The Relevant Request Determination in the Public Transport System

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Abstract: **-** For the moment, "the relevant request determination in the public transport system" is solved using heuristic rules. This paper proves that this method, trying to simplify the maximum demanding, looses circumstances that modify essentially the results. We propose a new method for solving this issue, not using only maximum, but a combination of maximum and minimum, which, we will prove, has better results.

*Key words***: -** Request determination in public transportation; reduction of rides requests in time; Bellman's optimal principle; dynamic programming, linear programming.

1. Introduction

The identification action of the traveler's volume which can be covered by only one vehicle is called "the relevant request determination in the public transport system". Harnessing the favorable situation due to the circuit movement of the vehicles (on succeeding semi-races of going and returning) is possible, because during the process of transport, takes place a phenomena called "**the reduction of rides requests in time**".

Thus, if between the hours $\mathbf{12^{00}}$ **-** $\mathbf{12^{30}}$ on the junction 9 - 10 placed 1 hour from the main active terminal on the going direction, we have a request of rides that can be satisfied with 2 vehicles, and between $\mathbf{13^{00} - 13^{30}}$ on the junction 27 - 28, placed 2 hours from the active terminal on returning direction, we have a request of rides that can be satisfied with 5 vehicles, then if we dispatch 5 vehicles from the active terminal between the hours $\mathbf{11^{00} - 11^{30}}$, we will ensure the ride request from both junctions.

If we enlarge these behavior to the whole day, with the consideration of the maximum values of ride request on the two semi-races, then we obtain the actual method of vehicles determination for covering the request addressed to the analyzed line. This point of view was accepted by the public transport theory used nowadays for the needful of vehicles, but it proved to be false. Indeed, the graphic representation in fig.1 is a counter-example.

If we try to take out the method of maximum number of transportation means in a interstation by considering all the requests (not only a pair for each semi-hours interval), the problem will extend nonconvenienty.

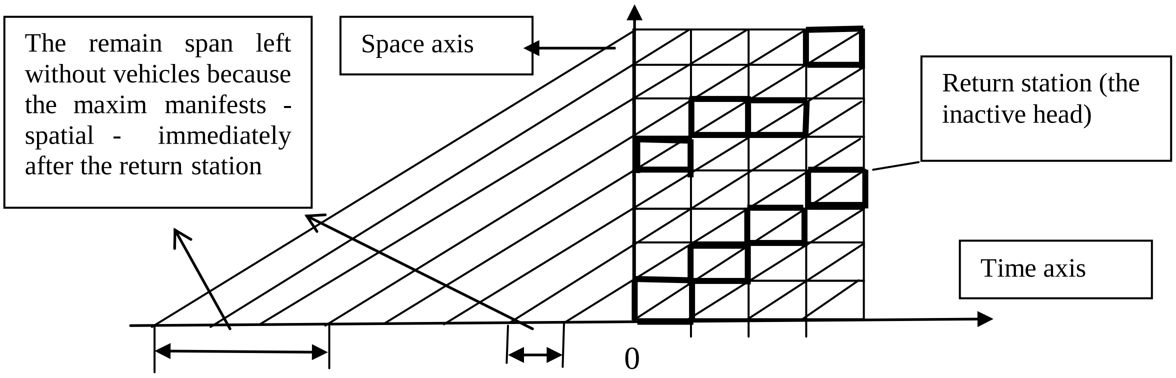

Fig. 1. The request reduction considering two junctions where the maximum request is manifesting

2. Problem Formulation

The search for the number of the necessary vehicles, which are sending off in precisely moments, to cover the transports necessity, in the right quantity and rate, leads to a new type of schedule problem. To simplify we start with the next situation :

● there are 4 square areas which must be roamed by a number of routes;

● the routes have their origin in the S – W corner of the geographic area, and they must insure the crossing of the areas in an way that the terminus point will be located in the N – E;

● the routes can serve one, two or three areas (but they must follow the pre-ordained direction S – W towards N – E, so they cannot dissuade and cross all 4 areas).

Let us look for the minimum number of routes.

From the mathematical point of view, the problem must be solved in integer numbers, and the restrictions are the same as in the case of linear programming ; precisely, there is a liner objective contained by non-negativity conditions.

Description:

● each zone is divided by the direction (fig. 3).

● we note with α, β, γ, δ four variables which represent the number searched by the routes for the partial components of the zones (for the other components, the routes number is imposed by arithmetic considerations). In these conditions, the mathematical objective is:

$$\min_{\alpha,\beta,\gamma,\delta..} \{\alpha + \max_{\beta,\delta}\{\beta, 2-\alpha, \delta\} + \\ + \max_{\beta,\gamma,\delta}\{10-\beta, \gamma, 9-\delta\} + 5-\gamma\},$$

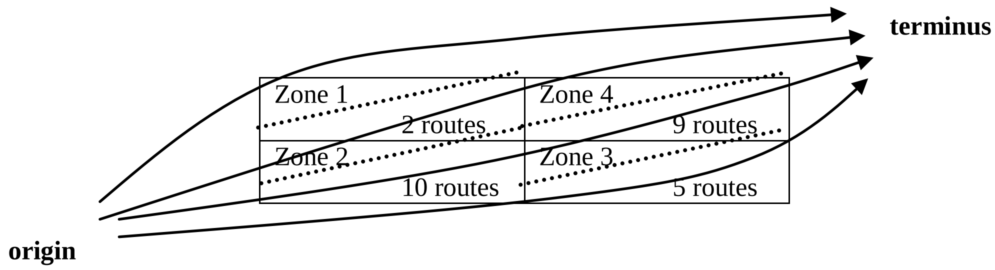

Fig. 2. Test problem for minimum routes

and the mathematical restrictions are:

$$2-\alpha \geq 0,$$
$$10-\beta \geq 0,$$
$$5-\gamma \geq 0,$$
$$9-\delta \geq 0,$$
$$\alpha, \beta, \gamma, \delta \text{ from N.}$$

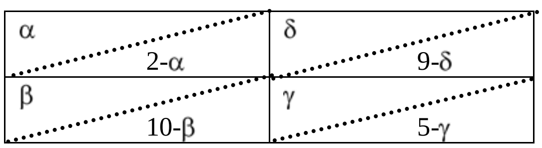

Fig. 3. Test problem formalization.

As we can notice, the problem is similar to a linear programming one, because it is referring to a first degree function, but the request of keeping the minimize function, of the maximum values from some multitude, introduces a further complexity degree.

We must not disregard that for this simple problem we require 4 variables, so the graphically representation is not possible (as a last resort, the problem can be treated by decomposing it into linear problems, but the number of the linear problems will be too large).

Another way to solve is by keeping in mind the first simplification: if we pursue the minimization of the objective relation, we must admit that the first and the last brackets must be null (the physique equivalent will be : the routes which cross the N – W and S – E corners of the geometrical representation of the problem cannot be fully used, because they serve just one of the areas).

As a consequence, if $\alpha = 0$ and $\gamma = 5$, the objective relation simplifies to

$$\min_{\beta,\delta}\{\max_{\beta,\delta}\{\beta,2,\delta\}+\max_{\beta,\delta}\{10-\beta,5,9-\delta\}\} .$$

Further, we can speak of a second simplification, which has its origin in the statement that every route that crosses through zone 2 must cross through zone 4, and so, for resolving, it we take only the dominant value from the two (overall : we take only the bigger value placed on the slanting lines - lines that in physics reality represent the speed of the vehicles in the space-time plane). Returning to the concrete problem, we put on the x axis of a graphic representation of the real problem the time variable (30 minutes periods, called semi-hour intervals), and on the y axis we place the space variable- distances from the active head of a transport line until the ending of the race – tab.1.

The solution will be based on a hybrid transposition modality of the problem in the dynamic programming context, but using an elementary algebraic relation

$$\max\{A, B\} = \frac{A+B+|A-B|}{2}$$

3. Problem Solution

Returning to the concrete problem , we put on the x axis of a graphic representation of the real problem the time variable (30 minutes periods, called semi-hour intervals), and on the y axis we place the space variable- distances from the active head of a transport line until the ending of the race – tab.1.

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$$\max\{A, B\} = \frac{A+B+|A-B|}{2} .$$

The structure of the request is (for four semi-hour intervals and four junctions)

Tab.1

Transport request in vehicles	First semi-hour interval	Second semi-hour interval	Third semi-hour interval	Fourth semi-hour interval
Fourth junction	2	5	7	1
Third junction	4	3	1	7
Second junction	2	9	0	8
First junction	6	5	4	1

The domination for the movement after the direction S–W to N–E is represented in tab.2, where by domination we understand to take the greatest value along a slanting line.

Tab. 2

Transport request in vehicles	First semi-hour interval	Second semi-hour interval	Third semi-hour interval	Fourth semi-hour interval
Fourth junction	2	5	7	
Third junction				7
Second junction		9		8
First junction				1

The algebraic relations are conform to the observations from the test-problem – tab.3 :

Tab. 3

Transport request in vehicles	First semi-hour interval	Second semi-hour interval	Third semi-hour interval	Fourth semi-hour interval
Fourth junction	0 / 2	α / 5 – α	β / 7 – β	
Third junction				δ / 7 – δ
Second junction		γ / 9 – γ		η / 8 – η
First junction				1 / 0

The variables domain is : α = 0 … 5 , β = 0 … 7 , γ = 0 … 9 , δ = 0 … 7 , η = 0… 8.
In these conditions, the optimization function becomes:

$$\min_{\alpha,\beta,\gamma,\delta,\eta..} \{\max_{\alpha}\{2,\alpha\} + \max_{\beta,\alpha}\{5-\alpha,\beta\} + \max_{\beta,\gamma}\{7-\beta,\gamma\} + \max_{\gamma,\delta}\{9-\gamma,\delta\} + \max_{\delta,\eta}\{7-\delta,\eta\} + \max_{\eta}\{8-\eta,1\}\}$$

The module transcription is:

- $\max_{\alpha} \{ 2 , \alpha \} = [2 + \alpha + |2 - \alpha|]/2,$
- $\max_{\alpha,\beta} \{ 5- \alpha , \beta \}=[5 - \alpha + \beta + |5 - \alpha - \beta|]/2$

  …………
- $\max_{\eta} \{ 8 - \eta , 1\} = [9 - \eta + |7 - \eta|]/2.$

The pattern objective has now the following aspect :

$$\{39 + \min_{\eta}\{\min_{\delta}\{\min_{\gamma}\{\min_{\beta}\{\min_{\alpha}|2-\alpha| + |5-\alpha-\beta|\} + |7-\beta-\delta|\} + |9-\beta-\delta|\} + |7-\delta-\eta|\} + |7-\delta|\}/2$$

The practical modality of solving is based on the particular situation in which each of the variables is present only in two modules. Or, in relation with Bellman's optimal principle, the favorable value per assemble; can come just from partial favorable values. On phases, the solution can be traced downwards:

● For the most inner minimum:

$$\min_{\alpha}\{ |2-\alpha| + |5-\alpha-\beta| \},$$

we make a chart of values (tab. 4):

Tab.4

			β								β							
α	|2-α|	|5-α-β|	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
0	2	|5 - β|	5	4	3	2	1	0	1	1	7	6	5	4	3	2	3	4
1	1	|4 - β|	4	3	2	1	0	1	2	3	5	4	3	2	1	2	3	4
2	0	|3 - β|	3	2	1	0	1	2	3	4	**3**	**2**	**1**	**0**	**1**	**2**	**3**	**4**
3	1	|2 - β|	2	1	0	1	2	3	4	5	3	2	1	2	3	4	5	6
4	2	|1 - β|	1	0	1	2	3	4	5	6	3	2	3	4	5	6	7	8
5	3	β	0	1	2	3	4	5	6	7	3	4	5	6	7	8	9	10
											Σ = |2 - α| + |5 - α - β|							

which indicates firmly the choice α = 2.
(because the values 3, 2, 1, 0 are inferior to any succession from the left side of the chart, and the values 1,2,3,4 are not superior to the successions from the right side of the chart).

● for the next minim:

$$\min_{\beta}\{ |3-\beta| + |7-\gamma-\beta| \}$$

we build another chart (tab 5),

Tab. 5

			γ								γ							
β	$\|3-\beta\|$	$\|7-\beta-\gamma\|$	0	1	2	…	6	7	8	9	0	1	2	…	6	7	8	9
0	3	$\|7-\gamma\|$	7	6	5		1	0	1	2	10	9	8	…	4	3	4	5
1	2	$\|6-\gamma\|$	6	5	4		0	1	2	3	8	7	6		2	3	4	5
2	1	$\|5-\gamma\|$	5	4	3		1	2	3	4	6	5	4		2	3	4	5
3	0	$\|4-\gamma\|$	4	3	2		2	3	4	5	**4**	**3**	**2**		**2**	**3**	**4**	**5**
4	1	$\|3-\gamma\|$	3	2	1		3	4	5	6	4	3	2		4	5	6	7
5	2	$\|2-\gamma\|$	2	1	0		4	5	6	7	4	3	2		6	7	8	9
6	3	$\|1-\gamma\|$	1	0	1		5	6	7	8	4	3	4		8	9	10	11
7	4	γ	0	1	2		6	7	8	9	4	5	6		10	11	12	13
											$\Sigma = \|3-\beta\| + \|7-\beta-\gamma\|$							

which indicates the choice $\beta = 3$.
The same way, by discussing all the possibilities, we find $\gamma = 4$ and $\delta = 5$.
The last minimum,

$$\min_{\eta}\{\,|2-\eta|+|7-\eta|\,\},$$

has the corresponding chart presented in tab.6,

Tab. 6

η	$\|2-\eta\|$	$\|7-\eta\|$	$\Sigma = \|2-\eta\| + \|7-\eta\|$
0	2	7	9
1	1	6	7
2	**0**	**5**	**5**
3	**1**	**4**	**5**
4	**2**	**3**	**5**
5	**3**	**2**	**5**
6	**4**	**1**	**5**
7	**5**	**0**	**5**
8	6	1	7

which indicates the indifferent choice. Considering all these, we obtain that the optimized solution for this particular situation is:

Tab. 7

Transport request in vehicles	Minimum vehicle needful	First semi-hour interval	Second semi-hour interval	Third semi-hour interval	Fourth semi-hour interval
Fourth junction		0 / 2	2 / 3	3 / 4	
Third junction	2				5 / 2
Second junction	3		4 / 5		2 / 6
First junction	4				1 / 0
Total 22 vehicle	2+3+4+5+2+6	5	2	6	Minimum no of vehicles needful

We will consider the next complex situation: four junctions and 12 semi-hour intervals, which is indeed more complicated than the previous example, but still is not as complex as a real situation can be.

Tab. 8

	Semi-hour intervals											
	1	2	3	4	5	6	7	8	9	10	11	12
The fourth junction	5	3	2	5	7	8	1	3	2	5	1	6
The third junction	4	6	2	3	9	2	2	2	8	1	6	2
The second junction	4	3	2	1	6	6	5	5	4	4	1	6
First junction	2	1	3	4	3	5	6	6	6	5	6	2

The domination conducts to the reduction of the problem:

Tab. 9

	Semi-hour intervals											
	1	2	3	4	5	6	7	8	9	10	11	12
The fourth junction	5	3			7	8		3				6
The third junction	4	6			9				8		6	
The second junction					6	6						6
First junction								6	6		6	2

Or, by isolating the traffic volume by the direction of the speed line, but only for one particular from the N – W area, we find the situation of the tab. where:

$x \in N, x \leq 5$

$y_1 \in N, y_2 \in N, y_1 + y_2 \leq 4$

$z_1 \in N, z_2 \in N, z_1 + z_2 \leq 6$

$p_1 \in N, p_2 \in N, p_1 + p_2 \leq 7$

$r_1 \in N, r_2 \in N, r_1 + r_2 \leq 8$

$t_1 \in N, t_2 \in N, t_1 + t_2 \leq 9$

$s_1 \in N, s_2 \in N, s_1 + s_2 \leq 6$

$k_1 \in N, k_2 \in N, k_1 + k_2 \leq 6$

….

Tab. 10

0 0 5	0 x 3-x			p_1 p_2 7-Σp	r_1 r_2 8-Σr	
y_1 y_2 4-Σy	z_1 z_2 6-Σz			t_1 t_2 9-Σt		
				s_1 s_2 6-Σs	k_1 k_2 6-Σk	

The problem is reduced now to the determination of:

$$\min_{x,y_i,z_i,..}\{\max_{x,y_1}\{y_1,5,x\}+\max_{y_2,z_1,x}\{y_2,z_1,3-x\}+$$
$$+\max_{z_1,z_2,p_2,r_1}\{6-z_1-z_2,\,p_2,r_1\}+...\}$$

But :

$$\max_{x,y_1}\{y_1,5,x\}=\max\{\max_x\{x,5\},\max_{y_1}\{y_1,5\}\}=$$
$$\frac{\max_x\{x,5\}+\max_{y_1}\{y_1,5\}+|\max_x\{x,5\}-\max_{y_1}\{y_1,5\}|}{2}=$$
$$=\frac{\frac{x+5+|x-5|}{2}+\frac{y_1+5+|y_1-5|}{2}+|\frac{x+5+|x-5|}{2}-\frac{y_1+5+|y_1-5|}{2}|}{2}=$$
$$=\frac{x+5+|x-5|}{4}+\frac{y_1+5+|y_1-5|}{4}+\frac{|x-y_1+|x-5|-|y_1-5||}{4}$$

Analogous:

$$\max_{x,y_2,z_1}\{y_2,z_1,3-x\}=\frac{y_2+3-x+|y_2-3+x|}{4}+\frac{z_1+3-x+|z_1-3+x|}{4}+$$
$$+\frac{|y_2-z_1+|y_2-3+x|-|z_1-3+x||}{4};$$

$$\max_{y_i,z_2,p_1}\{4-y_1-y_2,z_2,p_1\}=\frac{z_2+4-y_1-y_2+|z_2-4+y_1+y_2|}{4}$$
$$+\frac{p_1+4-y_1-y_2+|p_1-4+y_1+y_2|}{4}+$$
$$+\frac{|z_2-p_1+|z_2-4+y_1+y_2|-|p_1-4+y_1+y_2||}{4};$$

…….

As a consequence, the optimization function becomes:

$$\min_{x,y_i,z_i,p_i,...}(\frac{x+5+|x-5|}{4}+\frac{y_1+5+|y_1-5|}{4}+\frac{|x-y_1+|x-5|-|y_1-5||}{4}+$$
$$+\frac{y_2+3-x+|y_2-3+x|}{4}+\frac{z_1+3-x+|z_1-3+x|}{4}+$$
$$+\frac{|y_2-z_1+|y_2-3+x|-|z_1-3+x||}{4}$$
$$+\frac{z_2+4-y_1-y_2+|z_2-4+y_1+y_2|}{4}+$$
$$+\frac{p_1+4-y_1-y_2+|p_1-4+y_1+y_2|}{4}+$$
$$\frac{|z_2-p_1+|z_2-4+y_1+y_2|-|p_1-4+y_1+y_2||}{4}+...)=$$

$$=\min_{x,y_i,z_i,p_i,...}(\frac{|x-5|}{4}+\frac{|y_1-5|}{4}+\frac{|x-y_1+|x-5|-|y_1-5||}{4}+$$
$$+\frac{|y_2-3+x|}{4}+\frac{|z_1-3+x|}{4}+\frac{|y_2-z_1+|y_2-3+x|-|z_1-3+x||}{4}+$$
$$+\frac{|z_2-4+y_1+y_2|}{4}+\frac{|p_1-4+y_1+y_2|}{4}+$$
$$+\frac{|z_2-p_1+|z_2-4+y_1+y_2|-|p_1-4+y_1+y_2||}{4}$$
$$+\frac{10+6+8+...-x-y_1-y_2-z_1-z_2-p_1-p_2-...}{4})$$

In this situation, if we try to solve using the same technique (building the partial charts), conducts to a high volume of equations. The simplification is based on the following properties.

We consider next that a and b are natural numbers.

Prop:

a) If $x=\overline{0,a},\ \ y=\overline{0,b}$,x and y independent variables, and $m\in N$ fixed value, then

$$\min_{x,y}(|x-m|+|y-m|+|x-y+|x-m|-|y-m||)=$$
$$=\min_x(|x-m|)+\min_y(|y-m|);$$

b) If $x=\overline{0,a}$, si $m\in N$ fixed value, if

$$\min_x(|x-m|)=|x_0-m|\text{,then}$$
$$\min_x(|x-m|-x)=|x_0-m|-x_0;$$

c) If $x=\overline{0,a},\quad y=\overline{0,b}$, $m,n\in N$ two fixed values, then

$$\min_{x,y}(|n-x|+|m-x-y|)=\min_x(|n-x|)+\min_y(|m-x_0-y|)$$

where by x_0 we understand the x value for which $\min_x(|n-x|)$ has been achieved.

The proofs of its entire are very simple just taking in consideration all the possible situations.

For exemplification, for proving c) property, we have to discuss four possibilities:

if $\min_x(|n-x|)=0$ **and** $\min_y(|m-x_0-y|)=0$;

if $\min_x(|n-x|)\neq 0$ **and** $\min_y(|m-x_0-y|)=0$;

if $\min_x(|n-x|)=0$ **and** $\min_y(|m-x_0-y|)\neq 0$;

if $\min_x(|n-x|)\neq 0$ **and** $\min_y(|m-x_0-y|)\neq 0$.

We take further the demonstration of one of the situations which makes the structure of the last sentence, in the most complex situation .

Case 4 :

If $\min_x(|n-x|)\neq 0$ **and** $\min_y(|m-x_0-y|)\neq 0$.

In the situation m-n>=0, it follows:

$\min_x(|n-x|)\neq 0$, so a<n, x_0=a,

and

$\min_y(|m-x_0-y|)=\min_y(|m-a-y|)\neq 0$,

from here the condition b<m-a.

The sum of the 2 minimum is, in this case, m+n-2a-b.

On the other hand :

I. For x = 0,

$$\min_{x,y}(|n-x|+|m-x-y|)=n+\min_{y}|m-y|=$$

$$\begin{cases} m+n-b, & if \quad b<m \\ n, & if \quad b\ge m \end{cases}.$$

If, b<m, then,

$\min_{x,y}(|n-x|+|m-x-y|)$ =m+n-b>m+n-2a-b ,

and if b>=m, then

$\min_{x,y}(|n-x|+|m-x-y|)$ =n$\ge$n+m-2a-b.

……

II . For x = a-k, k>0,

$\min_{x,y}(|n-x|+|m-x-y|)$ =n-a+k+

$$\min_{y}(|m-a+k-y|)=$$

$$=\begin{cases} m+n-b-2a+2k, & if \quad b<m-a+k \\ n-a+k, & if \quad b\ge m-a+k \end{cases}$$

If b<m-a+k, then m+n-2a+2k-b>m+n-2a-b,

and if b>=m-a+k, n-a+k>=m+n-2a-b.

….

III. For x=a

$$\min_{x,y}(|n-x|+|m-x-y|)= n-a+\min_{y}(|m-a-y|)=$$

$$=\begin{cases} m+n-2a-b, & if \quad b<m-a \\ n-a, & if \quad b\ge m-a \end{cases}.$$

If b<m-a, m+n-2a-b=m+n-2a-b

and if b>=m-a, n-a>= m+n-2a-b.

So, for all situations,

$$\min_{x,y}(|n-x|+|m-x-y|)=$$

$$\min_{x}(|n-x|)+\min_{y}(|m-x_0-y|).$$

Using those three properties and Bellman's optimal principle, it follows that, in fact, for solving our problem, we have to follow the next steps:

Step 1: We go first into the first area where we have just 2 simple modulus, we minimize its, then after we have some established values for the variables present here, we enter into the second area.

In our example case, the first area from tab10 contains $|x-5|$ and $|y_1-5|$, and taking care of the constraints of x and y_1 ,we find x=3 and y_1 =4.

Step 2: We go next into the second area defined by the slanting lines, and inside we will do exactly like into the previous step, only that this time we will be able to fix other variables.

We repeat the method until we will finish the areas, and ,at the end, we will have the result for the min-max problem asked.

When we apply the algorithm for the situation described by tab 3 , we find the same solution as the one given by the charts, but the effort is less because we only have to minimize five modulus, which, of course , is easy.

We had also applied the algorithm for the particular case described by table 10, and we had found that we need 40 vehicles in order to obtain the optimum solution . The modality of distributing these vehicles is presented next in Tab 11.

Tab. 11

	Semi-hour intervals											
	1	2	3	4	5	6	7	8	9	10	11	12
The fourth junction	0 0 5	0 3 0			0 6 1	6 1 1		1 2 0				6 0 0
The third junction	4 0 0	0 0 6			1 1 7				0 6 2		2 0 4	
The second junction					6 0 0	0 0 6						2 0 4
The first junction								0 4 2	4 2 0		0 6 0	2 0 0

We present in table 12 the result obtained using the “heuristic” method, which uses only the maximum demanding of the two components of the ride, and the result of this method is 41 vehicles. Comparing it with the solution proposed by our method, the result of the heuristic method doesn’t respect exactly the structure of the demanding(takes only the maximum values) , and also needs an extra vehicle, which is totally unnecessary for covering the demanding.

Tab. 12

	Semi-hour intervals											
	1	2	3	4	5	6	7	8	9	10	11	12
The fourth junction	5 / ***5***		2	5		8 / ***2***		3 / ***1***		5		6
The third junction		6 / ***6***			9 / ***7***		2		8 / ***3***		6 / ***3***	
The second junction	4	3			6	6 / ***5***				4		6
First junction			3	4			6	6 / ***3***	6 / ***3***		6 / ***3***	

4. Conclusion

Some problems that seem to be intuitive are proven to be of a large mathematical consistency.

On the other hand, some heuristic type rules used in daily practice by the engineer need the mathematical confirmation, after a maturity period and confirmation on cases proven to be correct.

The same case is with the relevant urban passenger transport request. We have proposed a new and better method for solving those problems, which is easy to apply and gives better results.

The motivation of the above writing was a result of trying to approach two manifested positions at a narrow type of specialists (mathematicians and engineers).

By trying to overcome the barrier, otherwise accepted, **as ‘the mathematicians do what they can - as they should, while the ngineers do what they should – as well as they can’, but we need them both, in order to make things happened.**

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