ROUTES MANAGEMENT IN COMPLEX RAILWAY JUNCTIONS: METHODOLOGY AND TOOLS FOR OPTIMIZING OPERATION AND LAYOUT

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ABSTRACT

This paper describes the methodology used to create a model for supporting the definition of an efficient timetable given a station layout. The objective is to assess the capacity of the physical infrastructure in terms of simultaneous movements in a defined time horizon.
A computational procedure (software SNJ) is formalized to perform a morphological analysis of junctions themselves. It returns an indicator of capacity (mean number of possible safe movements) and the list of the n-tuples capable to saturate the station. In a stable state condition different combinations of n-tuple activations could return very different levels of capacity. Following the identification of a mathematical formulation (model SLC) and a solution algorithm, a software is implemented (coded in APL) for being able to face capacity problem in any complex layout. The Station Layout Computing (SLC) model described in the paper, allows to find the optimal solution in terms of activation frequency of each n-tuple satisfying the timetable demand efficiently, i.e. in the shortest possible period of time.
The computational analysis evaluates the performance of a realistic station layout under real operational conditions. It allows to determine the combination of n-tuples that provides the highest number of train movements in the time horizon, respecting all scheduled frequencies (respecting scheduled frequencies on all lines). This solution optimizes the layout utilization, sets additional feasible movements and proves layout reliability. Such a reliability is assessed through the leftover time values that can be used to deal with operating variances or perturbations (uncertainly of arrivals, prolongations in the stopping).

Keywords: railway junction, station capacity, layout optimization, traffic management, support timetable.

1. OVERVIEW AND STATE OF ART

1.1 General theory

Railway junctions are places where switches between different lines are carried out. The topology locations, the number of convergent lines, the number of arrival sidings, and the existing cross-over enable or deny such possibilities and determine the maximum number of simultaneous train movements that can take place in safety (capacity). Indeed, the criterion governing traffic management is the complete independence of the train movements taking place in the time of reference T. This condition is granted by the control system that authorizes incoming, internal, or out-coming movements in the train station, only after having verified that routes in possible conflict (direct incompatibilities due to partial route overlapping; or indirect incompatibilities due to safety margins intended to prevent human mistakes) are blocked, also through the temporary stabilization of the point switches. The greater the number of the lines converging in a station and of the switches between these lines, the lesser the possibilities of simultaneous movements, and the greater the interferences. Indeed, the theoretical capacity depends on the total independence of the routes, that is to say on the definition of lines dedicated to different start/destination points. Nevertheless, complete independence is hardly achievable, although in current facility renovations the tendency is the specialization of the station tracks (in some cases this specialization is based on the kind of service --long or short distance--, in other cases it is based on the lines served). Summarizing capacity depends on: tracks layout, signalling system, planned services and management system (Hansen and Pachl); increase it is theoretically always possible for any layout and dimension, but the real question is "how to determine capacity, which are its possible indicators and what are the improvements/applications".
Several researches have been conceived on capacity matter with a single purpose "increasing the number of running movements in a defined time" by:

- structuring a combinatorial procedure independent upon the timetable structure (Potthoff, 1965);
- formalizing a model able to reschedule the trains' routes minimizing the total delay (Muller, 1960);
- developing a topological analysis of a railway junction in order to optimize circulation by probabilistic method (Corazza, 1987);
- verifying the problem of routing trains through a railway station and the possibility of adding new services (Zwaneveld, 2001);
- developing a software to evaluate station capacity (Rodriguez, 2007);

- optimizing the timetable (Delorme, 2008).

Starting from these studies, the present research addresses capacity focusing on static analysis of the junction, a useful planning tool that allows for the identification of limits and potentials of the facility itself in terms of possible configurations. The variability of these configurations depends on the presence and location of the switches, which determine the routes singularly feasible, and also on the possibility of simultaneous movements in pairs, triplets or larger n-tuples. The average number of possible safe movements, hereafter indicated as $\bar{n}$, is one of the synthetic indicators, formalized in literature in different ways (Potthoff, 1965; Muller, 1960), which enable the calculation of the junction capacity. In the following paragraph the steps needed to identify the allowed parallel running movements allowed are summarized.

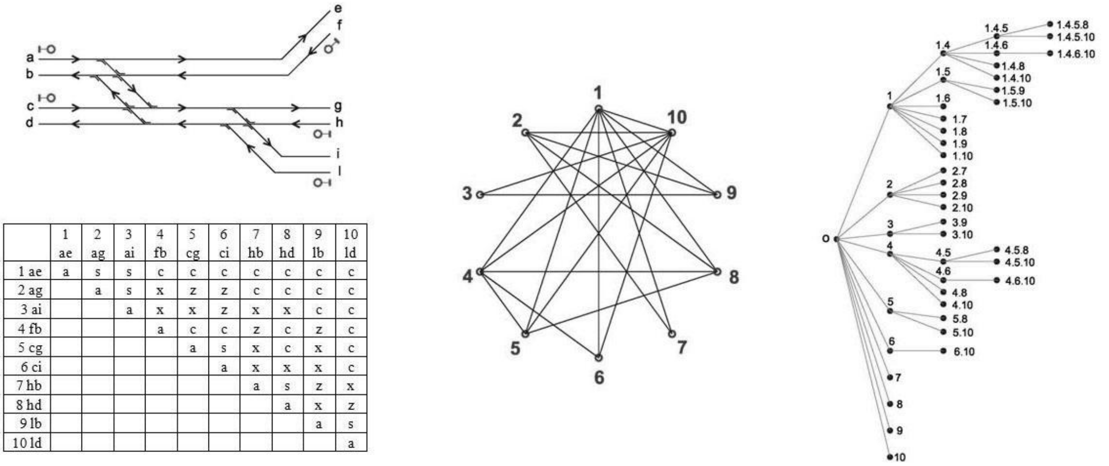
1.2 Methodologies for the identification of compatible movements

All the methods for the exhaustive and orderly analysis of the circulation possibilities provide for some common actions:

- taking routes (safe predetermined paths for single train movements) as minimal elements to investigate;
- the identification and the listing of the routes that can be obtained through different operational configurations of the junction (by arranging the switches in different ways);
- the comparison between two routes in order to define the mutual compatibility through the *route locking table*. In this matrix, each row and each column are assigned to a route, so that the elements of the matrix (route locking table) identify the compabilities/incompabilities between the pairs.

At this stage, methodologies differ in the estimate of synthetic indicators. For instance the **Potthoff methodology** introduces an empirical evaluation allowing for the frequency in route usage during the time of reference T. By combining the matrix and the number of the trains that utilize each route it is possible to calculate the mean number of possible safe movements $\bar{n}$, the mean time of occupation $\bar{t}$, and the amount of delays generated. The **graph theory** allows to establish a relation between matrix and graph (Potthoff): drawing routes as points and connecting the compatible ones with lines. These lines define also triangles or squares, or other geometric figures which represent n-tuples of compatible routes. The result is a complete representation of all the configurations that a junction could have; however this method does not work for complex junctions because of reading difficulties. **Corazza** in 1987 developed a method which seeks for all the circulation possibilities. Starting from the identification of compatible pairs, auxiliary matrices are built each time of a superior order; the rows will carry the pairs of compatible routes (found in the matrix previously created), which will be compared again with the single route, leading to the determination of compatible triplets. This process is repeated until a matrix showing only incompatibilities is generated.

The list of n-tuples, thus completed, lends itself to being represented by a hierarchical tree structure that represents all the configurations that a station layout can assume (Figure 1).



	1 ae	2 ag	3 ai	4 fb	5 cg	6 ci	7 hb	8 hd	9 lb	10 ld
1 ae	a	s	s	c	c	c	c	c	c	c
2 ag		a	s	x	z	z	c	c	c	c
3 ai			a	x	x	z	x	x	c	c
4 fb				a	c	c	z	c	z	c
5 cg					a	s	x	c	x	c
6 ci						a	x	x	x	c
7 hb							a	s	z	x
8 hd								a	x	z
9 lb									a	s
10 ld										a

Figure 1 - An example of layout junction, its route locking table, its graph representation, and tree diagram solutions. Source: University of Rome, issue Railway Engineering Master, Corazza and Malavasi

The tree of compatible movements shows all the possible solutions (single routes, pairs, triplets, etc.); to obtain only the list of route combinations **saturating the junction** it is necessary, starting from n-tuples of higher grade, to eliminate the n-tuples completely included[1].

Depending on the number of saturation n-tuples obtained, the mean number of possible safe movements, $\bar{n}$ is determined as:

$$\bar{n} = \frac{1 \cdot E_1 + 2 \cdot E_2 + 3 \cdot E_3 + \cdots + n \cdot E_n}{E_1 + E_2 + E_3 + \cdots + E_n} \tag{1}$$

Where E_1, E_2, E_3,: respectively: single routes, pairs, triplets saturating the junction.

This method is of interest for its results: particularly examining the list of n-tuples of saturation could allow to detect some links that generate low profits or redundant routes. Consequently it would be possible to design a simplification of the junction for improved parallel movements and reduced maintenance costs. The exclusion of some crossovers or point switches gives new results; these outputs could be used to evaluate the capacity obtained (in terms of compatible movements) in relation to the layout of the different physical components.

With this first goal a computational procedure (software) has been formalized to assess the index $\bar{n}$ and to determine list of saturating n-tuples as explained in the following paragraph.

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[1] E.g.: the compatible triplet 7 4 3, requires the elimination of the pairs 7 4, 7 3, 4 3, and of the single routes 7 4 and 3.

2. SATURATION N-TUPLES JUNCTION (SNJ) MODEL[2]

2.1 Definitions

Routing trains through a station is allowed only if no infrastructure element is occupied by two different trains within a certain headway time. So, the first step necessary for the analysis of the station consists of the identification of all the possible routes and the list of all infrastructure elements passed by the train: track circuits (hereafter t.c.). The routes can be of two kinds:

1. **incoming routes**: they connect the railway lines to the platform tracks, and are defined as the set of the t.c. going from the entry signal to the stabling of a train;

2. **outgoing routes**: they connect the platform tracks to the railway lines, and are defined a set of t.c., analogously to the incoming routes.

This classification is sufficient for schematic plans showing routes of short length; in case of complex junctions, it is necessary to evaluate the possibility of creating global routes or hemi-routes (simple routes that may form global routes). The routes determine the possibility of carrying out intermediate movements inside the facility (movements which are not necessarily originated from or destined to the lines).
The evaluation of the movements in specific facility areas (elementary stations) can be carried out by hemi-routes; in this case inputs and t.c. will have to be re-defined.

2.2 Language and structure of the software SNJ

The computational procedure has been implemented using the programming language APL, whose mathematical structure allows to write complex procedures in a limited amount of instructions and to handle a high number of data and operations.
The logical architecture built to apply the n-tuples method has considered, first of all, the numerical coding of the input data routes and track circuits necessary to univocally identify the different elements and lighten the burden of their elaborations.
The procedures described in paragraph 1.1 have been formalized by the use of an algorithm that can build the matrix of routes by verifying the conditions of compatibility (value 0) or conflict (value 1) on the basis of one or more t.c. tracks being part of the two routes compared[3].
Determining the algorithm for assessing the $\bar{n}$ and the list of the n-tuples of saturation has required the construction of a cycle that, at each iteration, calculates the matrix of routes of a higher grade than the previous iteration. This new matrix uses, as input for the rows, the n-tuples which have proven compatible in the previous cycle, but it has been ridded of the n-

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[2] The program was implemented thanks to prototype laboratory for Transportation Planning, University of Florence.
[3] This preliminary condition has to be implemented by verifying the route setting circuit diagram, in order not to overlook any conflict that may not involve t.c. circuit sharing.

tuples that have been repeated only because the order in which the constituting routes have been written is different. The method then considers removing, from the compatible n-tuples, all the n-tuples included in others of higher grade so as to determine only the n-tuples saturating the facility.

Some considerations are necessary with regard to the dimensions used in calculating the matrices[4] because, being combinatory processing, they can turn out to be very demanding in terms of response time. Therefore, a usage different from planning analysis (medium term) would need computing improvements for better performances.

2.3 Input and output

The software uses the [Microsoft Office] Excel environment as external interface; the input data consists of a sheet in which a label is defined:

>CIRCOL; this label subtends a table in which the routes' abbreviations lie in the first column, the number of running movements of each route lie in the second column, and the list of t.c. of the route itself (considering also the t.c. devoted to safety allowances) lie from the third column onward.

The software returns, on the same sheet, the following outputs:

- NMEDIO: mean number of train movements calculated according to the methodology of the tree diagram;
- NENN: total number of the combinations of n-tuples saturating the station;
- ENN: total number of n-tuples saturating the facility, subdivided based on types (single routes, pairs, triplets, quadruplets, etc.);
- IT_SGLE: shows the compatible routes saturating the facility.

Other results that can be obtained are the matrices of conflicts for the single routes, the n-tuples of higher grade, and the specifications relating to t.c. composing the n-tuples of saturation.

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[4] The test carried out in Padua station, taken as terminus, has considered the connections with the Bologna-Vicenza-Vigodarzere lines, involving the construction of a preliminary matrix of routes of size 128 x 128, and the subsequent determination of the n-tuples (pairs, triplets, quadruplets, etc.) generating matrices of higher and higher dimension/size. The matrix with the maximum number of elements has a size of 18.240 x 128 elements (step needed for the identify the compatible sextuples), for a processing time of about 20 minutes.

3. STATION LAYOUT COMPUTING (SLC) MODEL

3.1 Definitions and notation

The subject under examination is a railroad station and its connection with railroad lines. A station is a facility at which passengers may board and alight from trains, but also a place where several routes, lines, or roads meet, link, or cross each other allowing train movements between different directions. First of all a physical representation of the station area is necessary: the layout allows to define the elements and the connected directions. As usual to every direction corresponds a line. But each line could be a single, double or quadruple track line. In the elaboration performed here each single track line is called line *l*; as a consequence if direction d is reachable by a double track line these will be named respectively line l_{d1} and line l_{d2}. Routes are defined as in previous description as incoming or outgoing routes. N-tuples are collections of non conflicting routes.
The software SNJ allows to determine the number of saturation n-tuples and the routes they belong to.
In the following *activation* correspond to *opening to traffic,* and it could relate to different elements:

- *activation of a route* means setting up and interlocking a route to receive an approaching train;
- *activation of a line* means to have the possibility of setting up one of the routes that belong to the line;
- *activation of a n-tuple* means to allow setting up of parallel movements; the number of compatible routes depends on the n-tuple grade.

The following notation is adopted:

Table 1 – Symbology[5]

$\mathbf{f}$	$\{f_l\}$, frequency vector of line l from timetable;
$\mathbf{h}$	$\{h_l\}$, frequency vector of activations of the line l;
$\mathbf{n}$	$\{n_k\}$, frequency vector of activations of the saturation n – tuple k;
$\mathbf{t}$	$\{t_i\}$, running times vector of the route i;
$\mathbf{I_l}$	$\{i_{l1}, i_{l2}, \ldots\}$, indexes vector of routes that belong to line l;
$\mathbf{B}$	$\{B_{ki}\}$, incidence matrix n – tuples/routes;
$\mathbf{t^*}$	$\{t_k^*\}$, maximum running times vector of routes that belong to saturation n – tuple k;
$\mathbf{m}$	$\{m_{ki}\}$, activations matrix of route i during activation of the saturation n – tuple k;
$\mathbf{g}$	$\{g_i\}$, frequency vector of activations of route i;
$\mathbf{s}$	$\{s_l\}$, allocation net times vector to line l;
$\bar{\mathbf{t}}$	$\{\bar{t}_l\}$, actual average running times vector of line l;
F	Total running movements scheduled by timetable;
H	Total running movements achievable in the unit time;
S	Net total time allocated for the runnings;
S^*	Gross total time allocated for the runnings;
T	Total time requested for the runnings

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[5] H, S*, S and T (and their relationships) are the decision variables as explained in the following paragraphs.

A stationary state in which the timetable is fully represented by the frequencies f is assumed. The choice of action, however, will be completely represented by the frequency of activation of saturation n-tuples. This vector will be the subject of the optimization problem that will be defined later.

3.2 Correlation between routes and n-tuples

As described in paragraph 1.2 each saturation n-tuple k is formed by the routes that are compatible with each other, those which, if set up simultaneously lock any movement inside the station (Cappelli, Ricci and Staffini). When an route *i* is activated, it involves the activation of one of the saturation n-tuples of which is a part and it gives the ability to activate all the other routes which belong to it. Therefore, the time for which it will remain active t_k^*, will be the greater of the running times of the different routes belonging to that n-tuple:

$$t_k^* = \max_i\{t_i B_{ki}\} \tag{2}$$

Time t_k^* will be totally used for a movement on route *i* only if its running time is equal to t_k^*. With $t_i < t_k^*$, there is some lost time, equal to $t_k^* - t_i$ if not sufficient for other movements. Assuming, t_i equal to half of t_k^*, or less than this, the route can be activated two or more times. The number of times m_{ki} that the route can be activated during the activation of n-tuple k is:

$$m_{ki} = B_{ki}\text{INTEGER}\left(\frac{t_k^*}{t_i}\right) \tag{3}$$

Therefore, when activating the route i, which is part of the n-tuple k, the unused time is represented by: $t_k^* - m_{ki}t_i$

3.3 Route possibilities, running times, line time slots

Single route frequency activation is due to the number of times that is activated every saturation n-tuple n_k[6]:

$$g_i = \sum_k m_{ki} n_k \tag{4}$$

The line *l* activation frequency h_l represents the maximum feasible number of movements on every line. These values are related to vector n_k (n-tuples number of activation) and correspond to the sum of route frequency activation g_i over all routes *i* in the set I_l (routes that belong to line *l*):

$$h_l = \sum_{i\in I_l} g_i = \sum_{i\in I_l} \sum_k m_{ki} n_k \tag{5}$$

The allocation net total time s_l of line *l*, that allow to complete h_l movements, is:

$$s_l = \sum_{i\in I_l} \sum_k t_i m_{ki} n_k = \sum_{i\in I_l} t_i \sum_k m_{ki} n_k = \sum_{i\in I_l} t_i g_i \tag{6}$$

Actual average running time of line *l* corresponds to the mean running time values evaluated on the routes that belong to line *l*, multiplied by probability that it occurs (equal to the weighted sum over all routes that belong to line *l* of running times and their number of activations divided by total number of line activations):

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[6] The selection between n-tuples and their compatibility are assured by the optimization procedure (13).

$$\bar{t}_l = \frac{\sum_{i \in I_l} g_i t_i}{\sum_{i \in I_l} g_i} = \frac{\sum_{i \in I_l} g_i t_i}{h_l} \tag{7}$$

3.4 Movements and times junction

A railway timetable consists of the journey schedule (arrival, departure and passing times) of the trains at the station, but also contains origin and destination lines. The number of trains coming from or going to line *l* is the timetable demand frequency f_l. In a station the *total movements scheduled F* originating from the sum of single frequency line is:

$$F = \sum_l f_l \tag{8}$$

The *total movements allowed H* by track layout plan, in safe conditions, is the sum over all lines of line frequency requests h_l which rely on n_k:

$$H = \sum_l h_l = \sum_i g_i = \sum_i \sum_k m_{ki} n_k \tag{9}$$

To avoid delay planned H having to be greater than or equal to F station layout has to be improved because it is insufficient with respect to the demand, or the train services have to be reduced.

The *net total time allocated S* for the running movements (that allows to developing all movements H) is calculated as the sum of time allocated for each line:

$$S = \sum_l s_l = \sum_i t_i \sum_k m_{ki} n_k = \sum_i t_i g_i \tag{10}$$

The *gross total time allocated* S^* for the train movements, is defined as follows:

$$S^* = \sum_k \sum_i B_{ki} t_k^* n_k = \sum_k t_k^* n_k \sum_i B_{ki} \tag{11}$$

S^* represents the whole time that the system needs to complete all running movements, it includes lost times due to simultaneous activation of two routes that belong to same n-tuple but have different running time. S corresponds to the total needed times estimated on the proper time of routes. Thus the difference between these two indicators $S^* - S$ give the measurement of the percentage of time not usable for any running.

The *total time required T*[7] for the overall movements needed to satisfy timetable frequency is obtained from the summation over all lines of the product between timetable frequency f_l and mean running time $\bar{t}_l$ of each line:

$$T = \sum_l f_l \bar{t}_l \tag{12}$$

The comparison between S and T allow to know whether the combination of n-tuples utilized to serve the timetable demand left elapsed time for additional running movements. If this condition can be *prove*n it would be possible to add running trains without any interference or delay on the existing services.

Thus if the total numbers of feasible routes H (that is dependent on the choice parameter n) in a chosen unit time is a measure of the capacity of the station, the optimal solution is a combination of n-tuple activations which minimize the sum of the running times (gross

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[7] T is the time for completing all movements in sequentially way; in the computation test is also used the time T_H indicator, this one is the *actual time required* to develop all movements considering simultaneous possibilities and it must be compared with the available DT.

assigned time, S*), needed for all the movements that belong to activated n-tuples. Thus the objective is to:

$$minimise\ S^* = \sum_k t_k^* n_k \sum_i B_{ki} \qquad (13)$$

Such a constraint may indicate that the offered frequencies have to satisfy the timetable demand while paying attention to the minimal interval time for consecutive activations, as explained in the following paragraph.

3.5 Constraints

Let **n** be the frequency vector of activations of the saturation n-tuple k. This vector will be subject to a constraint: the minimum frequency value of activations of line f_l has to satisfy the scheduled frequencies from timetable h_l.

$$f_l \leq h_l \qquad (14)$$

Examining the capacity of nodes and routes, constraints like minimum headways are considered; in the present research when some parallel movements (n-tuple$_1$) are opened to traffic the following n-tuple$_2$ activation would be possible only after clearing of the longer routes that are part of previous n-tuple$_1$: it happens after t_1^* the period of time. Therefore frequency activations of each n-tuple have to satisfy the following constraint:

$$n_k \leq \frac{1}{t_k^*} \qquad (15)$$

4. COMPUTATION TEST

The model has been applied to a simple diagram of a station to verify the indicators. The scheme used is about a terminal railway station with six tracks (platform 1 to 6) linked with four lines (a, b, c, d). This layout allows the creation of 20 different routes.

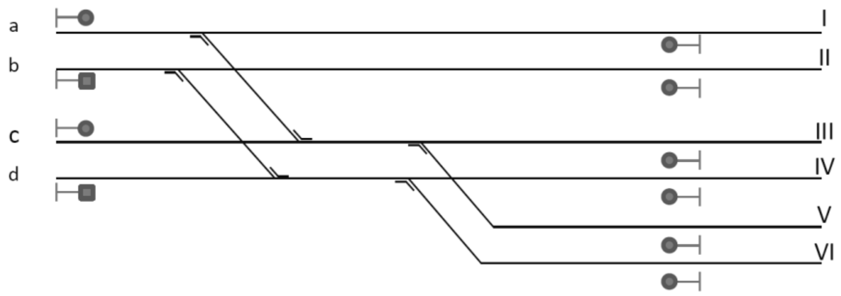

Figure 2 - Example of station layout

The software application SNJ (see also paragraph 2) has determined using the incidence matrix n-tuples/routes B_{ki}: the average number of movements $\bar{n}$ equals 3.2 (Table 2) and calculates and sets out the n-tuples of saturation: these are a total of 80 including 32 second-level (pairs) and 48 of the fourth (quatrains).

Table 2 - Quantification n-tuples of each level and calculation of average running movements

n-tuples of saturation					
First level	**Second level**	**Third level**	**Fourth level**	**Total**	$\bar{n}$
0	32	0	48	80	3.2

The model SLC (see also paragraph 3) operates in stationary state[8] in which the analyzed phenomenon repeats itself indefinitely in any unit time; this means a constant presence of trains to serve. The objective is to verify if the layout allows to solve the timetable demand (train frequencies). The test performed[9] assumed:

- a reference time ΔT equal to one hour, corresponding to a rush hour;
- a demand equal to 6[10] train/h for each line, f_l *frequencies vector of line l from timetable*;
- a vector reporting running times[11] of each route, t_i running time vector of the route i (Table 3);

Table 3 - Running times of each route [minutes]

Routes																			
a-I	**a-III**	**a-V**	**II-b**	**c-III**	**c-V**	**IV-b**	**IV-d**	**VI-b**	**VI-d**	**I-a**	**III-a**	**V-a**	**b-II**	**III-c**	**V-c**	**b-IV**	**d-IV**	**b-VI**	**d-VI**
5	7	8	4	3	5	6	3	7	9	5	7	8	4	3	5	6	3	7	9

The algorithm checks different solutions for n_k frequency vector of activations of the saturation n-tuple k until it finds out the optimal combination that allows to serve the timetable demand subject to the compliance with the constraints. The result is a line capacity provided by sequential activation n-tuples, evaluated in movements/hour. Therefore it is possible also to verify if the condition exists to add new running movements on the different lines.

The following table 4 reports the results. As described above (paragraph 3) the variable to be minimized is S*, gross total time allocated for the running movements.

Simulation B and D do not satisfy:

1. the line frequency request by the timetable (constraint referring to the (14), and reported as C1 in the table): in case B the offered frequency for $line_a$ and $line_d$ are insufficient with respect to the requested values f_a and f_d, in case D the offered frequency for $line_b$ and $line_c$ are insufficient with respect to the requested values f_b and f_c;

2. the available time ΔT (constraint referring to the (15)): the time needed T_H (see note 5) to develop all the scheduled movements is higher than ΔT (74' instead of 60').

Simulation A and C meet the frequency constraint but not in time ΔT; also in this case the second constraint was not satisfied.

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[8] A stationary state has the derivative of time equal to zero.

[9] SLC computational time is less than 1 second in the test realized and it requires some seconds for more complex layout, but, in the latter case, SNJ computational time could be very long (several hours).

[10] This value has been set observing real operating planning in Padua and Bologna stations.

[11] The determination of the running times is done starting from the open line (home signal) to station tracks (exit signal) and the contrary for the outgoing movements.

The last simulations E and G met both the constraints, but the optimization procedure, that consists in minimizing S*, identify G as the best solution.

Table 4 - Model results

Variables	**Symbol**	**Number of test**																							
		A				**B**				**C**				**D**				**E**				**G**			
Time period	***DT***	60’				60’				60’				60’				60’				60’			
Line identification	***l***	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
Requested frequency	***f***	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Offered frequency	***h***	10	16	16	10	5	8	9	5	6	10	10	6	10	5	0	6	6	12	18	6	6	10	10	6
Check parameter	**C1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Gross total time allocated	**S***	296’				148’				184’				156’				216’				184’			
Net total time allocated	**S**	234’				119’				146’				144’				186’				146’			
Total time required	**T**	113’				112’				116’				129’				126’				116’			
Residual time for additional movements	**S-T**	121’				7’				30’				15’				60’				30’			
Actual time required	**T_H**	74’				74’				74’				74’				54’				46’			
Residual actual time	**$DT-T_H$**	-14’				-14’				-14’				-14’				+6’				+14’			

In this case the offered number of train movements is close to the demand, occupying not totally the available time DT. During this time period the solution G allows, without introducing any timetable perturbation, to serve 8 trains more than the scheduled ones, 4 on line$_b$ and 4 on line$_c$. These additional movements could take place in the *residual time S-T* between the net total time allowed for running movements *S* and the total time used for the train movements *T*.

Instead, the part of the total time period ($DT-T_H$), that is not needed for any movement (14’, in this case), could be used in two different ways:

1. as buffer times to avoid the transmission of occurring delays on scheduled services, offering a large margin of flexibility in relation to the uncertain distribution of the arrivals and to the stop times[12];

2. as a new time period in which to plan other running movements, this means a possible value of offered routes in *D*T larger than H (summation of f_l).

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[12] Stop times are not taken into consideration in this elaboration.

5. CONCLUSIONS AND FINAL REMARKS

For each station, given a timetable, routing solutions are solved traditionally on the basis of the traffic controller's own experience, without any consideration about the optimal use of the available facility. The SLC model is a proficient tool that identifies the best routes combinations (and parallel movements) that have to be set up to serve the train demand in order to achieve a better timetable than the existing one. The procedure coded with APL programming language allow to solve also complex station layouts and to investigate the result indicators of altering layout (exclusion of some crossovers or point switches). Indeed on the basis of some input, such as:

- station layout: lines connected and routes section (as sequences of track circuit) and the compatibility matrix B_{ik};
- average running time of each route, t_i;
- assigned station timetable F;

the application of optimization SLC models may lead to improvements in several criteria at the same time:

- work out timetable frequencies: solve the scheduled demand in the shortest time horizon;
- ensuring timetable robustness: saved time could be allocated to guarantee existing services (buffer times);
- improve train movements: to find out the time slots available to add new trains.

A major challenge for further research is to improve the SLC model to manage the demand of the real operating processes inside the station, taking into account other constraints: platform destinations, duration of stops, arrival distributions (Cappelli, Musso and Ricci, 1989).

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