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# Information management in passenger traffic supporting system design as a multi-criteria discrete optimization task

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This paper presents a concept of an Integrated System of Supporting Information Management in Passenger Traffic (ISSIMPT). The novelty of the system is an integration of six modules: video monitoring, counting passenger flows, dynamic information for passengers, the central processing unit, surveillance center and vehicle diagnostics into one coherent solution. Basing on expert evaluations, we propose to present configuration design problem of the system as a multi-objectives discrete static optimization problem. Then, hybrid method joining properties of weighted sum and  $\epsilon$ -constraint methods is applied to solve the problem. Solution selections based on hybrid method, using set of exemplary cases, are shown.

**Key words:** multi objective optimization, discrete static optimization, Pareto solutions, integrated systems.

## 1. Introduction

In recent years one can observe intensive development of monitoring and diagnostics systems enhanced by the development of modern technologies. It also applies to rail vehicles, which devotes more and more attention in scientific publications, standards and regulations due to the need to monitor individual modules of the vehicle as well as some elements of railway infrastructure [1, 9, 10]. We found similarities in this process in two countries: Poland and Romania.

Polish railway is after the liberalization process of the rail passenger market, where there has been a significant increase in the shares of companies outside the PKP Group, mainly local carriers from 1% to 48% [2]. An important factor in this process is the creation of market competition in the segment of interregional transport (dynamic develop-

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ment of the companies in the local passenger transport). This factor results in favorable conditions for the development of new features and facilities offered by the railway.

Romania, after the 1989 revolution, has one of the most used railway networks in Europe, but at the same time, lagging behind in maintaining its infrastructure. This, combined with the economic decline of the 1990s, lead to a period of relative decline of CFR group. Some less traveled routes, especially in rural areas, have been cancelled and the existing rolling stock has entered in a lack of repairs period. The situation continued until 1998 when the National Society of Romanian Railways was reorganized into four independently-funded institutions to increase the efficiency. Romanian railways situation has improved also due to a better economic situation of the country after 2000, which allowed the start of major investment projects. A liberalization process allowed the access to railway infrastructure to all licensed railway operators, which led to the establishment of private rail operators. Some railway lines, so-called "non-interoperable sections" were leased to private operators, passenger transport is done by them, using their own or leased rolling stock [11].

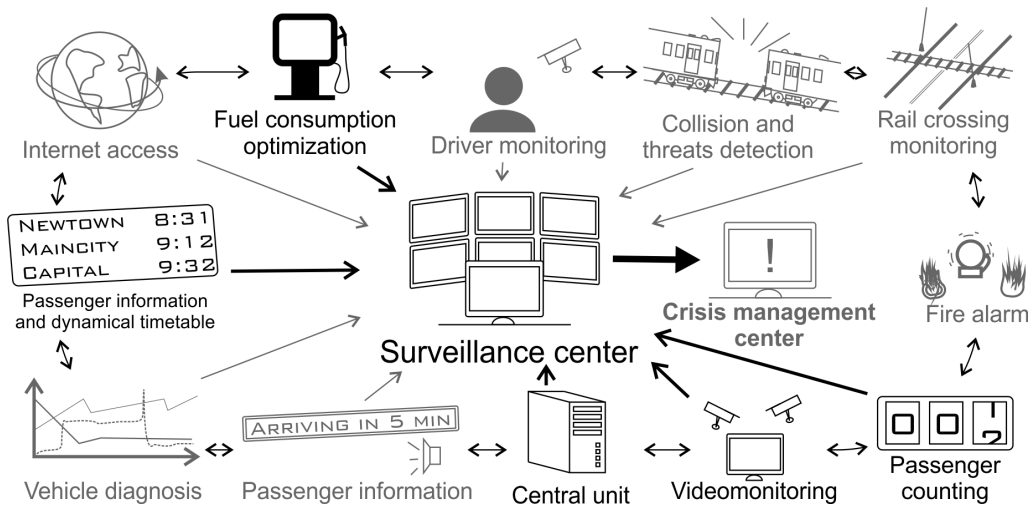


Figure 1: The structure of the telemetry system of Supporting Information Management in Passenger Traffic (ISSIMPT). The highlighted items are analyzed in the article

The designed system in its current state concerns the passengers safety aspect. The system is realizable thanks to installation of following modules: video monitoring, counting passenger flows, dynamic information for passengers, the central processing unit, surveillance center and vehicle diagnostics and integration with the Control Center according to diagram from Figure 1 [3]. Other modules configuration problem has been considered in our earlier works [6, 7]. To some extent, the described project of ISSIMPT affects the aspect of reducing the effect of the digital divide by providing access to Internet services implemented by the module wireless access to the Internet and Intranet in public transport.

As part of the work associated with the development of conceptual assumptions, for each module, a team of expert reviewed three different methods of its implementation. Each of the methods has been evaluated by the design team, with regard to three evaluation criteria:

1. Functionality and expandability;
2. Compliance with standards;
3. Costs.

The grading scale is following: 1 - very low, 2 - low, 3 - medium, 4 - high, 5 - very high. It is worth noticing that grading in third criterium: Costs, high rating (high grade in terms of costs) means low price.

Comparative analysis of possible construction of video monitoring module are presented in Table 1 and of passengers counting module - in Table 2. Other modules has been analysed in similar way and finally all results are summarized in Table 3.

Considerations are based on Table 3 containing the assessment of the suitability of all six designed modules that are mentioned above. The stated problem is the task of maximizing the objective functions vector consisting of 3 components:

$$\max \leftarrow F(x) = (f_1(x), f_2(x), f_3(x)), \quad (1)$$

where:

- $f_1(x)$  is a sum of grades in criterium 1, depending on method,
- $f_2(x)$  is a sum of grades in criterium 2, depending on method,
- $f_3(x)$  is a sum of grades in criterium 3, depending on method,
- $x$  - space of feasible solutions.

The grades are in  $\langle 1, 5 \rangle$  range, thus for 6 modules the range of sum values is  $\langle 6, 30 \rangle$ .

### 1.1. Example

Let variant number 1 of feasible solution will be the choice of method 1 concerning implementation of each of the build modules. Therefore on the basis of Table 4, the new table describing this solution can be build (Table 3). It can be observed that variant 1 has low functionality (low sum of grades in criterion 1), but is cheap (high sum of grades in criterion 3). The example shows that the criteria are contradictory, thus there exist no ideal solution of the problem, that is the indication of the best module build method.

Table 1: Comparative analysis of monitoring methods

Parameter	Method 1	Method 2	Method 3
	Machinist optical observation	Standard video monitoring within the vehicle and the railway station	Video monitoring module of ISSIMPT
Functionality and expansion possibility	Vehicle operator observation. The method is limited by the field of view of the door mirrors. Inability of entrance monitoring.	Video monitoring allowing camera observation from cameras installed on and within the vehicle. Ensuring the safety of structural and (partially) the safety of travelers	Image observation, integration of module with fire alarm. Observation of images from mirror, track, pantograph and entrance cameras. Ensuring the security of passengers and protection against attacks of aggression. Scalable system.
Score:	1	3	5
Compliance with the standards and guidelines	No compliance with the standards and the applicable guidelines for the monitoring.	Partial compliance with standards concerning the structural parts and security of passengers resulting from the technical conditions.	Compliance with the standards and current guidelines
Score:	1	4	5
General costs (installation, observation, ease of use, costs)	Low cost, low efficiency	Interference in the vehicle hull, involving the need to install additional devices. Expandability and scalability of the system. Average costs, high efficiency.	Interference in the vehicle hull, involving the need to install additional devices. Upgradeability and scalability of the system and integration by the newly developed modules. Open architecture. High implementation costs, very high efficiency of video monitoring system adapted to the dynamic situation within the vehicle.
Score:	4	3	2

Scores scale: 1- very low, 2-low, 3-medium, 4-high, 5-very high.

## 1.2. Contribution

In the paper a method that optimally solves the problem of Information Management in Passenger Traffic Supporting System design is proposed. This method joins classical multi-criteria optimization methods: weighted sum and  $\epsilon$ -constraint methods and was proposed in earlier works to solve simpler problems [6, 7]. In section 2 the problem of modeling system configuration as a optimization problem is presented, in section 3 optimization results are presented and, finally results are concluded in section 4.

Table 2: Comparative analysis of passengers counting methods

Parameter	Method 1	Method 2	Method 3
	IR/thermal	Laser	3D stereosc. cameras
Functionality and expansion possibility	Necessary deduction of people movement direction, limited system, low sensitivity, historical solution.	The system is not intelligent, and there is no possibility of distinguishing people. Two people passing through the laser beam at the same time are counted as one.	Observation and analysis of the dynamic image from 3D cameras, which can be added to the monitoring system. Easy to verify of the quantities entering/outgoing passengers.
Score:	1	2	5
Compliance with standards and guidelines	Compliance with the standards.	Compliance with the standards.	Compliance with the standards.
Score:	5	5	5
General costs (installation, observation, ease of use, costs)	Low cost, low efficiency	Low cost, low efficiency.	Precise measurement with use of advanced stereoscopic cameras. Relatively high costs.
Score:	4	4	2

Scores scale: 1- very low, 2-low, 3-medium, 4-high, 5-very high.

Table 3: Designed modules grades

Method		Crit. 1	Crit. 2	Crit. 3
<b>Videomonitoring</b>	1:	1	1	4
	2:	3	4	3
	3:	5	5	2
<b>Passenger counting</b>	1:	1	5	4
	2:	2	5	4
	3:	5	5	2
<b>Passenger information and dynamical timetable</b>	1:	1	2	4
	2:	3	3	3
	3:	5	4	1
<b>Central unit</b>	1:	1	3	5
	2:	3	3	3
	3:	5	4	3
<b>Surveillance center</b>	1:	3	5	5
	2:	4	4	4
	3:	5	4	5
<b>Fuel consumption optimization</b>	1:	2	5	4
	2:	4	5	3
	3:	5	5	3

Table 4: Exemplary feasible solution

Variant	Module 1			Module 2			Module 3			Module 4			Module 5			Module 6								
	Method	Crit. 1	Crit. 2	Crit. 3	Method	Crit. 1	Crit. 2	Crit. 3	Method	Crit. 1	Crit. 2	Crit. 3	Method	Crit. 1	Crit. 2	Crit. 3	Method	Crit. 1	Crit. 2	Crit. 3				
1	1	1	1	4	1	1	5	4	1	1	2	4	1	1	3	5	1	3	5	5	1	2	5	4

**2. The problem of system configuration choice as a multi-criteria optimization task**

Real optimization problems are often formulated as a multi objective ones, e.g. [4, 13]. It is assumed that the optimal solution is the indication of methods from individual modules resulting from maximizing rating. Basing on Table 4 it is assumed that:

- $i = 1, 2, \dots, 6$  is a module index,
- $j = 1, 2, 3$  is a criterium index,
- $k = 1, 2, 3$  is a method index,

then  $x_{i,j,k}$  describes the values from Table 3 (i.e.  $x_{4,2,2} = 3$ ).

The set of all  $x_{i,j,k}$  constitute the space of feasible solutions  $\Omega = \{x_{i,j,k} \in \mathbb{Z}^n : 1, 2, 3, 4, 5\}$  for all  $i, j, k$ . The aim of the problem is to select the configuration resulting from the maximization of individual ratings criteria, that is:

- $f_1(x)$  - criterium 1 defined as sum of grades for all modules.  
 $f_1(x) = \sum_{i=1}^6 x_{i,1,k}; i = 1, 2, \dots, 6; k = 1, 2, 3;$
- $f_2(x)$  - criterium 2 defined as sum of grades for all modules.  
 $f_2(x) = \sum_{i=1}^6 x_{i,2,k}; i = 1, 2, \dots, 6; k = 1, 2, 3;$
- $f_3(x)$  - criterium 3 defined as sum of grades for all modules.  
 $f_3(x) = \sum_{i=1}^6 x_{i,3,k}; i = 1, 2, \dots, 6; k = 1, 2, 3;$

For the exemplary configuration from Table 3, the values substituted to consecutive criteria are:

$$\begin{aligned}
 f_1(x) &= \sum_{i=1}^6 x_{i,1,1} = 1 + 1 + 1 + 1 + 3 + 2 = 9; \\
 f_2(x) &= \sum_{i=1}^6 x_{i,2,1} = 1 + 5 + 2 + 3 + 5 + 5 = 21; \\
 f_3(x) &= \sum_{i=1}^6 x_{i,3,1} = 4 + 4 + 4 + 5 + 5 + 4 = 25.
 \end{aligned}
 \tag{2}$$

This states that the variant 1 has low functionality ( $f_1(x) = 9$ ) and low cost ( $f_3(x) = 25$ ). Number of all possible configurations of the system is:  $L = 3^6 = 729$ .

On order to chose the besteonfiguration, a hydride method has been applied. This method consist of elements of weighted sum methods and  $\varepsilon$ -constraints [5, 6, 12]. The objective vector has been divided into two sets: primary objectives  $F_p$  and secondary objectives  $F_s$ :

$$\begin{aligned} F_p(x) &= [f_1(x), f_2(x), \dots, f_{kp}(x)]^T, \\ F_s(x) &= [f_{kp+1}(x), f_{kp+2}(x), \dots, f_k(x)]^T, kp < k, \end{aligned} \quad (3)$$

which leads to the following problem statement:

$$\min_{x \in \Omega} F'(x) = \sum_{i=1}^{kp} w_i f_i(x), \quad (4)$$

with constraints:

$$f_i(x) \leq \varepsilon_i, i = kp + 1, kp + 2, \dots, k. \quad (5)$$

The advantage of the above problem formulation is that the result fulfills the secondary objective at least on  $\varepsilon$  level. Other objectives are meet according to the set weights.

### 3. Optimal system configurations

For the described problem from equation 1, the divided objective functions are in form:

$$F_p(x) = [f_1(x), f_3(x)]^T, F_s(x) = f_2(x). \quad (6)$$

Thus the problem can be described as:

$$\min_{x \in \Omega} F'''(x) = (-w_1 f_1(x) - w_3 f_3(x)), -f_2(x) \leq -\varepsilon. \quad (7)$$

Despite the objective function  $f_2(x)$  being called secondary, in the process of configuration selection it is the most important. Due to standards compliance assurance the solution has to fulfill the given weights and constraints. Regardless of the set weights  $w_1$  and  $w_3$ , the solution ensures the standards compliance at desired level. Figure 2 presents the objective subspace  $(-f_1(x), -f_3(x))$  with Pareto solutions for  $\varepsilon = 27$ .

Thus, one can generate a set of optimization problems assuming different weights, e.g.: case 1:  $w_1 = 1, w_3 = 1$  (or  $w_1 = 0.5, w_3 = 0.5$  if one normalize the sum of wiegths to value 1) in this example the main objectives are equivalent; case 2:  $w_1 = 0, w_3 = 1$ , it is a border case, where optimization problem is reduced to costs; case 3:  $w_1 = 1, w_3 = 0$ , it is a border case, where optimization problem is reduced to functionalities.

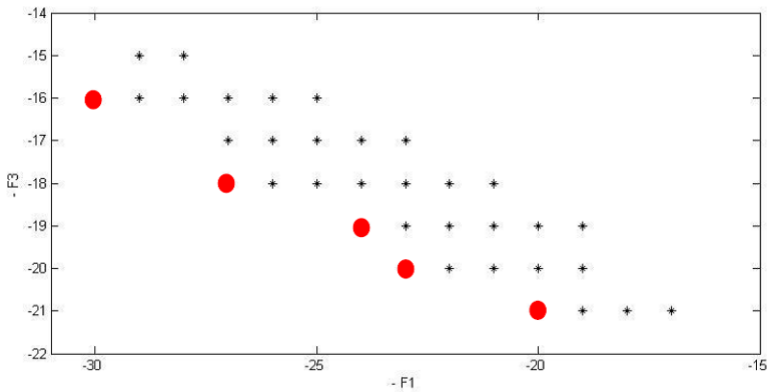


Figure 2: Objective subspace  $(-f_1(x), -f_3(x))$  with Pareto solutions for  $\epsilon = 27$

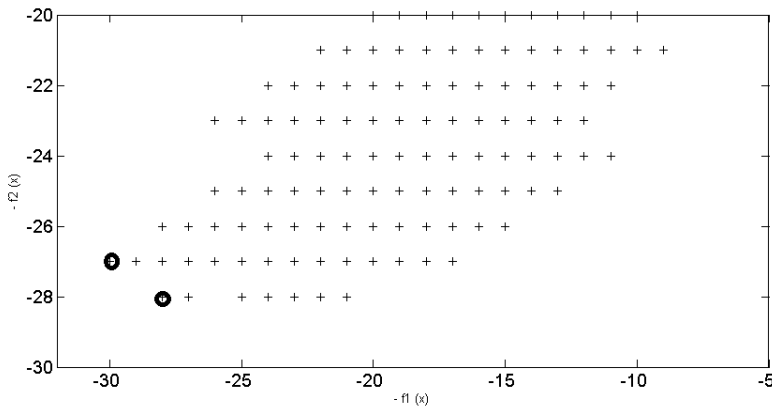


Figure 3: objective space for  $F_t$  problem

Table 5: Exemplary optimal solution

Variant	Module 1			Module 2			Module 3			Module 4			Module 5			Module 6									
	Method	Crit. 1	Crit. 2	Crit. 3	Method	Crit. 1	Crit. 2	Crit. 3	Method	Crit. 1	Crit. 2	Crit. 3	Method	Crit. 1	Crit. 2	Crit. 3	Method	Crit. 1	Crit. 2	Crit. 3					
723	3	5	5	2	3	5	5	2	3	5	4	1	3	5	4	3	1	3	5	5	3	3	5	5	3
729	3	5	5	2	3	5	5	2	3	5	4	1	3	5	4	3	3	5	4	5	3	5	5	3	3

The optimal solution e.g. for  $\epsilon = 28$  is variant number 723 with objective function value  $F'''(723) = 44$ , while for  $\epsilon = 27$  is variant number 729 with objective function value  $F'''(729) = 46$ . The final system configurations resulting from the solution are presented in Table 5.



In order to compare the solution to possible solutions that are not limited by costs we present solution space for limited two objective problem  $F_I$ :

$$F_I(x) = [f_1(x), f_2(x)]^T \quad (8)$$

in Figure 3. Pareto front is now limited to two solutions leading to values  $F_I(728) = [30, 27]^T$  and  $F_I(726) = [28, 28]^T$ , respectively.

#### 4. Conclusion

The article presents the problem of designing the system configuration comprising of six modules as multi-criteria optimization task. Considered in the design of each of the modules in three different ways, with each of the methods has been assessed by experts in terms of the three criteria. Using the basic methods of multi-criteria optimization, indicated sets of Pareto solutions of possible system configuration and sample solutions optimized using assumed values of additional parameters. It should be mentioned that pilot installation of integrated system has been implemented and successfully tested on electrical and diesel type passenger trains in Poznan and Warsaw, Poland, as result of research and development project No UOD-DEM-1-243/001.

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