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TRASPORTI E STRADE

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Techniques and methodologies for railway capacity analysis: comparative studies and integration perspectives

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Introduction

- The first part of the current research provides an accurate description of the methods classified by sector of interest, with a particular attention to point out all factors having a direct relation to the obtained results (Input/output).
- In the second part, a first preliminary comparison allows to estimate the ability of the methods to manage the typical operational situations and standards.
- The results are summarised in a comparison framework including quantitative elements useful for the planning of railway capacity analysis.
- The current research will continue with an application of all methodologies and simulation environments at a portion of a railway network.
- The global aim is to take into consideration all parameters affecting on railway capacity and be able to compare the results of each method.
- At the end, for some selected methods, there will be estimated a new proposal of coordinate use, which will define new categories of methodological approach to capacity calculation.

Railway Capacity

Definitions

Types of Capacity

Reference parameters for Capacity Calculation

Definitions

Although capacity seems to be a self-explanatory term in common language, its scientific use may lead to substantial difficulties when it is associated to objective and quantifiable measures.
It is a complex term that has numerous meanings and for which numerous definitions have been given.
When referring to a rail context, it can be described as follows:

"Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan."
(Krueger, 1999).

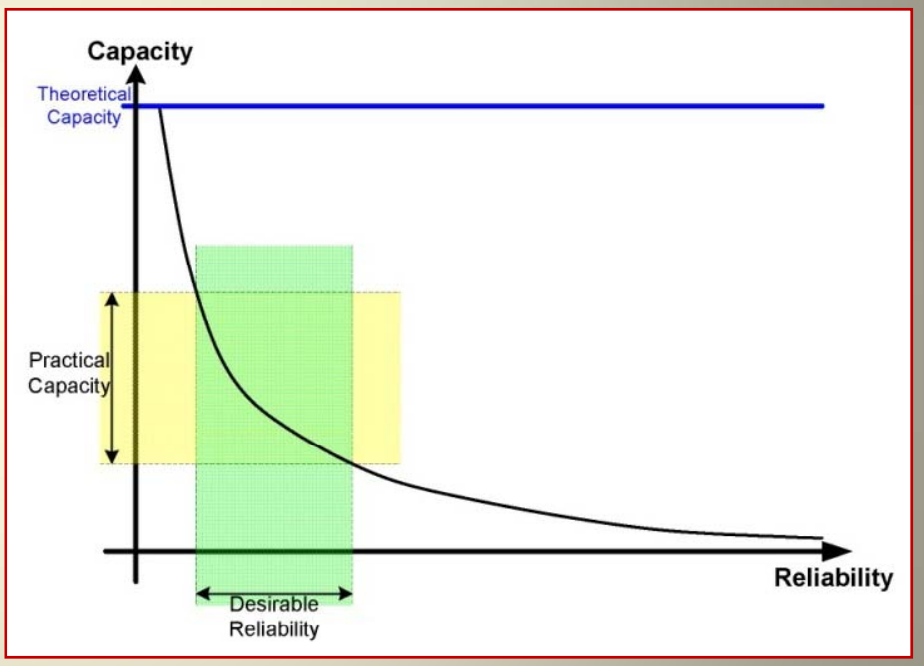
- Route capacity: Maximum traffic flow per track (# trains per day and peak hour respectively)
- Transport capacity: Maximum transport volume per route (# passengers and tons respectively per time period)

Types of Capacity [1/2]

Theoretical Capacity: It is the number of trains that could run over a route, during a specific time interval, in a strictly perfect, mathematically generated environment, with the trains running permanently and ideally at minimum headway. Represents the upper theoretical bound

Practical Capacity: It is the practical limit of "representative" traffic volume that can be moved on a line at a reasonable level of reliability intended as terms of punctuality. Represents a more realistic measure

Is calculated under more realistic assumptions, which are related to the level of expected operating quality and system reliability. It is the capacity that can permanently be provided under normal operating conditions. It is usually around 60%-75% of the theoretical capacity, which has already been concluded by Kraft (1982).



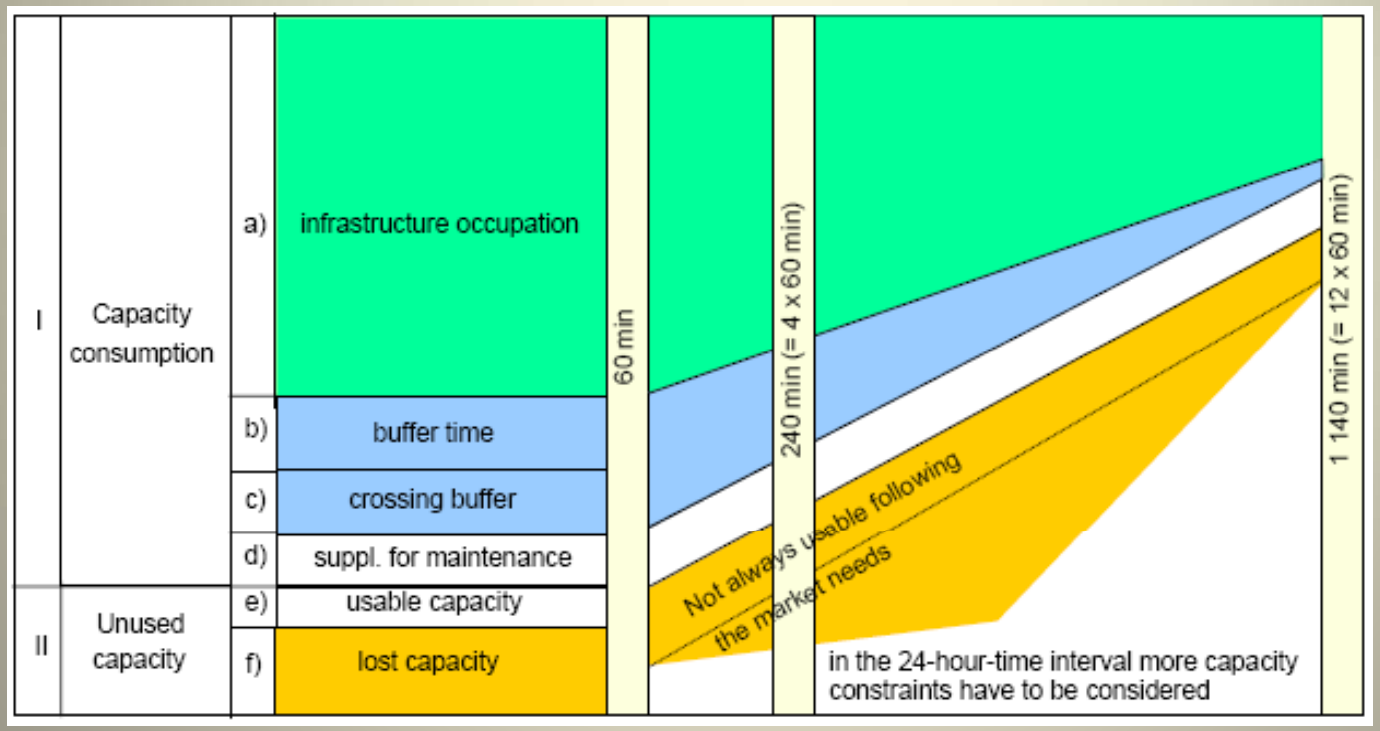
Types of Capacity [2/2]

Used Capacity: It is the actual traffic volume occurring over the network. It reflects actual traffic and operations that occur on the line. It is usually lower than the practical capacity.

Available Capacity: It is the difference between the Used Capacity and the Practical Capacity.

It is an indication of the additional traffic volume that could be handled in the route.

If it allows new trains to be added, it is a useful capacity; otherwise, it is lost capacity.



Reference parameters for Capacity Calculation

1. Infrastructure Parameters

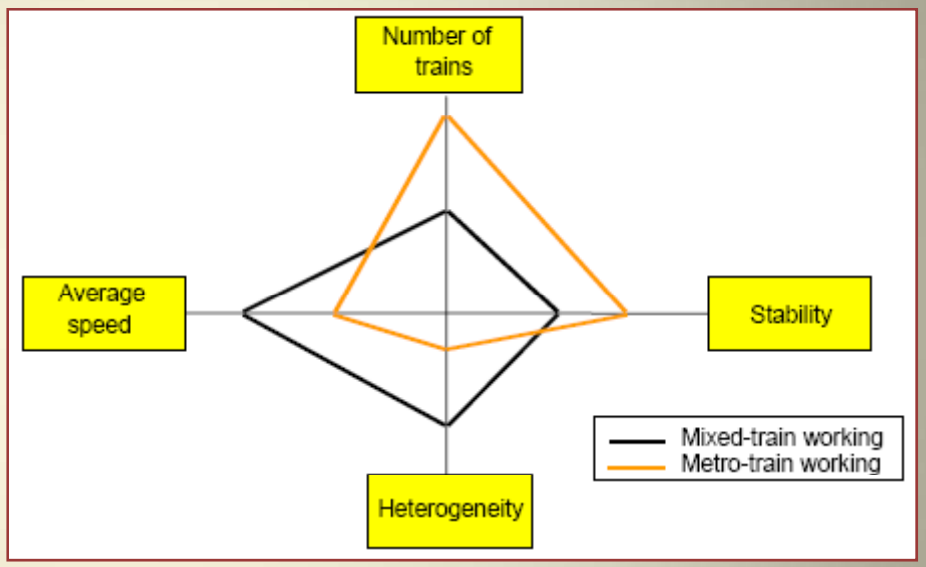
- ❑Block and signaling system
- ❑Single/double tracks
- ❑Definition of lines and routes

2. Network effects

- ❑Track structure and speed limits
- ❑Length of the critical block section

3. Operational effects

- ❑Track Interruptions
- ❑Train stop time
- ❑Maximum trip time threshold
- ❑Time window
- ❑Block occupation time
- ❑Headway distance
- ❑Headway
- ❑Running time supplement
- ❑Quality of service, punctuality or timetable robustness



Source: UIC

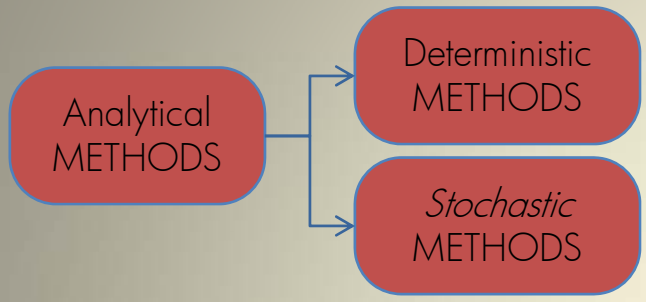
Techniques and Methodologies

Classification

Analytical Methods

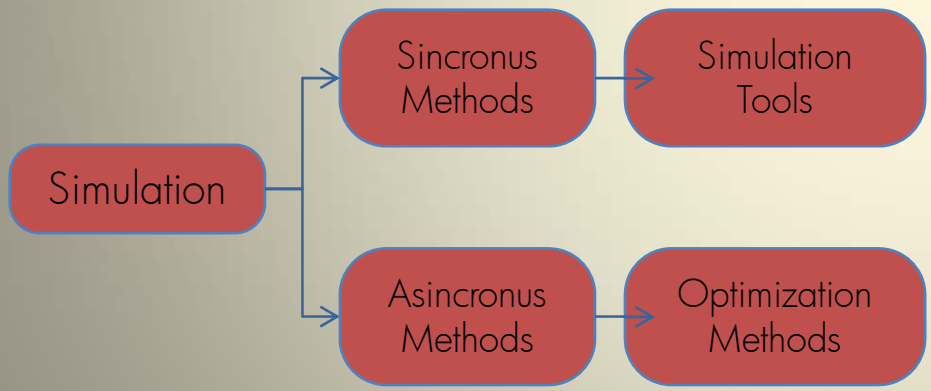
Simulation Enviroments

Classification



every event, including human cognition and behaviour, decision and action, is causally determined by an unbroken chain of prior occurrences

a state's next state is determined both by the process's predictable actions and by a random element.



✓ each process has a bounded time between its execution steps

✓ process's local clocks may drift either from each other or from global physical time only by a bounded

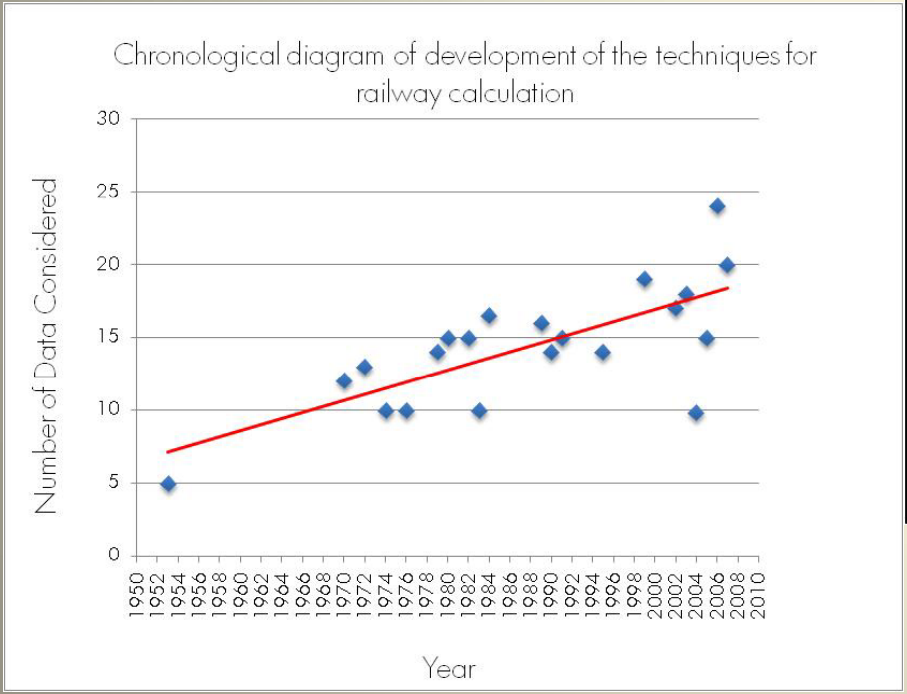
The asynchronous model has no bounds on execution entity - arbitrarily long (but finite) times may occur between execution steps

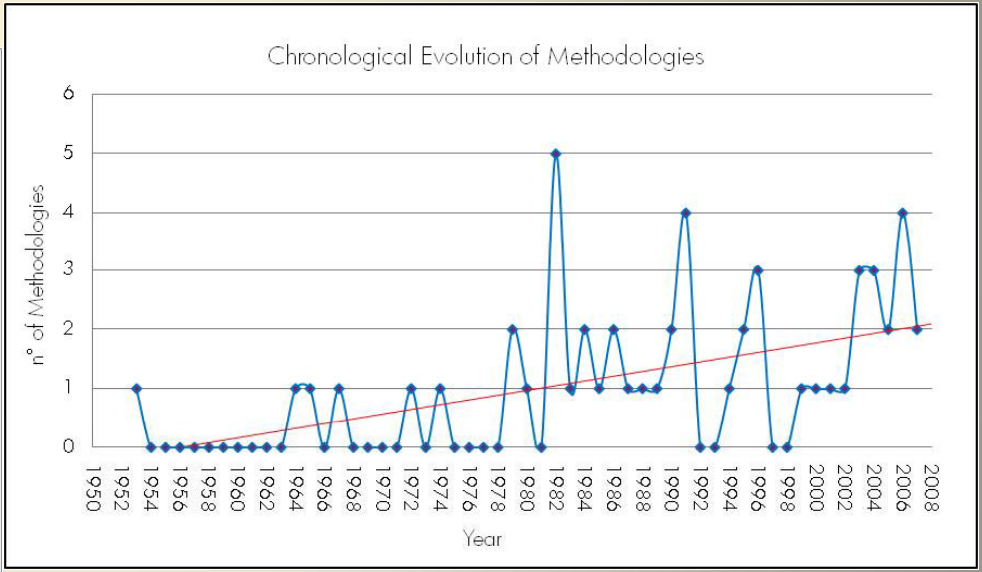
Analytical Methods

1953 → *2008*

53 methods

Analyzed in the present paper :
28



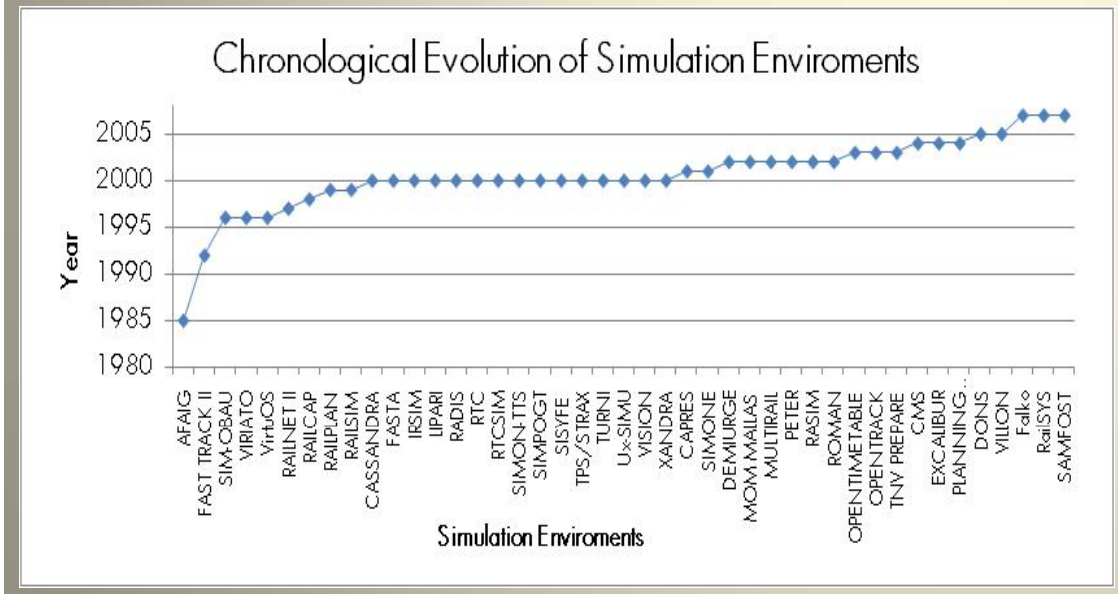


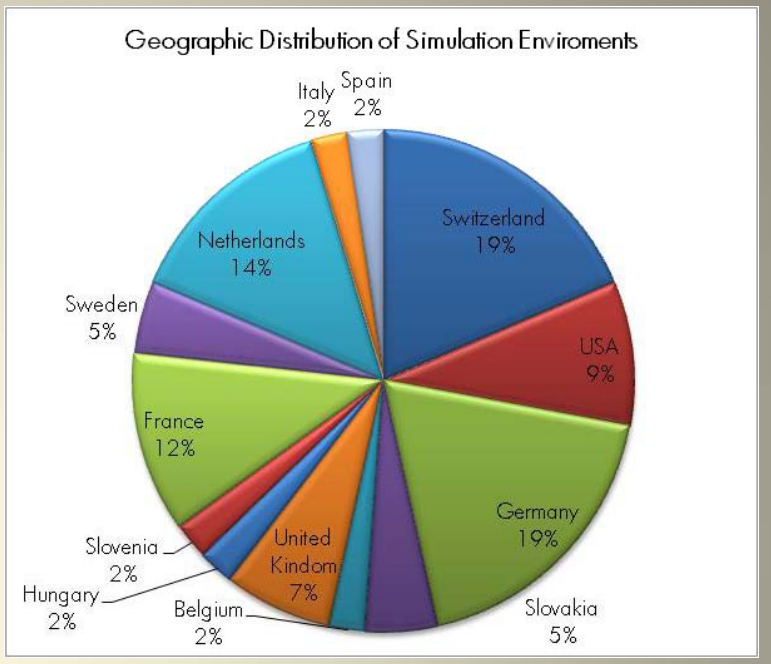
Simulation Tools

1953 → *2008*

43 tools

Analysed in the present paper
3





Preliminary Comparative Analysis

Evaluation Process

Methodologies

Simulation Enviroments

Evaluation Process [E.P]

Research of Available Data

Methodologies
Simulation

:

Bibliography
Private Companies

+

Railway Networks
Railway Networks

Examination of the existing techniques and terminology equalization

Input

Infrastructure Parameters

Network effects

Operational effects

Capacity Analysis

- ✓ Theoretical Capacity
- ✓ Practical Capacity
- ✓ Used Capacity
- ✓ Available Capacity

Output

Main Functions

- ✓ Crew Scheduling
- ✓ Infrastructure Manager
- ✓ Station Manager
- ✓ Timetable Manager
- ✓ Timetable Optimization
- ✓ Economic Evaluation
- ✓ Sensitivity Analysis
- ✓ Simulation

Input/Output Comparison Analysis

Methodologies E.P 1/2

1. The detailed analysis of consolidated methodologies for capacity calculation counts today a total of 28 techniques.
2. The following step was to fill in the table reported in order to offer some results of the comparative analysis.
3. The first demarcation is relative on which part of the network the methodologies can be applied. Stations and nodes capacity analysis are totally different by lines analysis. In fact the table is structured as follows.

- All methods have been classified based on which part of the railway network, nodes or lines is concerned.
- Input Data are classified in Infrastructure and Operating parameters and network effects
- Output Data are classified in Capacity Analysis (theoretical, practical, used and available capacity), Delay Detection and Performance Indicators.
- In order to give a global indicator of evaluation of capacity analysis during the time window of the present research, an assumption that each technique is able to perform a certain number of functions
- They are displayed in the table with the following symbols: ✓ ✗ ?

Methodologies E.P 2/2

COMPARATIVE ANALYSIS			Potthoff	Corazza, Florio	Formula FS	Formula DB	Petersen	Cascetta , Nuzzolo	Corriere	UIC 405-R	Corriere	Florio, Malavasi	Giuliani, Malavasi, Ricci	Chen and Harker	Corazza, Musso	Malaspina and Reitani	Galaverna, Sciutto	Galatola	Delfino, Galaverna	Formula RFI				Galatola	UIC 406-R	Galatola	Genovesi, Ronzino	Burdett and Kozan	Kaas; Landex	Ciuffini
		YEAR	1970	1979		1979	1974	1980	1982	1983	1984	1984	1989	1990	1991	1995	1999	2002	2003	2004	2004	2004	2004	2004	2004	2005	2006	2006	2007	2007
		ID NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Network	STATIONS - NODES	Analytical Methods	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
	LINE		✗	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
Input Data	Infrastructure Parameters	Line : Double Track	✗	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗
		Line : Single Track	✗	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✗	✓	✓	✗	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✗
		Nodes : Track layout	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	?	✗	✓
		Train Routes	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	?	✗	✓
		Conflicting Routes	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	?	✗	✓
		Fixed Block	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✗
		Moving Block	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✗
		Length of Block Section	✗	✗	✓	✓	✓	✓	✓	?	✓	✗	✓	✓	✗	?	✓	✓	✓	✗	✗	✗	✗	?	?	✓	✓	✓	?	✗
		Number of Subsections	✗	✓	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✗
		Signal aspects	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✓	✗	✓	✓	✓	✓	✓	✗	✗	✗	✓	✓	✗	✓
	Operating Parameters , Network Effects	Number of trains	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓	✓	✓	✓	✗	✓
		Length of Trains	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓
		Train mix / Rolling Stock	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓
		Total consumption time	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Track Interruptions period	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓
		Eterogenous speed traffic	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Homogeneous speed traffic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Commercial - Mean Speed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✗	✓	✓	✓	✓	✓	✓	✓
		Running time	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗	✗	✓	✓	✓	✓	✗	✓
		Time occupations by delayed trains	✗	✓	✗	✗	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	?	✓	✓	✗	✓
		Crossing Time	✗	✗	✗	✗	✗	✓	✗	✗	?	✓	✓	✓	?	✗	✓	✓	✓	✗	✓	✗	✗	✗	✗	?	✗	✓	✗	✗
		Mid Delay factor	✓	✓	✗	✗	✗	✓	✗	?	✓	✗	✗	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	?	?	?	✗	✗	?	✓
		Headway distance	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓
		Headway time	✗	✓	✓	✗	✗	✓	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓
		Blocking time	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓	✗	✓
		Signal headway	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓
		Buffer time	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓
		Dwell time	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓
		Reductive Factor -quality of service	✗	?	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓
		Compression of Timetable	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✓
		Margin Dilation	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗	✓	✗
Output Data	**Delays**	**Delay Detection**	✗	✗	✗	✗	✓	✓	✓	✗	✓	✗	✗	✓	?	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✓
	Performance	**Performance Indicators**	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✓	✗	?	✗	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓
	Capacity Analysis	**Theoretical Capacity**	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓	✓	✗	✗
		Practical Capacity	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗	✗	✗	✗	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓	✓	✗	✗	✗
		Used Capacity	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗
		Available Capacity	✓	✗	✓	✓	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✓	✓

Simulation Enviroments E.P 1/2

The detailed analysis of consolidated simulation environments counts today a total of 20 tools.

The following step was to fill in the table reported in order to offer some results of the comparative analysis. In fact the table is structured as follows:

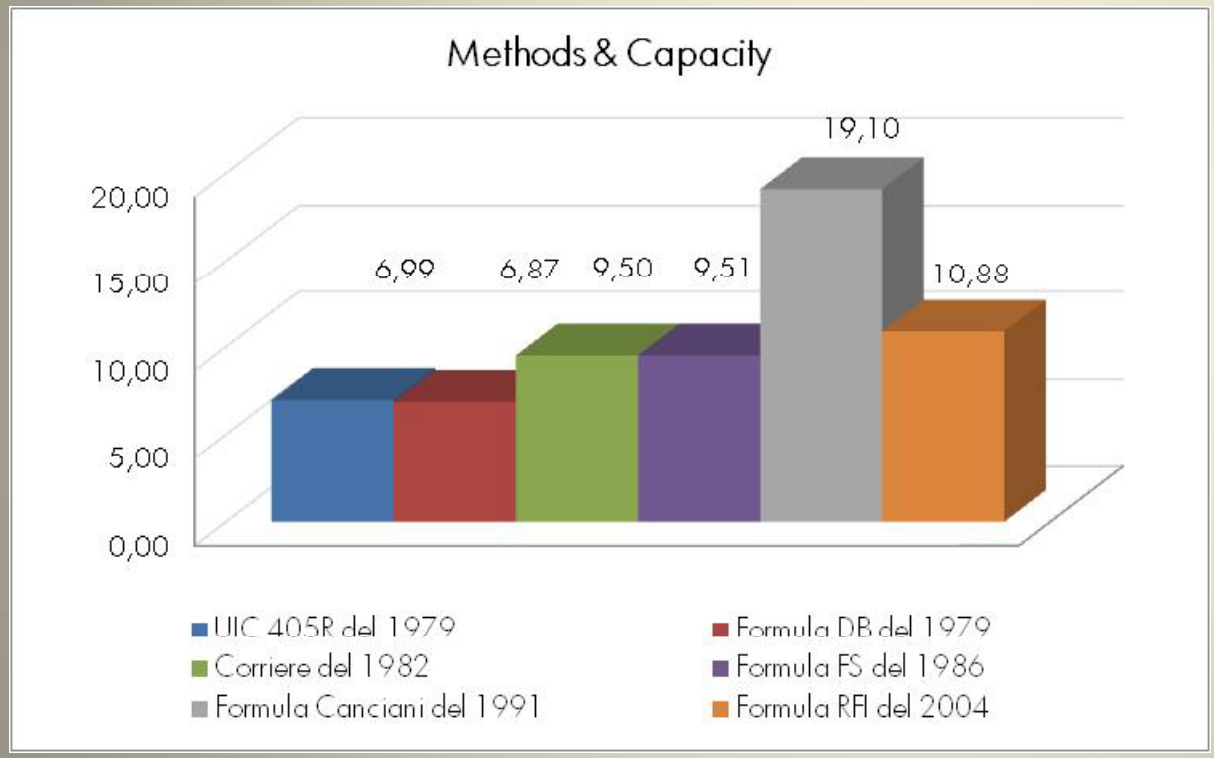
- Simulation: The tool provides the function to emulate and graphically display real train operations in order to generate simulation models of railway networks where finer analysis of the timetable can be assessed.
- Timetable Optimization: The tool provides optimization algorithms which schedules train movements and generate a timetable in accordance with a objective function, schedule priorities and network constraints.
- Timetable Manager: The tool provides the function to edit train timetables date in graphic or tabulate way.
- Capacity Analysis: The tool can be used to assess railway capacity.
- Infrastructure Manager: The tool provides the function to model the existing infrastructure and to build up different infrastructure variants.
- Station Manager: The tool assists the planners in solving the problem of routing trains through a railway station.
- Crew Scheduling: The tool can be used for planning and crew scheduling
- Economic Evaluation: The tool provides planning and economic evaluation
- Sensitivity Analysis: The tool can simulate different scenarios and provides sensitivity analysis indicator

Simulation Enviroments E.P 2/2

COMPARATIVE ANALYSIS			Simulation Enviroments - TOOLS																				
			AFAIG	CAPRES	DEMIURGE	FALKO	FAST TRACK II	FASTA	IRCIM	LIPARI	MOM MALLAS	OPENTIMETABLE	OPENTRACK	PETER	RAILCAP	RAILNET II	RAILPLAN	RAILSIM	RAILSYS	ROMAN	SISYFE	TPS/STRAX	VIRIATO
		ID NUMBER	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
input data	Infrastructure Parameters	Single/double tracks	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Moving Block System and signalling system	✓	?	✗	✓	✓	?	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
		Definition of lines, routes	✓	✓	✓	✓	✓	✓	✓	?	?	✗	✓	✓	✓	✗	?	✓	✓	✓	?	✓	✓
	Network Effects	Track structure and speed limits	✓	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Block occupation or blocking time	?	✓	✗	✓	✓	✓	✓	?	?	?	✓	✓	✓	✓	?	✓	✓	✓	?	✓	✗
		Headway distance	?	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
		Headway time	?	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
		Blocking time stairway	?	✓	✓	✓	✓	?	✓	?	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✗
		Signal headway	?	?	✓	✓	✓	?	✓	?	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✗
		Minimum Line Headway	?	✓	✓	✓	✓	✓	✓	?	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✗
		Buffer time	?	✓	✓	✓	✓	?	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✗
		Running time supplement	?	✓	✓	✓	✓	?	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✗
		Dwell time	?	✓	✓	✓	✓	?	✓	?	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✗
		Total consumption time	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Train mix / Rolling Stock	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Traffic peaking factor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓
		Priority	?	✓	✗	✓	✓	?	✓	?	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	?	✓	✓
	Operating Parameters	Track Interruptions	?	✗	✓	✓	✓	?	✓	?	✓	✓	✓	✓	✓	✓	?	✓	✓	✓	?	✓	✓
		Train stop time	✓	✗	✓	✓	✓	?	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Maximum trip time threshold	?	✗	✓	✓	✓	?	✓	✓	✓	?	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓
		Quality of service, reliability, or robustness	✗	✗	✓	✓	✓	?	✓	✓	✓	?	✓	✓	✓	✓	?	✓	✓	✓	✓	✓	✓
output data	Capacity Analysis	Theoretical Capacity	?	✓	✓	✗	✓	?	✓	✗	✓	✓	?	✗	✓	✗	✗	✓	✓	✗	✗	✗	✗
		Practical Capacity	✗	✗	✓	✗	✓	✗	✓	✗	✓	✗	?	✗	✓	✗	✗	✓	✓	✗	✗	✗	✗
		Used Capacity	✗	✗	✓	✗	?	✗	✓	✗	✓	✗	?	✗	✓	✗	✗	?	✓	✗	✗	✗	✗
		Available Capacity	✗	✓	✓	✗	?	✗	✓	✗	✓	✗	?	✗	✓	✓	✓	?	✓	✗	✗	✗	✗
	Main Functions	Crew Scheduling	✗	?	?	?	?	?	✗	✗	✗	✗	✗	?	?	?	✗	?	?	?	✗	?	✓
		Infrastructure Manager	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓
		Station Manager	✓	✓	✓	✗	✓	✗	✗	✗	?	✗	✗	✗	✗	✓	✗	✓	✓	✗	✗	✗	✓
		Timetable Manager	✗	✗	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✓	✓
		Timetable Optimization	✗	✓	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
		Economic Evaluation	✗	?	?	?	?	?	✗	?	?	?	?	?	?	?	?	?	?	?	?	?	?
		Sensitivity Analysis	✗	?	?	?	?	?	✓	?	?	?	?	?	?	?	?	?	?	?	?	?	?
		Simulation	✗	✗	✗	✓	✓	✓	✓	✗	✗	✗	✓	✗	✓	✗	✓	✓	✓	✓	✓	✓	✗
	Statistical Analysis	occupancy rates of platform lines and route	✓	✓	✗	?	✓	✓	✓	✗	?	✗	✓	✓	✓	✓	✓	✓	✓	✓	?	?	✓
		histograms of margins between trains	✓	✓	✗	?	✓	✓	?	✗	?	✓	✓	✗	✗	✗	✓	✓	✓	✓	?	?	✗
		list of margins between trains	✓	✓	?	?	✓	✓	?	✗	?	✓	✓	✗	✗	✗	✓	✓	✓	✓	?	?	✗
		statistics of train assignements by direction	✓	✓	✓	?	✓	✓	✓	✗	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	?	?	✓
		Conflicts detection	?	?	?	?	?	?	?	?	?	?	?	?	?	✗	?	?	?	?	?	?	?
		Platform track occupation schedule	✓	✓	?	?	✓	✗	?	✗	?	✗	✓	✗	✗	✗	?	✓	✓	✓	?	?	✓

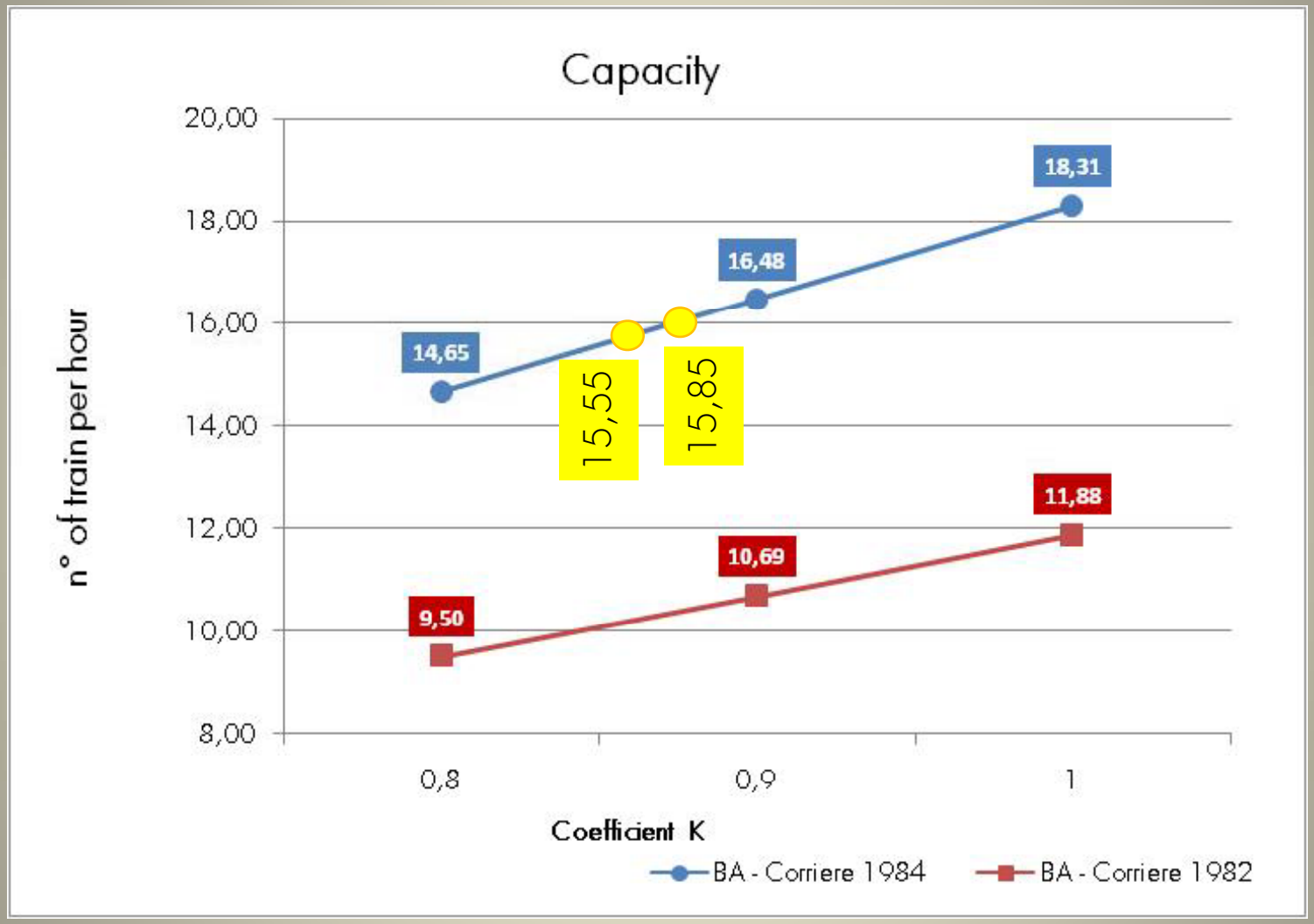
1° Case Study :
Railway Line CAPACITY

Comparison of Capacity Results

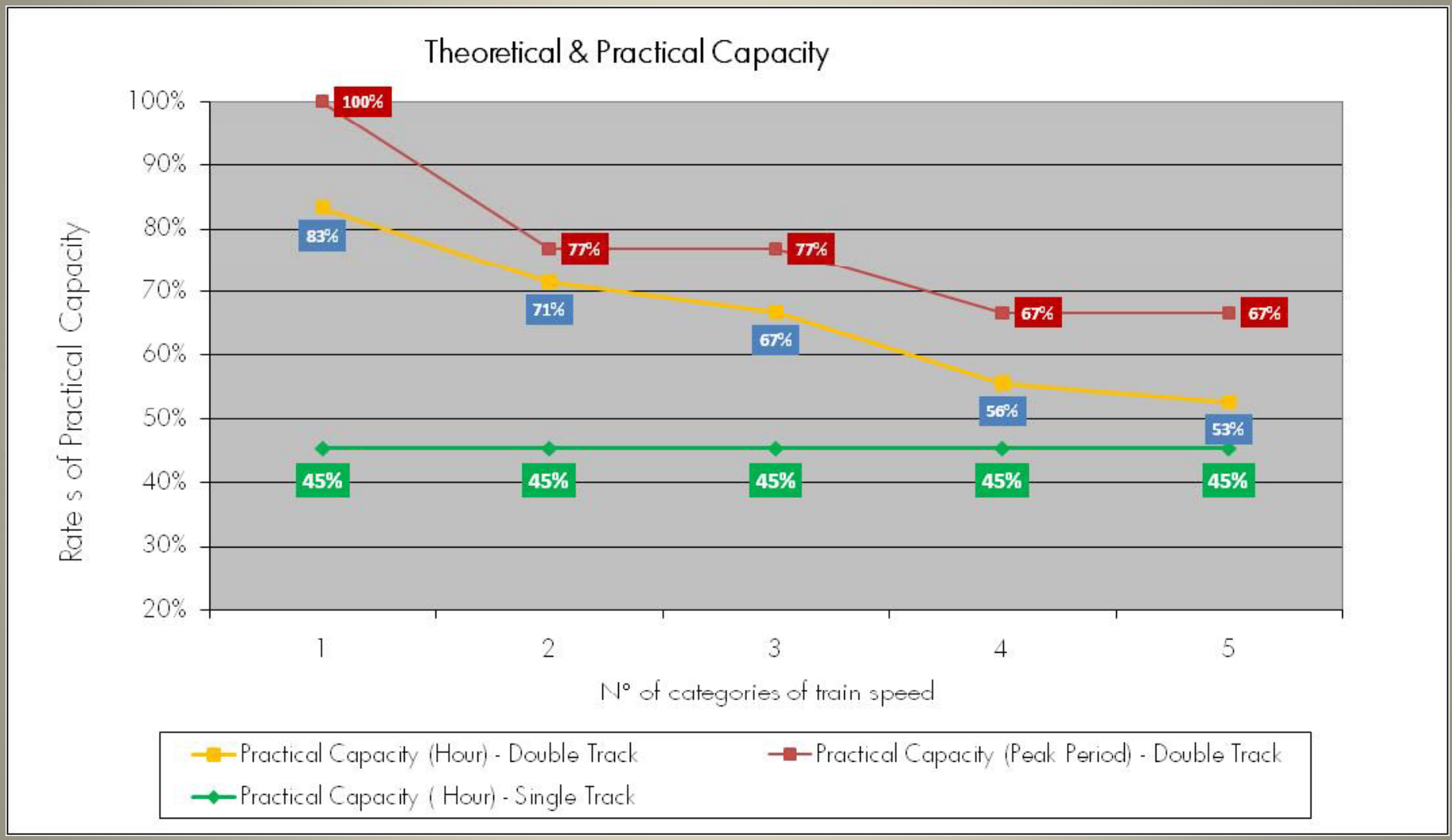


Data	Value
Type of Line	Double Track
Distance of stations[m]	8.434,00
Blocking System	BA
N° of blocks[n°]	4
Block section[m]	2.154
Headway Time [min]	0:05:00
N° of categories of train speed	4
Running Time [min]	0:03:31

Capacity by Corriere (1982,1984)



Capacity by Italian Railways, (RFI 2004)



Preliminary integration Perspectives

A preliminary comparative analysis consist in :

- A first operation of sorting by operational rules all the methods classified by sector of interest, with a particular attention to point out all factors having a direct relation to the obtained results (Input / output comparison analysis).

- This first comparison will allow estimating the ability of the methods to deal with the typical operational situations and standards.

- The outcome of this first approach is that available techniques and methods are very different not only because based on different mathematical modelling theory's but also because provide a huge amount of output data each one adaptable in certain hypothesis of railway circulation.

Preliminary SWOT Analysis

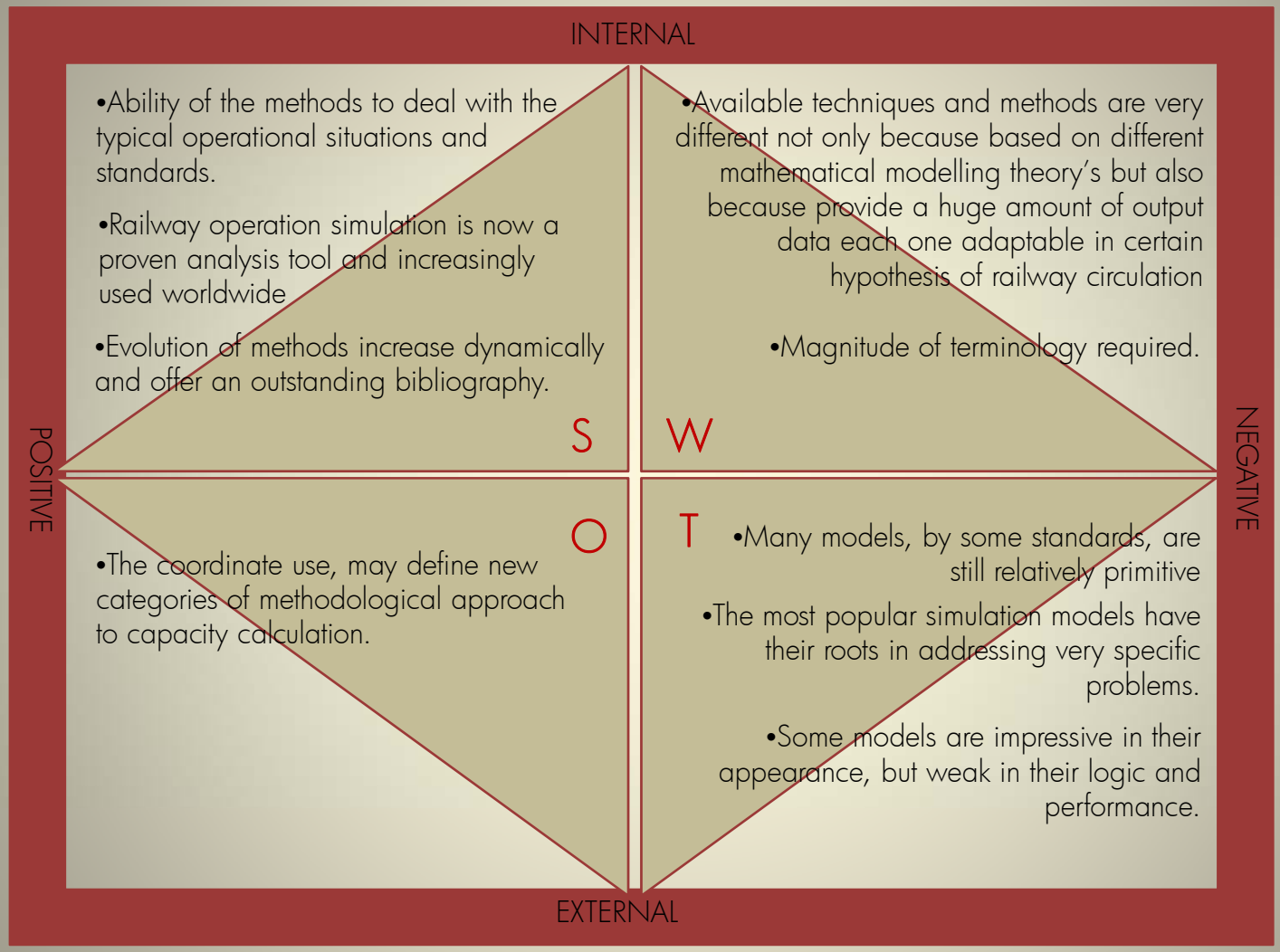
Strengths

Weaknesses

Opportunities

Threats

Preliminary SWOT Analysis



Thank you for your kind attention

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