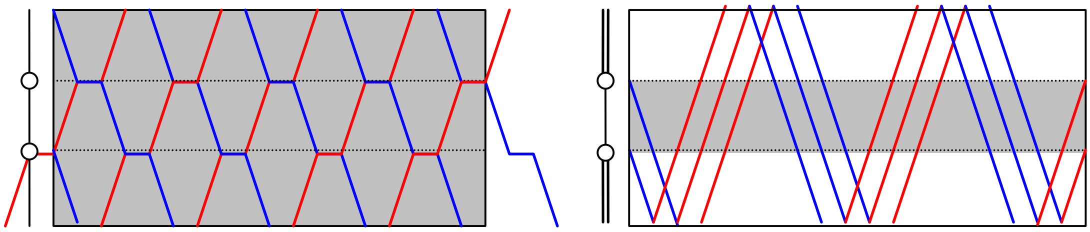
- n_{ij} number of sequences where a train of type *j* runs after a train of type *i*
- t_{fij} time gap between the sequence of trains of type *i* and *j*

[8] Buri, Moreira, al, Deliverable D6 - Task 5.1

For this formula knowledge about the timetable is required to count n_{ij} (the number of sequence cases where one train of type i follows one train of type j). One consequence of this formula, recognised in document UIC 405, is a strong dependency on the sequence of trains defined. In same cases, only the exchange of two trains in the sequence is enough to get different results in capacity. Therefore, the model uses a kind of "most probable" sequence approach.

Moreover, the developed method deals with three basic network and operation configurations, which influences significantly the above mentioned train sequences. Theses configurations are : double track lines, single track lines with alternate and grouped train-paths.

Figure 7: Single track lines with alternate and grouped train-paths.

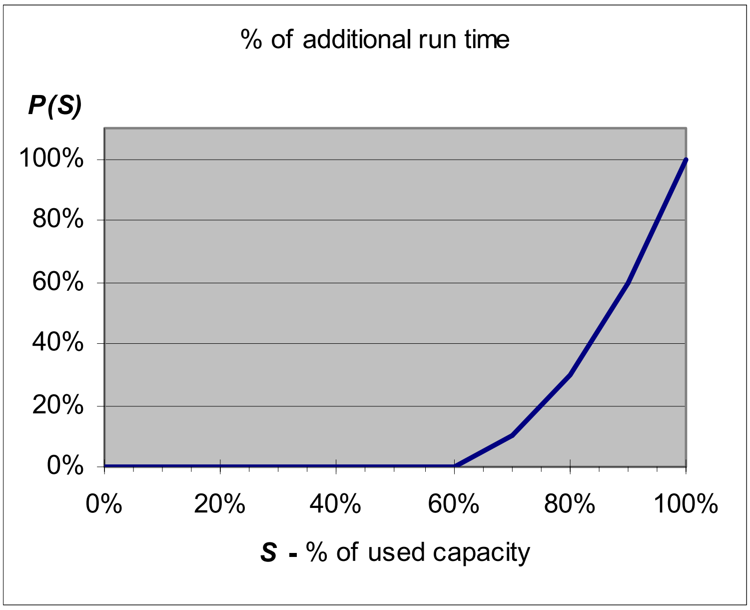


4.5.3 Service degradation costs (SDC)

Service degradation is represented as the increase of the travel time, due to *delays* or to *re-routing* (assignment on a line that isn't the fastest path).

Trains delays are defined as a function of the saturation rate of a link, as shown by the figure below. This function should be evaluated by the user of the model and could be based on statistical analysis of train operation records.

Figure 8: Delay in function of the saturation of a line : an example.



The service degradation due to re-routing are expressed as well as an additional travel time, but in comparison with the ideal route, that is to say, the fastest route.

The *service degradation cost(SDC)* of a train is defined as the cost of train delay due to congestion or re-routing. Given the *value of time* for each market segment, the service degradation cost of one train will be that value multiplied by the total delay, that is to say, the difference between the effective and the ideal travel time (using the shortest-path (in time) with a zero saturation level in the network).

4.5.4 Allocation Algorithm[9]

The developed algorithm is divided into four actions :

1. First allocation, with market segment prioritisation and capacity constraints, minimising the service degradation cost (SDC),
2. In case of unassigned demand, search for bottlenecks (on unassigned O-D pairs), and try to release capacity by rerouting trains from other market segments,
3. For each market segment, try to use rerouting to improve the solution,
4. For each market segment, search for a second market segment and try to reroute both market segments to improve the solution.

These steps are based on the same fundamental process :

The process consists in allocating the demand on the network, market segment by market segment, regarding a priority index that reflects the reserve of paths (available capacity) on the network, for each market segment. Thus, the allocation takes into account the maximal capacity of the network. The steps are :

- 1.1) For each market segment and for each origin-destination pair where there are unassigned trains, determine a priority index. This priority index (Idx_m)is defined as the number of available train-paths on the route where there are the most. The formulation is : Idx_m=Max{δ_{im}-[D_m-sum(x_{im})]}, where δ_{im} : available train-paths on path *i*, for market segment *m*, D_m : the total demand for an O-D of a market segment and x_{im}, the already allocated trains of segment *m*, on link *i*.
- 1.2) Select the market segment and the origin-destination pair with the lowest priority index and :
  - Search for the path characterized by the lowest service degradation cost,
  - Assign the selected origin-destination pair on that path and update number of free train-paths left on that route.
- 1.3) Return to step 1.1) until demand is completely assigned or until no more free capacity is available.

The other steps are variations of the above described process. The basic idea is to increase the capacity of the network by re-routing trains on (longer) alternative paths. These alternative

[9] Moreira, al, Deliverable D6 - Task 5.1

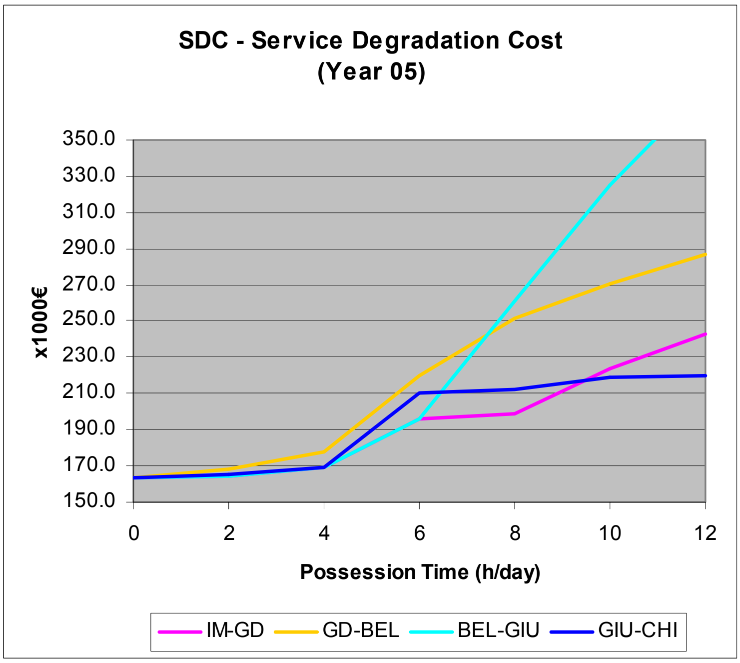
paths are selected by the user of the model. For each origin-destination pair of the O-D matrix a previous analysis of the network (or the application of the shortest paths algorithm) returns a set of alternative paths, different than the ideal one. In this selection of alternative paths for re-routing, all paths that not fully satisfy constraints related to train categories (e.g. maximum axle load, …) should be discarded. Algorithms try then to set as much trains as possible, using if necessary, alternative routes mentioned above.

4.5.5 Example of outputs

This chapter provides some results coming from the Swiss case study, elaborated for the WP5 of IMPROVERAIL.

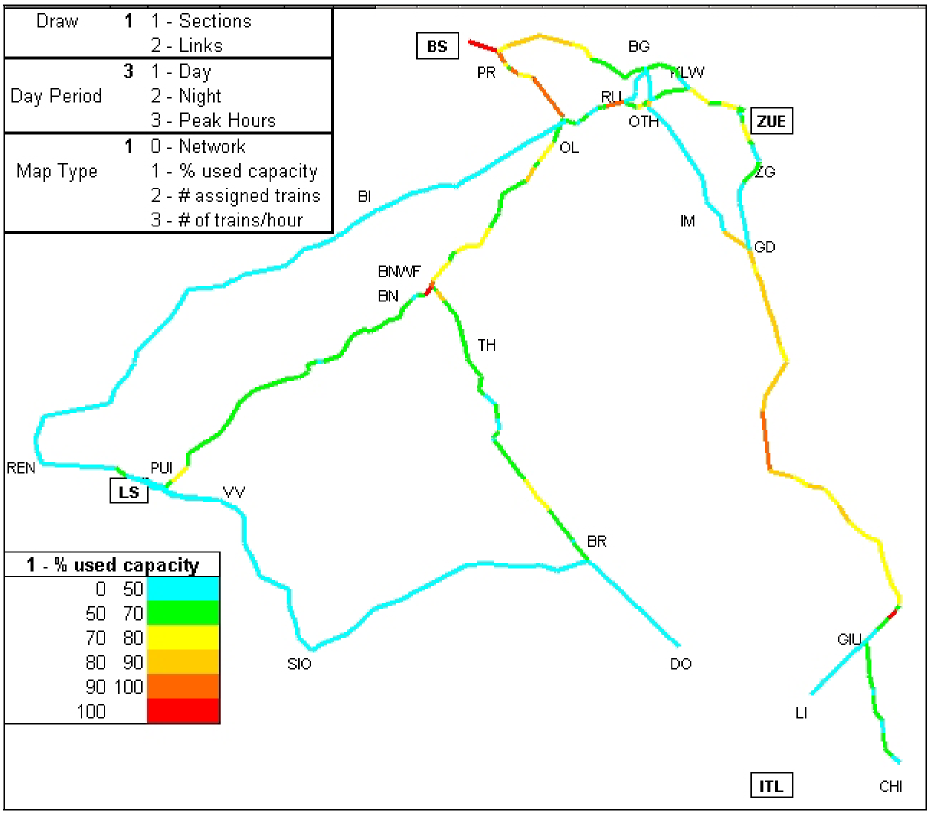
The graph hereunder shows the service degradation cost (SDC) on four links (namely Immensee – Arth-Goldau, Arth-Goldau – Bellinzona, Bellinzona – Giubiasco and Guibiasco – Chiasso) of the Gothard line, through Switzerland. Service degradation costs are shown as function of possession time, for one day. One can identify the offset (at 165'000 €) representing the "zero-maintenance" service degradation cost, that is to say, the cost of the *permanent capacity insufficiency*. The increasing curve above the offset represents the additional cost of the service degradation due to *M&R possession intervals*.

Figure 9: Service Degradation Cost on the Gothard line.



The next figure shows the network with saturation rates.

Figure 10: Saturation rates over the network.



4.6 Model 3 : Optimal possession interval

This part of the methodology consists in the determination of the optimal track possession interval, minimising costs of works plus possession intervals costs.

One has to keep in mind that the process should deal with the long-term planning. This implies some basic assumptions and some simplifications that shouldn't be made on operational planning level but that are adequate for strategic planning.

4.6.1 Key factors

Following factors play a key role in the cost function:

- Type of work to be undertaken
- Used technology and worksites organisation
- Layout of the network in the worksites region
- Saturation rate of the considered network section

Type of work to be undertaken

Obviously, the type of the intervention that must be done on the network influences the costs of the work. Some actions are very cost extensive.

Used technology and worksites organisation

The technology used for a specific intervention affects several cost drivers such as the cost of machines, the cost of manpower, the cost of interval possession,… Worksites organisation plays also a key role in the costs. However, it is very difficult to predict the way worksites will be organised in 20 years. So, the method proposes to use three basic worksite scenarios.

Layout of the network in the worksites region

When the track has to be freed for traffic, machines must be shunted to a siding. This requires a certain time, depending on the velocity of machines, and implies a specific cost, both of them depending on the distance separating the siding to the worksite. Obviously, a "slim" network – with few sidings – means bigger shunting time, decreasing the available time for the work and thus increasing related costs.

Saturation rate of the considered network section

Finally, the saturation rate of the network around the worksite is a major cost driver. On saturated links, any closure quickly leads to heavy consequences on the traffic. Possibilities to handle the traffic with a temporary reduced infrastructure are small and the quality of service can't be ensured. On these line, track possession intervals must be kept as small as possible or traffic replacement services have to be organised, both of these situation being cost extensive.

In opposition to this, light-loaded sections allow wider intervals, thus offering the chance to reduce costs.

4.6.2 Modelling

The concept is based on three worksite scenarios : one heavy machine intervention, combination of two heavy machines and, finally, light machines intervention.

For each case, the cost are calculated as follow :

- For each increment of possession time (from 1 to 12 hours)
  - calculate the number of day required by the worksite, with that possession time,
  - calculate the cost of the works over the total duration of the worksite, according to the type of machines, workforces,…
  - add these costs to service degradation costs (SDC).
- The minimal value of these costs (work and SDC) is then the real cost of the M&R action, corresponding to a specific possession interval.

One machine intervention is used for modelling work methodologies where only one machine is required. Typically, this could be the case of tamping activities.

Figure 11: One heavy machine intervention

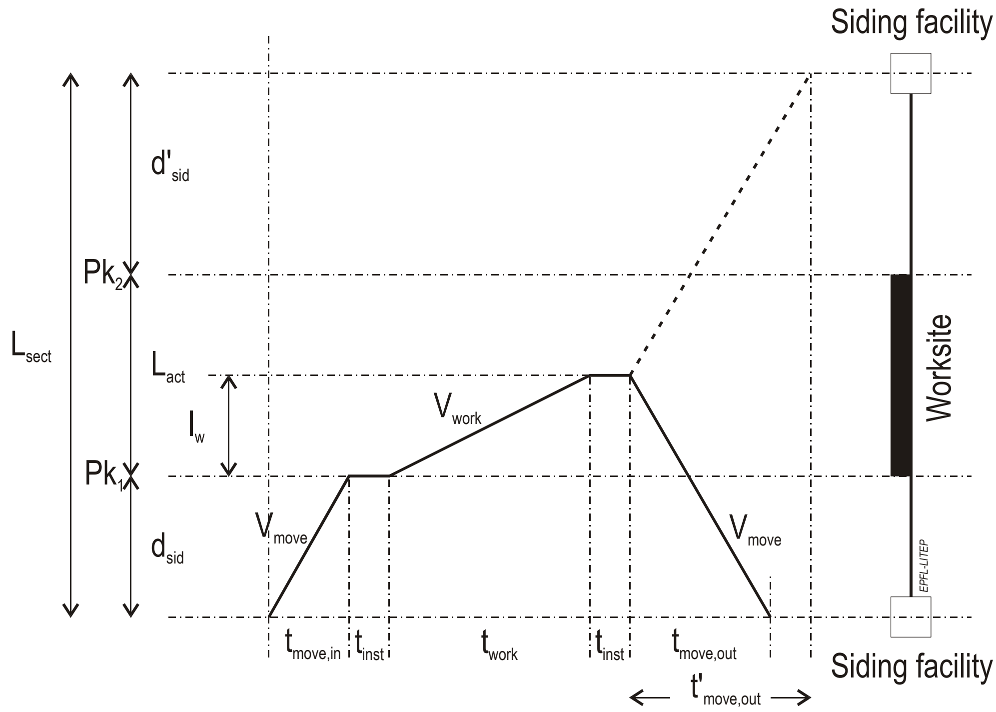
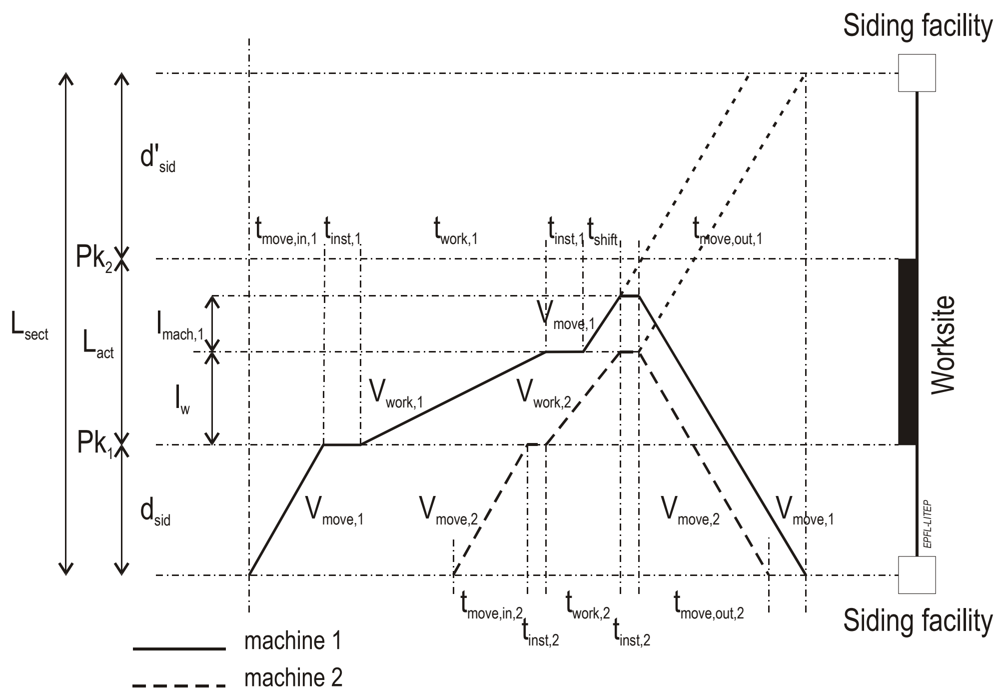


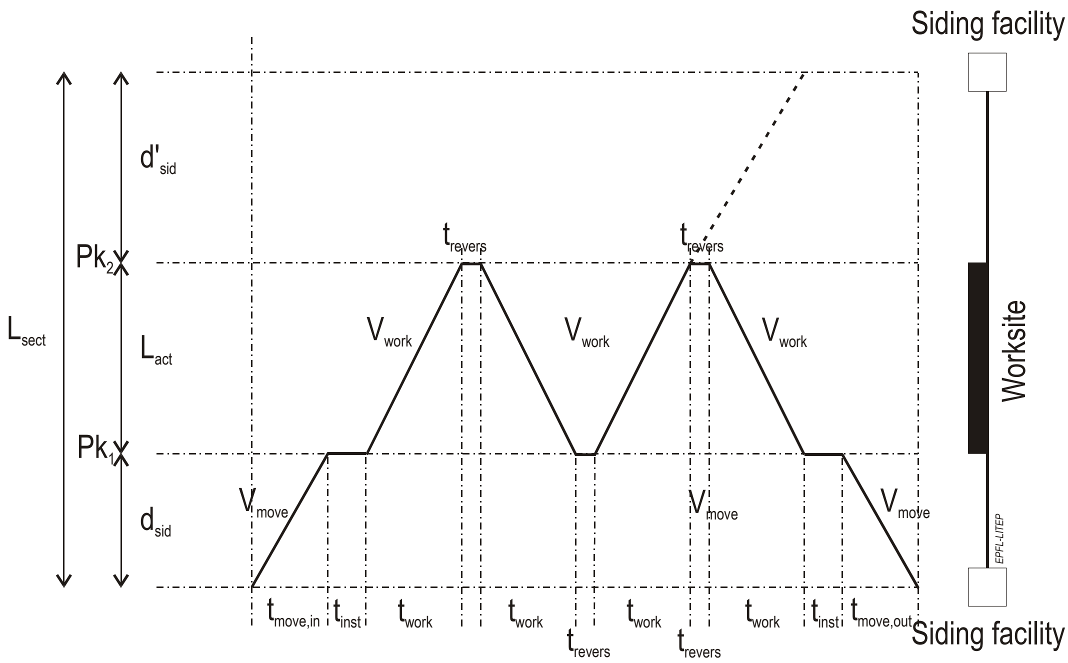
Figure 12: Two heavy machines intervention



Combination of two *heavy machines* is used when more than one machines usually work on the track. The model is limited to two, but the concept can easily be adapted to more machines. Ballast renewal could be executed that way, the first machine cleaning/renewing the ballast and the second one tamping the track.

Finally, in order to take into account the rail grinding process (quick process, but with several sequences), the last case of *light machine intervention* has been modelled.

Figure 13: Light machine intervention.



Usually, railways infrastructure maintenance machines need a kind of logistical chain, involving one or more other trains. These trains play a important role as well in the worksite organisation and should be taken into account. However, as IMPROVERAIL aims at rough modelling, the method has been reduced to the maintenance machines. Further development or model refining should include the whole logistic of worksites.

4.7 Model 4 : M&R policy simulation

4.7.1 Some comments on the approach

Infrastructure components, field of study

Although the infrastructure includes several elements, the developed model encompasses only three basic elements: *rails, sleepers and ballast*, leaving out bridges, tunnels, catenary and other items. The reasons are:

- M&R data for rails, sleepers and ballast are sufficiently available,
- these elements represent the major part of M&R costs,
- the engineering works related to these elements are more slot consuming than the others,
- bridges and tunnels should be seen as separate projects, where specific planning tools must be used (and already exist).

However, the methodology and approach proposed below should be suitable for any other elements for which a maintenance function (quantity of maintenance related to the age of the component) can be defined.

Combination of renewal actions

Renewal or maintenance of rails, sleepers and ballast can't be considered separately as the possible combination of actions on these elements influences costs dramatically. Therefore, the infrastructure is divided into homogeneous sections and the simulation process considers the three components simultaneously. Then, the cost calculation and possible budget check is done for the combination of the works.

Time coherence of actions

The time coherence of actions is checked, section by section. For instance, at the time of rail renewal, the simulation process controls the state of sleepers and ballast. If any of these elements reaches its respective threshold, the model launches its renewal as well. So, for instance, the process avoids non-coherent cases where sleepers are renewed one year after rails.

Spatial coherence of actions

As opposed to time coherence check, the simulation process doesn't deal with the spatial coherence of work actions. For instance, if renewal actions are planned on two adjacent, or nearly adjacent, homogeneous sections, two separate actions will be launched by the model.

Although it seems rather obvious that the spatial distribution and, furthermore, the combination of adjacent work sites have an effect on costs, it remains difficult to estimate the importance of the error caused by this simplification. Local conditions and used technology dramatically influence the impact of working site length on costs, particularly for renewal actions as the latter are usually characterised by a low work speed. Therefore, one could assume that, for the long term planning, such a simplification should be reasonable.

Quality of infrastructure – maintenance functions

The quality of the infrastructure plays a key role in the whole railway system. The quality and reliability of the operator's services as well as the wearing of rolling stocks and infrastructure itself depends on the quality of the infrastructure. The model takes into account this key input through the maintenance functions. The latter characterise every type of element and give the length that must be maintained as a function of the age (expressed in UIC fictive tons or in years) of the component. *Obviously, a higher maintenance rate should lead to an increase of quality*.

M&R rules

M&R rules are guidelines for tactical planning of the infrastructure M&R. Infrastructure managers may use many rules and it is difficult to encompass all of them. Thus, the approach considers three basic M&R rules. Two of them, mainly depending on the technology, are used by the simulation process to evaluate the third one. The input rules are:

- Renewal threshold: this is a certain amount of traffic, expressed in UIC fictive tons[10], or a certain number of years after which a renewal action should be launched.
- Type of components that must be used at the time of renewal.

The value of these rules, namely values of thresholds and type of components, will be considered as variables and their combined variation may lead to a minimal total of M&R actions over the planning span.

The third rule is an output of the process and will be an important guideline to the M&R tactical planning :

- Annual length that should be renewed and maintained: these 2 values set the target of any medium term M&R planning or optimisation processes. This is rather crucial as models dealing with medium term optimisations may lead to "only maintain" policy, the railway infrastructure having a high inertia.

The value of the last rule is computed and may vary over the planning period, depending on the cost of capacity (image of its availability),

Planning horizon

The objective of the model is long term oriented, long term being defined as the time period between 6 and 20 years ahead. The length of the planning range engenders the risk that the amount of information required by the simulation method grows tremendously. Therefore, the model uses a simple approach that ensures a reasonable amount of data while keeping the quality of results at an acceptable level, as the uncertainty related to long-term planning is usually rather high, especially on the side of demand forecast.

4.7.2 Process of simulation

The next lines describe the simulation steps for one homogeneous section and for one year. The process runs iteratively on each element over the whole planning period.

[10] UIC code 714-R

1. The accumulated load, as well as the age of the component, is compared with the thresholds set by the M&R policy. These thresholds constitute the first M&R rule.

2. The age or accumulated load of rails, sleepers and ballast are compared with the first M&R rule, namely the thresholds.

    a. If the considered component has reached its maximal age or accumulated load, the process checks if the two other components have reached or nearly reached their respective thresholds. This is done through the use of a margin, which is added to the current age or accumulated load, and the comparison of this sum to the thresholds. This allows the time coherence of renewal actions.

    b. This step is repeated for the three elements and the work combination table is updated at each step.

3. The cost calculation is undertaken on the basis of the combination table.

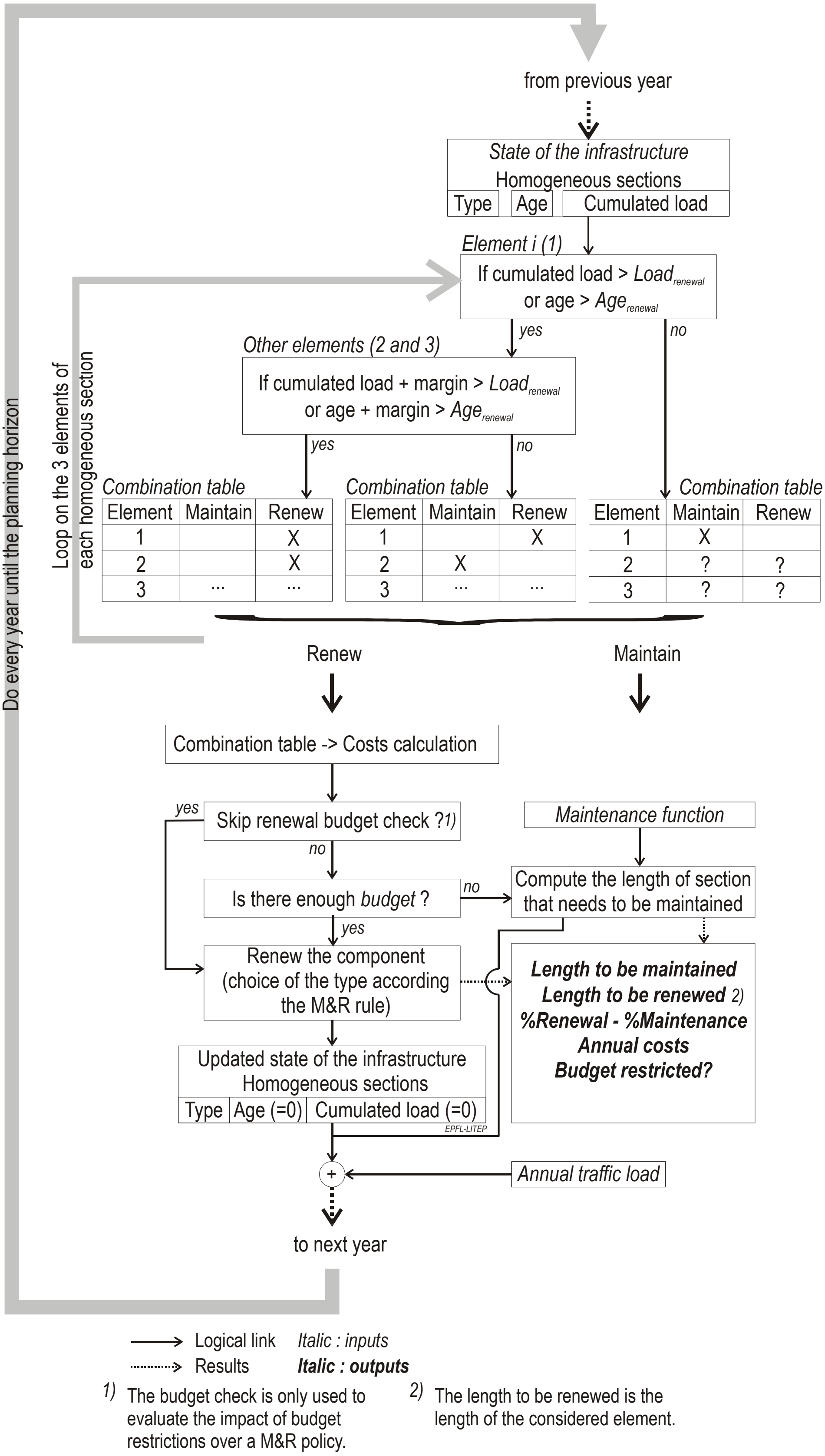
4. If the simulation process includes a budget limitation, the availability of the financial means is controlled. If the available budget does not allow the works specified by the combination table, renewal actions (6) are skipped and transformed into maintenance actions (5).

5. The length to be maintained is evaluated on the basis of the maintenance function of the each element. This function gives the percentage of the length of the section that must be handled, depending on the age or cumulated load of the elements.

6. Regarding the combination table, renewal actions are undertaken, with respect of the second M&R rule, namely the type of component to use at the time of renewal.

7. The simulation process goes through these steps over all homogeneous sections and for every year within the planning time span.

Figure 14: Concept of M&R simulation



4.7.3 Role of maintenance functions

The maintenance function characterises the influence of the traffic (load) on the maintenance actions that should be undertaken on the infrastructure. The more traffic a section gets, the more maintenance should be done on it, for a *given quality of the infrastructure*. Maintenance functions are expressed as a percentage of length to be maintained in function of the accumulated load or the age of the considered component.

These functions allow the calculation of a trade-off between renewal and maintenance expenditures. Logically, the less a network is renewed, the more it should be maintained, in order to keep a constant quality. So, one could expect that decreased renewal costs implies increased maintenance costs. Somewhere in between there must be an optimal ratio.

These maintenance functions should be extracted from the history of maintenance interventions of the infrastructure. This means that maintenance functions relate the M&R policy applied on the network in the past, including the quality level at which the infrastructure manager targeted. They should be updated each year.

In the case illustration, these maintenance functions have been extracted from the assets database from the Swiss Railways. The assets have been sorted into homogeneous section, according following parameters :

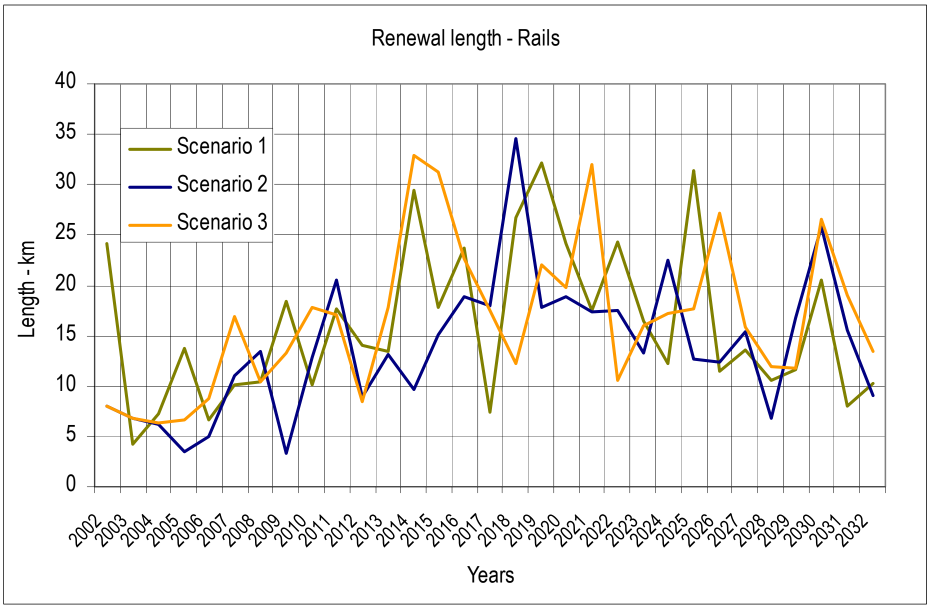
- Age
- Layout of the track (curves, cant)
- Normal speed of trains on the assets
- Type of material
- Quality of the sub-soil.

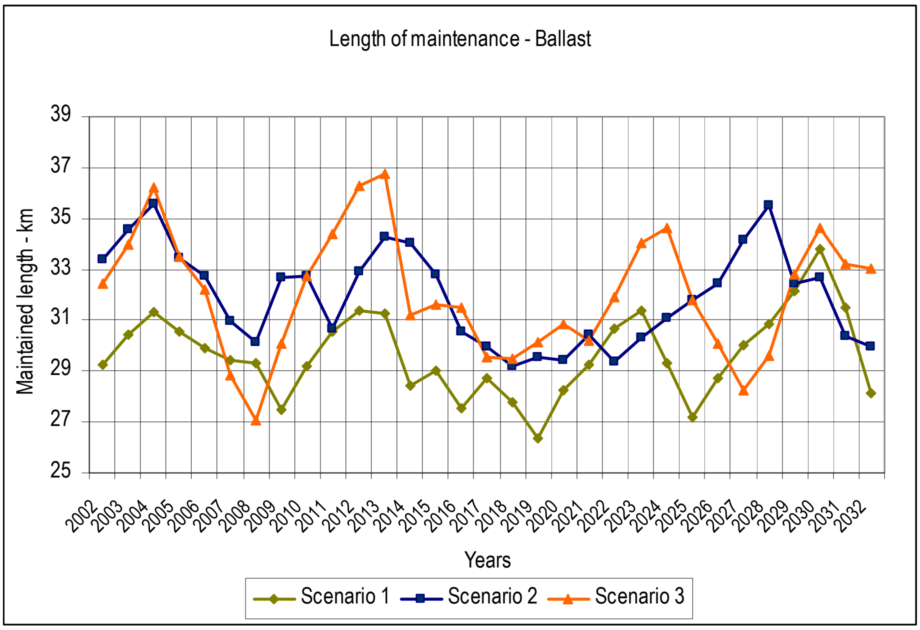
Maintenance functions have been elaborated by adding length of homogeneous sections that have been maintained (grinding or tamping) and dividing it by the total length of respective homogeneous sections. One gets then a ratio of maintenance, for each age, each layout and type of material.

4.7.4 Results

The M&R model is still in development and, by the time of writing the paper, only some tests have been done. The following figure shows a typical output of the M&R simulation.

Figure 15: Typical result of the M&R simulation model – Rail renewal program on a line and maintained length of rails on a line.





5. Conclusion

At the time of writing the present paper, research works of IMPROVERAIL were still on the way, making any in-depth conclusion premature. However, some facts can already be outlined.

Discussions and meetings held by researchers and railways decision makers have pointed out the necessity and the relevance of the dual modelling approach, including both network capacity and infrastructure M&R strategies. Many networks face capacity bottlenecks and are evaluating investments strategies. High construction costs and the limited availability of financial means urge infrastructure managers to extend the utilisation of their existing network, reaching the saturation point. It becomes more difficult to maintain and infrastructure durability concerns are appearing. Questions such as "how far can I saturated my network, without compromising its durability?" or "What is the best M&R strategy to maximise the capacity of my network?" are frequently raised by network decision makers.

Methods and concepts elaborated within the IMPROVERAIL project are able to give an answer to above mentioned questions. Obviously, proposed methods and concepts still need to be refined and transformed into ready to use software applications. However, the approach is promising and will be the subject of further research, in particular at the Laboratory for Intermodality, Transport and Planning (LITEP) of the EPFL.

6. References

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Improverail Consortium (2003), Methods for Capacity and Resources Management, *European project, Deliverable D6*, **task 5.3**.

NST stands for "Nomenclature Statistique pour les Transports" (i.e. Standard Goods Classification for Transport Statistics); http://www.ires.ucl.ac.be

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