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Comparative Assessment of CI Engine Response

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Abstract The response of the piston internal combustion engine provides an important indicator to assess the engine ability to adapt to constantly varying load conditions in its operation. It is the main criterion by which engines powering automotive vehicles are evaluated. It also affects road safety. The engine response depends on the profile of the curve that shows changes in the engine torque as a function of the crankshaft rotational speed. The paper presents a comparison of CI engines representing different generations with respect to constructional level. The engines that underwent comparison were equipped with the fuel system with a rotary injection pump and with Common Rail fuel system.

Keywords CI internal combustion engine, engine response, engine response assessment indicators, engine response modification, engine dynamics

JEL L99

1. Introduction

To power an automotive vehicle, a high-speed rotation, piston, internal combustion engine is necessary. It needs to dynamically respond to changing traffic conditions and to carry out fast manoeuvres, thus improving the economy and road safety. The first compression-ignition engines were low-speed rotation and they were, therefore, used in industries. Advancements in those engines, however, made it possible to employ them in trucks. Development of piston compression ignition engines was limited because it was not possible to increase the rotational speed. That resulted from a fairly large angle of rotation of the crankshaft that corresponded to the fuel auto-ignition delay. Long auto-ignition delay causes hard engine operation and considerable mechanical stress impact. CI engines had large weight and were noisy in operation. They were characterised by lower power extracted from piston displacement. As a result, their applicability to small passenger cars was very limited. The improvement was sought by shortening the auto-ignition delay and by modifying the profile of torque changes as a function of the crankshaft rotational speed. The use of classical multi-section injection pumps or rotary pumps did not make it possible to obtain high injection pressures. Improvements in the fuelling system due to the use of unit injector systems and Common Rail fuel systems with a high-pressure pump and electronically controlled injectors allowed the elimination of the drawbacks of CI engines.

Modern CI engines are much lighter, less noisy and, above all, they make it possible to obtain performance (power and torque) comparable with modern spark-ignition engines, at lower fuel consumption. These advantages resulted in increased interest in these engines with respect to their application to passenger cars, also the smallest ones [1]. Currently, CI engines with small piston displacement, which reach maximum crankshaft rotational speeds even above 5000 rpm, are commonly used in passenger cars.

2. Modern CI Engines

Presently used piston IC engines must be able to generate as small harmful environmental effects as possible, which means they need to produce low exhaust toxicity and noise. They have to consume little fuel, and to be characterised by response that allows dynamic driving under traffic conditions presently prevailing on the roads. Requirements posed for internal combustion engines make it necessary to search for different technical solutions to reduce exhaust emissions, fuel consumption and to improve engine traction properties [2, 3]. As regards CI engines, the most widely used technical solutions mentioned above include the following [4-11]:

- common use of direct fuel injection,
- the use of modern fuel systems producing high injection pressures, i.e. Common Rail systems or unit injector systems,
- the use of multi-valve timing gear system with controlled parameters of valve operation,
- the use of controlled supercharging systems with the charge-air cooling,
- the use of electronically controlled exhaust gas recirculation (EGR) systems with re-circulated exhaust cooling,

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- electronic control of injection,
- the use of multi-stage fuel injection,
- shaping of the combustion space geometry,
- the control of the working medium swirl and turbulence,
- the use of devices purifying the exhaust gas,
- the use of onboard diagnostic systems,
- the use of the cooling systems with a higher coolant temperature and faster engine warm-up time from the start-up,
- control that makes possible to optimise the process of combustion heat release by means of using high pressure injection, and also the fuel injection pattern modification in time.

3. Response of the Piston Internal Combustion Engine

If it were possible to ensure constant engine power as a function of the crankshaft rotational speed, the gearbox would not be necessary. Then, the engine would generate sufficient driving force on the wheels that would be able to overcome motion resistance. In fact, that is not possible because the processes occurring in the engine and its systems, and thus the engine power, depend on the crankshaft rotational speed. The efficiency of the processes in the engine is also varied because it depends on the conditions of the engine operation [12]. Those factors make the engine power vary with the crankshaft rotational speed. The ability of the engine to respond to changing conditions of operation was termed engine response. It is of vital importance for engines used to power automotive vehicles.

The response of an internal combustion engine involves its adaptability to changes in loads and rotational speeds [13]. With respect to piston internal combustion engines used to power automotive vehicles, the engine response provides an important indicator for the assessment of engine in-service performance. The notion of the response index was introduced to evaluate the engine response. The engine response index is expressed as the product of the torque response index e_M and the rotational speed response index e_n:

$$e = e_M \cdot e_n \tag{1}$$

Indexes e_M and e_n provide an assessment of the pattern of changes in the effective power N_e and torque M_o as a function of the crankshaft rotational speed when the engine operates under full load characteristics. That is equivalent to the settings of the fuelling system controls which ensure obtaining the maximum effective power every time. The pattern of effective power N_e and torque M_o as a function of the crankshaft rotational speed, for the engine operating under full load characteristics, with the denoted parameters necessary to calculate the response indexes is shown in Fig. 1.

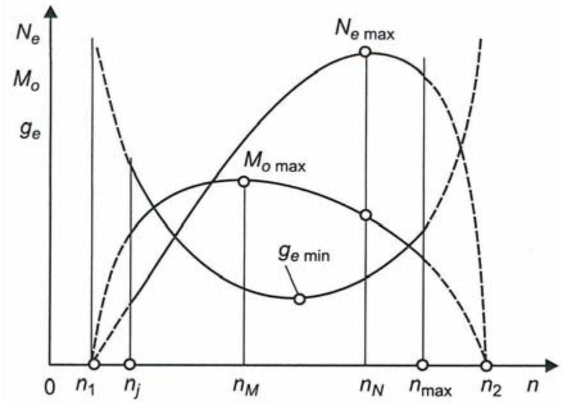

Figure 1. Engine full load characteristics with superimposed parameters necessary to calculate the engine response: n_1 – rotational speed at the engine start-up, n_j – idle speed, M_{omax} – maximum torque, N_{emax} – maximum effective power, g_{emin} – minimal specific fuel consumption, n_M – rotational speed at the maximum torque, n_N – rotational speed at the maximum power, n_{max} – maximum permissible rotational speed, n_2 – rotational speed at which the engine generated power is equal to zero

The index of the torque response e_M is determined as the quotient of the maximum torque M_{omax} and the torque M_{oN} corresponding to the maximum power N_{emax}:

$$e_M = \frac{M_{o\,max}}{M_{oN}} \tag{2}$$

The index of the torque response e_M provides an assessment of the engine capacity to overcome load increase and it depends on the torque curve profile. A higher value of this index is obtained when the torque curve is steeper. That makes it easier for the engine to overcome an increasing external load without the necessity to change the transmission ratio in the power transmission system. The torque curve can be shaped by the proper construction of the intake and timing gear systems, the use of supercharging and fuel injection, improvement in the course of mixture combustion in the cylinder, and, in particular, electronic control of the amount of air and fuel delivered into the cylinders, and of the processes that occur in the cylinders.

The index of the rotational speed response e_n is given as a quotient of the crankshaft rotational speed n_N, corresponding to the maximum effective power N_{emax}, and the engine crankshaft rotational speed n_M, corresponding to the maximum torque M_{omax}:

$$e_n = \frac{n_N}{n_M} \tag{3}$$

The index of the engine rotational speed response e_n indicates in what range of the rotational speed, the engine will be able to adapt its operation to changing driving conditions, i.e. to the increasing load. A higher value of the index shows that the engine is better applicable to the traction uses. Such an engine has a greater range of rotational speed that can be used [14]. The driver will less often have to change gears. The index of the engine rotational speed response depends on the rotational speed span between that at the maximum torque n_M and that at the maximum power n_N. This indicator can be modified by shifting the values of the maximum torque into the lower rotational speeds. An increase in the

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value of the index of the engine rotational speed response results in an increase in the engine response.

4. Characteristics of the Selected CI Engines

For the analysis, IC internal combustion engines that represent different design generations were selected. One of those is medium-speed, naturally aspirated Perkins AD3.152 UR engine, with the fuel system containing the mechanically controlled rotary injection pump. It is three-cylinder CI engine with direct fuel injection into the combustion chamber located in the piston bottom. Injection is performed by mechanical injectors. This engine was used to power agricultural tractors and light vans.

The other engine, namely FIAT 1.3 MULTIJET SDE 90 KM, shows a modern design. The engine uses new technical solutions, which results in meeting current requirements. This is a high-speed, turbocharged engine with Common Rail fuel system. The engine is equipped with a turbocharger with variable geometry vanes. The fuel charge, injected into the cylinders under specified conditions of engine operation, is divided into three portions. Electronic control unit controls the cylinder filling with air and fuel injection. FIAT 1.3 MULTIJET SDE 90 KM engine is used to power small passenger cars.

In the paper, the indexes of response of two other CI engines were also presented. Those are produced by the same manufacturer and have similar basic design parameters, but they are equipped with different fuel systems. The first of those, namely Perkins 1104D-44TA engine is fitted with mechanically controlled fuel system with a rotary injection pump. The other, i.e. Perkins 1104D-E44TA engine, has electronically controlled Common Rail fuel system. Those engines are mostly used to power machinery. The basic specifications of the engines mentioned above are given in Table 1.

Table 1. Basic specifications of the engines: Perkins AD3.152 UR, FIAT 1.3 MULTIJET SDE 90 KM, Perkins 1104D-44TA, Perkins 1104D-E44TA

Parameter	AD3.152 UR	1.3 MULTI-JET	1104D-44TA	1104D-E44TA
Cylinder arrangement	in-line	in-line	in-line	in-line
Number of cylinders	3	4	4	4
Type of injection	direct	direct	direct	direct
Type of the fuel system	rotary injection pump	Common Rail	rotary injection pump	Common Rail
Engine maximum power; kW	34.6	66	75	106.2
Rotational speed at the maximum power; rpm	2000	4000	2200	2200
Engine maximum torque; Nm	165.4	200	416	556.0
Rotational speed at the maximum torque; rpm	1300 ÷ 1400	1750	1400	1400
Engine cubic capacity; dm^3	2.502	1.251	4.4	4.4
Cylinder bore; mm	91.44	69.6	105	105
Piston stroke; mm	127	82	127	127
Compression ratio	16.5	17.6	18.2	16.2
Air supply system	naturally aspirated	turbocharger	turbocharger	turbocharger

5. Response of the Selected CI Engines

On the basis of full load characteristics, response indexes were computed for the engines of concern. Those include the index of torque response, the index of rotational speed response and the index of the engine response. The values of the indexes are presented in Table 2.

Table 2. Values of indexes determined to assess the response of the engines: Perkins AD3.152 UR, FIAT 1.3 MULTIJET SDE 90 KM, Perkins 1104D-44TA, Perkins 1104D-E44TA

Index	AD3.152 UR	1.3 MULTI-JET	1104D-44TA	1104D-E44TA
Index of torque response	1.032	1.324	1.156	1.209
Index of rotational speed response	1.428	2.285	1.571	1.571
Index of engine response	1.474	3.027	1.816	1.899

The computation results show that the lowest values of response indexes are found for the Perkins AD3.152 UR engine, which is the oldest design in the four engines. It is a three-cylinder, naturally aspirated, mechanically controlled engine. In the four-cylinder Perkins 1104D-44TA engine, also mechanically controlled, turbocharging with the charge-air cooling is used. That allows a considerable increase in the engine response value. In the Perkins 1104D-E44TA engine, the electronically controlled Common Rail fuel system is used and the compression ratio is reduced when compared with Perkins 1104D-44TA. That makes it possible to clearly increase the maximum effective power and the torque, and to increase the torque response index, and to a small extent, the engine response index. The index of rotational speed response, however, is unaffected because the maximum values of the torque and effective power are obtained for the same values of the crankshaft rotational speed as it is the case for Perkins 1104D-44TA engine. To increase the engine response, it would be necessary to increase the span of rotational speeds between that at the maximum torque and that at the maximum effective power. This engine, however, is used to drive machinery, thus high value of the engine response is not required. FIAT 1.3 MULTIJET SDE 90 KM was specially designed to power small passenger cars, in which high dynamics in fast-flowing traffic is of major importance. All modern solutions were applied to this engine, due to which it was possible to significantly increase the crankshaft rotational speed. The maximum power is obtained at 4000 rpm. The torque curve, as a function of the rotational speed, is shaped by means of electronic control of the engine supercharging, and of the amount and course of the fuel injection into the cylinders. The engine response index exceeds the value of 3. This value could be increased by reducing the rotational speed corresponding to the engine maximum torque.

6. Summary

The results of the tests on the response of selected internal combustion engines indicate that engines used to power passenger cars need to show highly dynamic characteristics in congested traffic. That is of major importance for, among others, traffic safety. Dynamic performance is ensured by high-response engines, i.e. those capable of adapting to variable loads. The application of supercharging, high pressure multi-stage fuel injection in Common Rail fuel systems and the electronic control of processes in the engine and its systems makes it possible to shape the pattern of torque changes as a function of the rotational speed. That allows improvement in the engine response and also makes it possible to meet the expectations of users.

The engine response is an indicator necessary to asses the engine dynamics. The engine response index provides an important instrument to evaluate the engine performance in service. A higher value of the index corresponds to better traction properties. Engine with high response allows drivers to accelerate, climb grades and overcome other loads in a more efficient way. Good dynamic characteristics of the internal combustion engine, expressed in the form of the engine response, should facilitate the dynamic performance of the vehicle powered by such engine. Engine response is of considerable importance in traffic fast flow and congestion. Poor engine response may adversely affect fluid traffic flow and pose a threat while performing overtaking manoeuvres.

When driving a car powered by high response engine, it is less often necessary to change gears. An increase in the engine load produces an increase in the fuel charge delivered to the engine cylinders. Appropriate torque reserve makes it possible to overcome motion resistance without the necessity to change the transmission ratio in the power transmission system. In overtakes, a higher response engine accelerates quicker because of the torque reserve, especially in higher gears. That makes it possible to perform overtaking manoeuvres faster, thus to prevent dangerous situations.

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Fuel Impact on the Response of AD3.152 UR Engine

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Abstract The paper presents results of investigations into the AD3.152 UR engine running on five fuels: commercial diesel oil DO, rapeseed oil fatty acid methyl esters FAME and their blends B10 (90% DO + 10% FAME), B20 (80% DO + 20% FAME), B30 (70% DO + 30% FAME). During the tests, the engine operated in accordance with the full load characteristics. Those characteristics were used to determine the engine response. The paper provides an assessment of the impact of the type of plant-derived fuel on the engine response.

Keywords diesel engine, engine response, biofuel

JEL L99

1. Introduction

Rapid developments in piston internal combustion engines, aimed at enhancing the dynamic properties of the vehicle, also contributed to the search for new, environmentally friendly energy sources. Fuels produced from natural raw materials are one of such sources. The advantage those fuels have, when compared with hydrocarbon ones, is that they are renewable, biodegradable and emit less carbon dioxide into the atmosphere [1, 2, 3]. The response of an internal combustion engine involves an ability to react to variable loads and crankshaft speeds. That provides one of the important indicators of the engine functional properties. The response of the torque depends on the profile of the engine torque characteristics. The magnitude of torque depends on numerous structural and functional parameters [4, 5]: the intake system, timing, the fuelling system, physical and chemical properties of fuel, etc. Presently, many research and development centres in the country and in the world conduct investigations to improve the dynamic properties of the internal combustion engine. The purpose of this paper is to analyse whether the use of alternative plant fuels may favourably affect the engine response.

The coefficient of the engine response e is determined on the basis of the profile of curves of variation in the effective power and the engine torque [6, 7]. This is the product of the engine torque response e_M and the response of the crankshaft rotational speed e_n:

$$e = e_M \cdot e_n \quad (1)$$

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The response of the engine torque e_M is the ratio of the maximum torque M_{omax} to the torque developed at the engine rated power M_{oNemax} [8]:

$$e_m = M_{omax} \;/\; M_{oNemax} \quad (2)$$

The response of the rotational speed e_n is the ratio of the rotational speed at which effective rated power n_{Nemax} occurs to the rotational speed of the maximum torque n_{Momax}:

$$e_n = n_{Nemax} \;/\; n_{Momax} \quad (3)$$

2. Object of Investigations and the Test Stand

The experimental investigations were performed on the engine test bed, which included the AD3.152 UR engine, the water brake, and the control and measurement cabinet. The diagram of the test bed is shown in Figure 1.

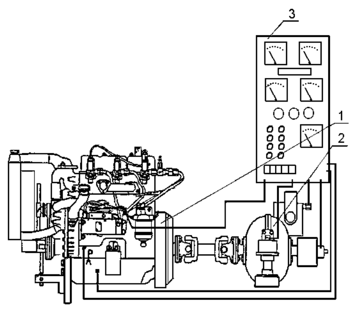

Figure 1. Diagram of the test stand: 1 – AD3.152 UR engine, 2 – water brake, 3 – control and measurement block

The object of investigations was three-cylinder, piston, internal combustion, compression ignition AD3.152 UR engine with fuel direct injection into the combustion chamber located in the piston bottom [9]. The engine was equipped with the fuelling system with the DPA distributor injection pump. The injectors had four-hole nozzles. Parameters and specifications of the AD3.152 UR engine are presented in Table 1.

Table 1. Basic specifications of the engine

Compression Ignition AD3.152 UR engine		
Parameter	**Unit**	**Value**
Cylinder arrangement	-	in-line
Number of cylinders	-	3
Type of injection	-	direct
Cylinder working order	-	1 – 2 – 3
Compression ratio	-	16.5
Cylinder bore	mm	91.44
Piston travel	mm	127
Engine cubic capacity	dm^3	2.502
Connecting rod length	mm	223.80÷223.85
Maximum engine power	kW	34.6
Rotational speed at maximum power	rpm	2250
Maximum torque	Nm	168.7
Rotational speed at maximum torque	rpm	1350
Static angle of injection advance	CA deg	17
Idle rotational speed	rpm	750±50

3. Fuels Used to Power AD3.152 UR Engine

During the tests, the AD3.152 UR engine ran on five fuels, namely Ekodiesel Ultra D commercial diesel oil (DO), rapeseed oil fatty acid methyl esters FAME and blends of those two fuels. Tests were conducted for the following blends of hydrocarbon and plant-derived fuels:

- 10% (V/V) rapeseed oil fatty acid methyl esters FAME + 90% (V/V) Ekodiesel Ultra D diesel oil→ denoted as B10,
- 20% (V/V) rapeseed oil fatty acid methyl esters FAME + 80% (V/V) Ekodiesel Ultra D diesel oil→ referred to as B20,
- 30% (V/V) rapeseed oil fatty acid methyl esters FAME + 70% (V/V) Ekodiesel Ultra D diesel oil→ labelled as B30.

Basic physical and chemical properties of Ekodiesel Ultra D diesel oil and rapeseed oil fatty acid methyl esters FAME are presented in Table 2.

Table 2. Basic physical and chemical properties of engine fuels used in investigations

Parameter	Ekodiesel Ultra D diesel oil	Plant-derived fuel FAME
Cetane number	51.4	51
Calorific value [MJ/kg]	43.2	36.7
Density at 15°C [g/cm^3],	0.8354	0.883
Kinematic viscosity [mm^2/s] (~40°C)	2.64	4.47
Surface tension [N/m] (20°C)	$3.64 \cdot 10^{-2}$	$3.58 \cdot 10^{-2}$
Ignition temperature [°C]	63	above 130
Turbidity point [°C]	-17	-2
Cold filter blocking temperature [°C]	-23	-14
Average elemental composition [%]		
- C	87.2	76.8
- H	12.7	12.1
- O	0	11
Sulphur content, S[mg/kg]	9	8.1
Water content [mg/kg]	43.8	113
Particulate matter content [mg/kg]	5	18

4. Results of Experimental Investigations

Figure 2 shows the full load characteristics of the effective power and torque of the AD3.152 UR engine running on five fuels: DO, FAME, B10, B20 and B30.

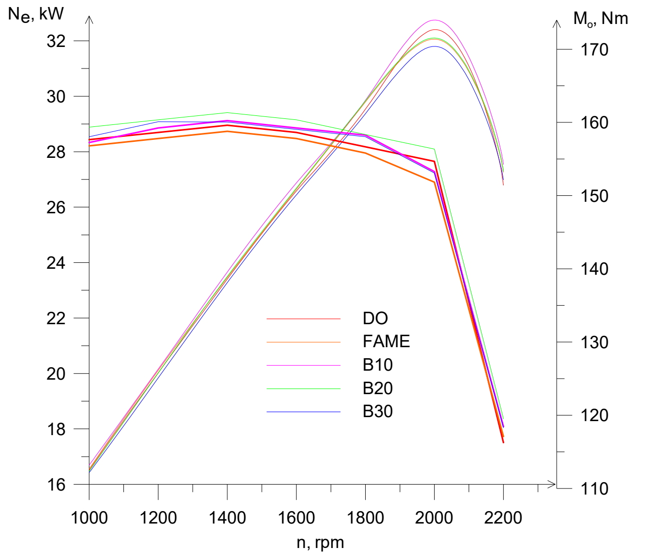

Figure 2. Diagram of the test stand: 1 – AD3.152 UR engine, 2 – water brake, 3 – control and measurement block

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Table 3 presents the values of the determined coefficients of the torque response, the rotational speed response and the response of the AD3.152 UR engine running on five fuels: DO, FAME, B10, B20 and B30.

Table 3. Determined values of response coefficients of the tested AD3.152UR engine

Fuel type	Torque response	Rotational speed response	Engine response
Diesel oil	1.05	1.43	1.502
FAME	1.07	1.43	1.531
B10	1.07	1.43	1.531
B20	1.07	1.43	1.531
B30	1.07	1.67	1.787

5. Conclusions

The following conclusions can be drawn on the basis of experimental results:

- the maximum effective power for the engine powered by the fuels of concern was found at the same rotational speed of 2000 rpm,
- for the engine fuelled by the B30 blend, the maximum torque occurred earlier, i.e. at the rotational speed of 1200 rpm, whereas when engine was powered by the remaining four fuels DO, FAME, B10 and B30, the maximum torque was produced by the engine at the crankshaft rotational speed n=1400 rpm,
- the highest value of the rotational speed response, which was equal to e=1.67, was obtained for the engine fuelled by B30,
- the torque response, which was e_M=1.05÷1.07, was comparable for the engine fuelling with commercial diesel oil, FAME, and also B10, B20 and B30 blends,
- when the engine was powered by FAME, and B10, B20 and B30 blends, the higher value of the engine response was obtained when compared with the engine fuelling with commercial diesel oil. The engine powered by the plant-derived fuel and the blends of this fuel demonstrated the strongest ability to overcome the load.

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Software Architecture of an Information System for Aviation Broker Center

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Abstract

This article describes an information system concept designed to provide large amounts of geospatial data to the public. It addresses specific software design challenges, including wide computational power and storage scalability and unclear definition of stakeholders. It defines functional, security and performance requirements and provides a conceptual system design proposal.

Keywords software architecture, geographical data, LIDAR

JEL L93

1. Introduction

Geospatial information is making a transition from paper onto the screen. There are numerous public sources of geospatial data available for commercial and noncommercial purposes. The demand for precise, high quality geospatial data is growing along with improving technologies and declining digital storage costs. Government institutions and high-end commercial clients expect better calibrated maps, higher resolutions, 3D digital terrain models, object identification and other geospatial services. The Aviation Broker Center (later "Broker Center") concept evolved to satisfy this growing market demand in the Slovak Republic. This innovative concept requires a complex and custom-designed information system, the analysis and design of which are discussed in this article.

2. Broker Center Goals

The Broker Center will provide to its clients geospatial data of the Slovak Republic from two main sources – 3D LIDAR and 2D terrain photographs. Customers will be able to choose either raw source data or deduced data, such as digital terrain models, road networks, utility networks, buildings, dams, etc.

The Broker Center will be implemented as a distributed information system, with public access via the internet [1].

Because of extreme storage demands, long-term tasks and specific security requirements, it is necessary to design a novel system, the architecture of which is described below.

3. Analysis of Requirements and System Design

At the point of concept analysis and design, the key Broker Center customer was not yet defined and there were no specific requirements to precisely anchor the system analysis. Therefore, part of the analysis was based on estimations, especially in terms of possible use cases and storage and processing requirements. Processing of LIDAR and OF data was proposed in several ways, and these proposals have not been definitely confirmed. Given this uncertainty, requirements for the new information system were defined relatively generally. That itself implied a highly modular, open and extendable system design.

The resulting information system is scalable in several aspects, including costs, hardware, richness of functionality, storage capacity, processing power, as well as variability of supported end products.

To achieve the Broker Center goals, minimal functional requirements were defined. The proposed information system is designed to enable, with comparable effort, the implementation of either a functional prototype or a real-life running system. Extending the prototype, which would process only a fraction of real-life data and provide a limited number of products, to a running system filling real-life demands, will be possible without significant increase in effort and costs.

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4. Information System Requirements

Defining requirements of an information system when there is no precise knowledge of its future use is extremely difficult. The guiding information system requirements must be balanced between the need for precision and clarity and the need for openness and flexibility. Moreover, the system design must be implementable within given cost plans while not being too general or too narrow; and the information system itself must be usable by customers from the general public.

4.1. Functional Requirements

The information system shall:

1. Store and backup stored LIDAR data and photographs of terrain.
2. Provide means to preprocess (manually or automatically) LIDAR data and photographs required for product processing – calibration, filtration, rectification, quality estimation, stitching, cropping, etc. Resulting data are orthophoto and points cloud.
3. Store, backup, and search orthophoto and points cloud.
4. Provide a public interface to present and sell products to public customers.
5. Provide means to process (manually or automatically) orthophoto and points cloud to prepare products.
6. Deliver products to their final customers.
7. Enable payment for products via the internet.
8. Present public information via the internet.
9. Provide means to perform analytical and research tasks on stored geospatial data for authorized users, independent from products and data.

4.2. Security Requirements

The information system shall:

1. Prevent downloading, manipulation or processing of the stored geospatial data by unauthorized persons or systems.
2. Process secure payments via the internet.
3. Provide means for identification of customers.
4. Prevent loss of expensive data (LIDAR data, OF, points cloud).

4.3. Performance Requirements

As it was not possible to precisely estimate performance requirements, expert estimates were used.

1. Amount of geospatial data may achieve petabytes. Therefore, the storage capacity may not fall under 100 terabytes; the storage must be scalable and distributed.
2. Data processing must be parallel, distributed and scalable.
3. Manual data processing requires prolonged duration of time. It must be finished correctly even in case the system undergoes a restart.

5. Architecture

Architectural design of this information system was especially challenging due to the open definition of the Broker Center. In an ordinary situation, boundaries and capabilities of an information system are provided by limits and requirements of its customer. In case of the Broker Center, the majority of parameters were open, yet also connected. The natural boundaries and limits of the requirements forced the authors of the information system design to define several independent subsystems with the highest isolation and clear responsibilities. The resulting design is independent from underlying technology or from one particular supplier. It is possible to develop the subsystems independently from one another, by different parties. In each subsystem, security requirements will be addressed using methods that are appropriate for the chosen technology.

5.1. Functional Units

Based on the discussed requirements the authors identified the following functional units (Figure 1 – Basic functional units with a communication protocol proposal.):

1. Web Shop – a public internet site to present public information (news, marketing, etc.) to the general public; and to sell products to customers. A customer wishing to purchase a product registers an order and pays electronically via the site.
2. Data Storage – a storage point designed to store and backup LIDAR data, orthophoto and points cloud. The Data Storage interacts with human users and allows them to manage data (add, delete, etc.). It also serves as an interface for other subsystems to access LIDAR data, orthophoto and points cloud. It allows data search. It enables attachment of additional attributes to imported data. Data compression has to be considered [2].
3. Virtualization System – a system that provides processing power in the form of a virtual machine.
4. Control Center – a system center designed to control and check the performance of all customer order processing steps. It provides an interface for the Web Shop to add product orders. It interacts with all subsystems and human operators.

There were more units defined in detail; however, they are beyond the scope of this article.

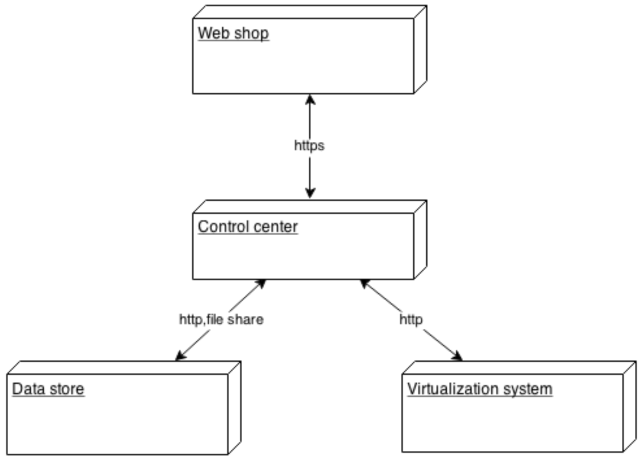

Figure 1. Basic functional units.

5.2. Actors, Use cases and Processes

Two groups of human actors involved in the operations of the Broker Centre information system were identified: internal human actors and external human actors.

External human actors access the information system of the Broker Center via the internet, through the public internet site of the Web Shop. The purpose of the information system is to fulfil their needs for information and purchase of products.

1. The General Public. The information system is designed to provide them with information about the Broker Center, its products and services.
2. Broker Center Customers. Prospective customers register in the information system through the public internet site, view its content and use the site by placing orders, paying for and retrieving their purchased products.

Internal human actors provide manual functionality for the Broker Center. Communication between internal human actors and the Broker Center runs in a variety of ways, including e-mail and the Center internal web site.

1. Data importer imports new raw and preprocessed data into the data store.
2. Data manager administers the stored data. The information system allows data manager to list and delete data, as well as manage additional data attributes.
3. Data operator manually processes the stored data. The information system allows data operator to download and process source data and store product data.
4. Delivery manager checks products before delivering them to the customer and performs the process of delivery. The information system provides delivery manager with the data pertaining to all Broker Center products.
5. System administrator manages the information system as a whole and obtains information about the state of the system at any given moment. System administrator uses management tools to control and configure the information system.
6. User administrator manages human users of the information system in their roles of internal human actors.

5.3. Use Cases

There were use cases and processes defined in detail; however, they are beyond the scope of this article.

6. Open Issues

To date, analytical and design phases of creating the Broker Center information system were undertaken. These two phases will be followed by implementation, during which new questions and challenges will arise. At present, there are several known problems requiring resolution, in order for the information system to be completed.

- Precise definition of products, which implies steps to implement the specific data processes.
- Detailed specification of interfaces between the various subsystems.

The key question to answer remains, specifically what kind of data should be stored and processed? It is necessary to define the correct way to store, index and search each kind of data.

7. Conclusion

This article describes the key issues of the analytical and design phases of the Broker Centre information system creation, including its challenges and conclusions. Requirements for an information system for the Broker center were defined. The information system based on these requirements will be able to deliver large amounts of geospatial data to customers. It will store and process LIDAR data and photographs of the Slovak Republic terrain. Its processing power and storage capacity will be scalable according to market demands. The information system will be open to future changes. It is possible to use the same system for scientific research independent of commercial usage.

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Different Allocation Systems

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Abstract Based on the London´s airports example it is obvious that there are differences between 3rd level airports. If the same coordination system would be introduced within various coordinated airports it could lead to various results. The results of analysis of intra-EU route data indicate that larger aircraft have been used at the 3rd level airports and there is no strong evidence of inefficient slot hoarding at these airports, not only before but also after the EC's recognition of secondary slot trading. In contrast, the analysis of slot trading at Heathrow and Gatwick show that slot trading has taken place more likely within alliance and the chances have been very small for carriers to obtain slots from their actual or potential competitors. For the time being, there may be no need for additional regulatory interventions into secondary slot trading as there is little evidence of inefficient slot hoarding. However, the scarce opportunity of slot trading may lead to less intense competition and then to less efficient use of slots in the long run.

Keywords slot allocation, coordination, third level airports, strategy

JEL L93

1. Introduction

Having defined the slot allocation strategies, an airport typology should be developed in order to identify the various airport environments/settings (i.e., airport clusters) within which the strategies will be evaluated. As a matter of fact, different airport environments/settings may exhibit different congestion patterns, delay figures, and traffic characteristics, while they most probably have different objectives and constraints and should comply with different policy priorities. This, in turn, means that they may require different congestion or demand management approaches for the allocation of slots. As a result, it should be examined whether different or a common slot allocation regime should be established and applied to the airport network.

Based on these there are four main types of coordinated airports:

- super hub airports,
- large international hub,
- large national spoke and small national hub,
- small national spoke.

There will be introduced five coordination schemes/strategies:

- semi-current strategy,
- sequential strategy,
- supervised trading strategy,
- congestion pricing strategy,
- radical strategy.

2. Types of the 3rd Level Airports

- 1st type – super hub airports – represents the largest, busiest and the most congested coordinated airports in EU with a worldwide presence and, last but not least, with a strategic role in the European airport network. Practically, the 1st type airports are the primary hubs of the major European airlines (British Airways, Lufthansa, and Air France KLM). Named airlines operate these airports as the major EU hubs by accommodating traffic between mostly international airport destinations.
    - Examples: London Heathrow and London Gatwick, Amsterdam Schiphol, Frankfurt, Paris Orly and Paris Charles de Gaulle

  They are the most severely congested airports, an observation that can be also deduced by the notable unsatisfied demand. On the other hand, despite the experienced lack of capacity, available slots are not efficiently used as reflected on the 20% of slot initially allocated but not eventually operated. This might account for slot complementarity reasons, i.e., airlines acquiring slots but not succeeding to match these slots with the corresponding slots at the destination or origin airport. Finally, the 1st type airports are the most 'captive' airport markets on the grounds that the vast majority of slots are subject to grandfather rights.

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- 2nd type – large international hub - contains major, metropolitan airports of the European airport network acting mostly as large international hubs (at least for certain national carriers) with focus on intra-European routes and a growth potential to establish one of the major European hubs included in 1st type. Practically, the airports included in 2nd type are primary and secondary large hubs of some of the major European airlines, which operate these airports as servers of traffic both among international destinations, as well as between domestic and international destinations.
  - o Examples: Madrid Barajas and Barcelona, Roma Fiumicino, Munich, Brussels, Copenhagen, Malpesa

  Lufthansa, Iberia, and Alitalia are example of based carriers at these airports. Allocated slots practically accommodate the entirety of existing demand expressed by the initially requested slots, which probably accounts for the large airport capacity, as well as the supporting or reliever service that some of these airports provide to 1st type airports. Nevertheless, the same does not hold true for the slot usage, where the highest figure (i.e., 26%) of slot misuse is observed. This could be probably explained by the fact that these airports mainly represent 'captive' markets of certain national/flag carriers who pursue to ensure their market share and foothold on their primary or reliever/supporting hubs. In effect, they overbid in their slot requests, while simultaneously maintaining their historic slots some of which are not eventually operated. Finally, the presence of dominant carriers is further explained by the quite low slot mobility (i.e., 71% of slots are grandfathered), a fact that indicates a rather close and 'captive' market with substantial entry barriers and well-established incumbent airlines.

- 3rd type – large national spoke and small national hub – contains small and medium-sized airports acting mostly as larger (as compared to the 4th type) spokes of the national airport network or small national hubs channelling traffic from the national spokes to international hubs and vice versa.
  - o Examples: Malaga, Thessaloniki, Palma de Mallorca, and Porto as 'large national spokes' and Vienna, Athens, and Lisbon as 'small national hubs'

  The average traffic figures amount at 93 500 aircraft and 8 500 000 passenger movements. No substantial differences in traffic volumes are observed as compared to 4th type airports. Besides, the slightly higher passenger traffic volume and lower aircraft movements seems to account for the national hubbing role for some of these airports (larger average aircraft sizes and load factors). The demand is not sufficiently covered with the use of existing capacity, where average hourly declared capacity is 36 runway movements and the initially requested slots slightly exceed 4.5%. On the other hand, a misuse of slots is also observed, since there is substantial number of slots allocated but not operated in 20%. Finally, only 32% of slots are grandfathered, a fact that indicates a rather open market with a promising growth potential. The latter is further supported by the unsatisfied demand especially for those airports 'small national hubs' aiming to take a hand in the international airport market shifting to 'large international hubs'.

- 4th type – small national spoke - contains small, satellite or regional airports acting as the spokes of their national airport network.
  - o Examples: Dublin, London Stansted, Manchester, Berlin Tempelhof, Berlin Tegel, Turin, Milan Bergamo, Milan Linate, Venice.

  The average number of aircraft and passenger movements amounts at 98 500 and 7 200 000 movements. The demand is sufficiently covered through the existing, relatively small capacity (average hourly declared capacity of 30 runway movements). On the other hand, a considerable misuse of slots is observed since there is a substantial portion 15% of slots that were initially allocated but not eventually operated. As well most of the operated slots represent historic usage rights.

3. Coordination Schemes

Coordinated airports were divided into four types/categories before; therefore, the coordination scheme/strategy for every airport type will be introduced here. These strategies are adapted to airports conditions and their needs for coordination and slot allocation. It is not exactly set which coordination strategy is for which coordinated airport type. But airports with low slot mobility could choose from strategies where primary and secondary trading is allowed.

- Semi-current strategy - involves the minimum contrast from the current coordination system on the grounds that it fully maintains the overriding principle of historic slot holdings based on grandfather rights. Basically, this scheme consists of:
  - o Grandfathering – yes
  - o Centralized trading with policy criteria – yes
  - o Primary trading – no
  - o Secondary trading – no
  - o Auctions – no
  - o Congestion fee – no
  - o Recycling – yes

- Use it or lose it rule – yes
- Policy-designated slots – yes
- All slots – yes, only pool

- Sequential strategy - involves a conservative approach albeit with a more clear orientation to market mechanisms and a slightly more drastic revision of the status quo especially with regards to secondary allocation. In principle, it also retains the grandfather rights in the primary allocation process; however, it attempts an application of market mechanisms in two parallel directions. Besides grandfather rights, the remaining slots will be auctioned at the airport level with monetary trading between airlines being also allowed on a secondary level. In particular:
  - Grandfathering - yes
  - Centralized trading with policy criteria – no
  - Primary trading - no
  - Secondary trading - yes
  - Auctions - yes
  - Congestion fee - no
  - Recycling - yes
  - Use it or lose it rule - yes
  - Policy-designated slots – yes
  - All slots – yes, only pool
- Supervised trading strategy - essentially combines conservative and innovative elements in one strategy. In particular, it retains with slight modifications/adaptations the principle of grandfather rights, but simultaneously allows full primary and secondary monetary trading based on bilateral negotiations either between the airport and airlines (primary trading) or between airlines (secondary trading). The characterization 'supervised' trading stems from the principle that although full trading is allowed, primary allocation is self-controlled by the historic slot holdings, which could be also subject to monetary trading. This strategy consists of:
  - Grandfathering - yes
  - Centralized trading with policy criteria – no
  - Primary trading - yes
  - Secondary trading - yes
  - Auctions - no
  - Congestion fee - no
  - Recycling - yes
  - Use it or lose it rule - no
  - Policy-designated slots – yes
  - All slots – yes
- Congestion pricing strategy - represents the most direct pricing method for addressing the real causes of the mismatch between capacity and demand for airport operations. Under the congestion pricing strategy, grandfather rights will be abandoned and a congestion-based scheme with fees varying with congestion throughout the day will be set by an administrative authority. In particular:
  - Grandfathering - removed
  - Centralized trading with policy criteria – no
  - Primary trading - no
  - Secondary trading - no
  - Auctions - no
  - Congestion fee - yes
  - Recycling - no
  - Use it or lose it rule - no
  - Policy-designated slots – yes
  - All slots – yes
- Radical strategy - represents the opposite extreme faced with the 'Semi-current' and the 'Sequential' strategy on the continuum of the proposed strategies. Grandfather rights will be abandoned with the entire slot pool being allocated by means of market-based instruments (decentralized auctions accompanied by secondary trading). Radical strategy consists of:
  - Grandfathering - removed
  - Centralized trading with policy criteria – no
  - Primary trading - no
  - Secondary trading - yes
  - Auctions - yes
  - Congestion fee - no
  - Recycling - yes
  - Use it or lose it rule - no
  - Policy-designated slots – yes
  - All slots – yes, only pool

There are 1st type airports called super hubs where the grandfathering slots exceed 99% of total slots. At these airports two strategies of the above mentioned could be recommended where this historic rule is removed (congestion pricing or radical strategy). After closer look at coordination statistics of every airport it is possible to adopt one or combination of more strategies.

4. Conclusions

Within airport slot researches there was question about the need for coordination strategies and it showed that the demand for differentiation of coordination schemes is low. The main reason of less demand for strategies is because of today coordination, which is still waiting for amendments. After the innovation of current system it is possible to think about more than one coordination scheme for 3rd level airports.

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Choosing the Suitable Method for Multimodal Logistics Object Location in the Slovak Republic and Setting up the Criteria Matrix

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Abstract This paper deals with the choosing of a suitable method for multimodal logistics object location in the Slovak Republic. The paper also describes several methods concerning the multimodal logistics object location in particular area, determines the crucial method related to this issue and presents setting up the criteria matrix for the needs of this object location in the Slovak Republic.

Keywords Multimodal logistics object, location, criteria matrix, method, variant, criterion

JEL R49

1. Introduction

Choosing the appropriate area for multimodal logistics object location can be considered a decision problem.

The decision means in a given situation choosing one option from a list of potentially viable variants against a large number of criteria.

Next to the list of criteria indirectly forming the objective of the decision analysis it is necessary to have a list of variants from which to choose. Cases where a clearly defined list of potential variants is available are more the exception than the rule. This list can be explicitly specified as the sum of a finite number of options, or specify the conditions that are considered acceptable and with which the decision options must comply.

If there is a list of criteria and a list of decision variants, it is necessary to consider in detail what form the final decision should take. If we insist that it is really necessary to choose only one optimal variant, we need to accept that in typical cases we want to get something out of unreliable and insufficient information that is almost certainly not included. For a task formulated in this way there is a requirement to create the order of variants.

2. Overview of Several Methods for Multimodal Logistics Object Location in Particular Area

Methods for the selection of a variant (variant for multimodal logistics object location) are divided depending on what information about the preference among the criteria is required [1-3]:

1. Methods not requiring information about criteria preference.

Methods that do not require information about the preference between criteria are very simple and in their plain form are rarely used.

2. Methods requiring aspiration level of criteria.

For methods that are based on work with aspiration information on preferences between criteria, it is characteristic that they do not try to transform the information of a user into a weight vector. Information about the importance of the criteria is expressed as the aspiration level of the criteria. These methods are useful in cases where aspiration values of criteria are known and cardinal evaluation of the variants according to individual criteria can be used.

3. Methods using ordinal information about the criteria.

Methods working with ordinal information about the criteria or variants require a specification of the order of criteria importance and the order of variants according to individual criteria. Some methods are very simple and the results are more or less indicative, others are quite complicated and provide a comprehensive view of the problem.

4. Methods requiring cardinal information about the criteria.

There are several methods that require cardinal information about the criteria in terms of weights and about the variants in the form of a criteria matrix with cardinal values. In this area there are three basic approaches to the evaluation of variants, according to:

- Maximizing the benefits,
- Minimizing the distance from the ideal variant,
- Preferential relationship.

2.1. Simple Method of Scoring

This method can be used if the model is specified using only the preference of variants according to individual criteria and criteria preferences are not known [1-3].

Appropriateness of method - Using the method in this paper is inappropriate.

2.2. Simple Method of Ranking

The method can also be used if the model is specified using only the preference of variants according to individual criteria and criteria preferences are not known [1-3].

Appropriateness of method - Using the method in this paper is inappropriate.

2.3. Lexicographical Method

The lexicographical method is based on the principle that the most important criterion has the greatest influence on the choice of an multimodal logistics object location variant. Only in cases where several variants are rated the same is the next most important criterion taken into account.

If an alternative variant is not selected on the basis of this second criterion, the third most important variant is taken into account, and so on. The algorithm stops at the moment when only one variant is selected or when all criteria taken into account have been considered. The alternative variants are then all those that remained equally evaluated after the last criterion [1-3].

Appropriateness of method - Using this method in this paper is inappropriate because it does not take into account values obtained by other criteria.

2.4. Permutation Method

With this method it is important to know the order of importance of individual criteria. Further, it is important to realize that the number of variant permutations *m* is *m!*, which is a major drawback of this method. For this method it is necessary to know either the weights of individual criterion or at least the order of their importance [1-3].

Appropriateness of method - Using this method in this paper is inappropriate.

2.5. Oreste Method

The method requires as input only ordinal information on criteria and variants. The investigator is required to complete quasi-ordering of criteria and to complete quasi-ordering of variants according to individual criteria, i.e. indifference of criteria and variants is permitted [1-3].

First, the distance of each variant according to each criterion from the fictional start is determined (order numbers of the fictional variant and fictional criterion are 0). On the basis of this calculated distance, the variants are arranged according to certain rules.

Appropriateness of method - Using the method in this paper is inappropriate.

2.6. Topsis Method

The TOPSIS method is one of the methods where the evaluation of options is performed by comparison with ideal variants. To express the distance between variants, different units are used. The TOPSIS method is based on the classical Euclidean metric space [1-3].

Appropriateness of method - Using this method in this paper is less suitable.

2.7. Weighted Sum Analysis – WSA

The weighted sum method requires cardinal information, criteria matrix *Y* and a vector of criteria weightings *v*. It constructs the overall rating for each variant and so it can be used for finding one of the most appropriate variants as well as for arranging variants on a scale from the best to the worst [1-3].

With this method we work with the weights of individual criterion which are either entered or estimated appropriately (see previous scoring method for determining criteria weightings). Thus we get the weightings $v=(v_1,v_2,...,v_k)$ for *k* of maximization criteria [1-3].

The method of weighted sum then maximizes the weighted sum, i.e.:

$$\sum_{j=1}^{k} v_j r_{ij}. \qquad (1)$$

Hence, we calculate the value of the weighted sum for each variant and, as a compromise variant, select the one with the highest weighted sum.

Appropriateness of method - Using the method in this paper is appropriate because it constructs the overall rating for each variant.

2.8. AHP Method

This method provides a framework for making effective decisions in complex decision-making situations, helping to simplify and accelerate the natural process of decision making. AHP is a method of decomposition of a complex unstructured situation into simpler components, thereby creating a hierarchical system for a problem [1-3].

At each level of the hierarchical structure the Saaty method of quantitative pairwise comparison is used. Using subjective ratings of pairwise comparison, this method then assigns quantitative characteristics to each component indicating their importance. Synthesis of these evaluations then determines the component with the highest priority which the investigator focuses on in order to obtain a solution to the decision problem [1-3].

The arrangement of the individual levels of hierarchical structure corresponds with the arrangement from general to specific. The more general the elements in relation to the given decision problem are, the higher they are in the hierarchy associated with the problem and vice versa [1-3].

Appropriateness of method - Using the method in this paper is less suitable.

2.8. Ardolana Method

The Ardolana method is one of the heuristic methods which is used to find the optimal placement for the deployment of objects in an area according to certain criteria. Calculations for the optimal allocation of objects are carried out by analyzing all the criteria that are to some extent able to influence the choice of allocation [1-3].

Appropriateness of method - Using the method in this paper is less suitable.

3. Choosing the Crucial Method

The selection of the appropriate method depends on the point of view of the investigator interested in the subject. Operational analysis methods from the field of graph theory deal with classical solutions for the allocation tasks. Most of the tasks from a real environment are too complex in terms of calculations for the application of these methods. Finding solutions for these tasks cannot be done without the use of a computer or even specialized software. [1].

There are many different methods which can help in the multimodal logistics object location issue (for example, methods of multi-criteria analysis). In practice, however, many methods cannot be used because they do not allow for the processing of all the intricacies intended in this article.

Many methods cannot be applied to the multi-criteria function in our case. Another significant problem area for the application of certain methods is that we do not know the details of the customers and users of multimodal logistics object, which we could have analyzed [1-3].

On this basis it was decided to use the weighted sum method - WSA, which appears to be relatively easy to handle and easy to apply to the complex and difficult task of multimodal logistics object location.

4. Setting up the Criteria Matrix for the Needs of Multimodal Logistics Object Location in the Slovak Republic

In the theory of Multiple Criteria Decision Making we work with a general number of criteria *k* and with a general number of *p*. The value achieved by variant *i* or *j-th* criterion is labelled as y_{ij} and is called the criterion value. The next step is to arrange these values into a matrix which we call the criteria matrix. The rows of the criteria matrix are formed by the individual variants. The columns of the criteria matrix correspond with the individual criteria [1].

The criteria matrix, therefore, has the following form (*Figure 1*):

$$\begin{pmatrix} y_{11} & y_{12} & \cdots & y_{1k} \\ y_{21} & y_{22} & \cdots & y_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ y_{p1} & y_{p2} & \cdots & y_{pk} \end{pmatrix}$$

Figure 1. The general form of the criteria matrix

Source: [1]

4.1. Identification of variants

In stage one it is necessary to identify a set of variants from which the final solution will be chosen. The regions of Slovakia where the multimodal logistics object should potentially be placed were identified as those of: Bratislava, Trnava, Trencin, Nitra, Zilina, Banska Bystrica, Presov and Kosice.

For a more accurate result it would be more appropriate to look at district level, but at this level it would be very difficult to obtain data to fulfil the criteria matrix (an essential part of multi-criteria analysis) because most of the data required is not available at district level.

4.2. Establishment of a set of criteria

Stage two of the process of multi-criteria analysis involves establishing a set of criteria which influence the process of decision making in the selection of variants. [4].

From the point of view of formality it is necessary to differentiate the criteria according to the type of preference and the way (form) of expressing and measuring the results of evaluations based on such criteria. Criteria according to their type preference can be placed in order of [5-6]:

- Increasing preference (maximization, profit) - in which higher values are preferred over lower ones,
- Decreasing preference (minimization, loss) - which are the opposite of the above,
- Alternating preference - preference changes when a certain value is achieved.

Criteria by way of expression and measurement of evaluations of results [5-6]:

- Quantitatively, the values of which can be expressed numerically by the number of units of measure,
- Qualitatively, which can only be expressed verbally, i.e. degrees of quality and a description of their intensity.

After determining the objectives of the analysis of available knowledge, relevant to this article, 6 criteria from socio-economic and transport areas were defined. For these criteria critical data were obtained based on the study of the functions and perspectives that are related to the activities carried out in an multimodal logistics object. Due to the prerequisite that all the data (associated with different factors) should be related to the same time period, only data collected for 2010 appears in this article.

For clarity, the criteria (factors) are summarized in the following table (*Table 1*). *Table 2* shows the specific values of criteria related to individual variants (regions in the Slovak Republic) and it is also the criteria matrix for the purpose of this article.

Table 1. Overview of criteria related to the solution of the problem of multimodal logistics object location

Criteria	Acronym (designation)
GDP per capita (PPS)	GDP
Amount of transported goods via public roads (thousands tonnes)	TGR
Number of small and medium size companies (< 250 employees)	NSE
Population size	NP
State of road network (km)	RN
Regional connections with network of railway lines AGTC	AG

Source: authors according to [3]

Table 2. Actual values of criteria related to individual variants (criteria matrix)

Variant \ Criterion	GDP	TGR	NSE	NP	RN	AG
Bratislava	43063	8255	49420	628686	241.75	3
Trnava	20078	5651	13136	563081	360.87	3
Trencin	15823	8921	11781	598819	508.52	2
Nitra	14841	2875	14301	704752	517.99	2
Zilina	15826	4320	13390	698274	593.54	2
Banska Bystrica	13215	3968	12525	652218	733.89	0
Presov	10104	4258	13120	809443	715.43	2
Kosice	14109	6369	14744	780000	371.88	2

Source: [7-8]

4.2.1. Transfer of Criteria to the Same Type

For the purposes of tasks related to the criteria matrix it is appropriate that all the criteria are of the same type (minimization or maximization). Transfer of the criteria to the same type is not difficult because each minimization criterion can be easily converted to maximization criterion [1,2].

1. The scale is given by the nature of the issue. In this case we take the maximum value that can be achieved, and subtract from it the value of the criterion.
2. The scale is not given. In this case, we find the variant with the highest (worst) value and subtract from it the value of the criterion. This step can be presented as protection against the worst variant.

In our case it is not necessary to perform a modification at any criterion, because all the criteria are of the same type (maximization).

4.2.2. Ideal and basal variant

Ideal variant is the best option which can be theoretically or practically achieved.

1. Relative (highest in criteria matrix for a given criterion),
2. Absolute (highest theoretically possible value).

In our case (*Table 3*):

Table 3. Ideal variant

Criterion	Ideal value
GDP	43063
TGR	8921
NSE	49420
NP	809443
RN	733.89
AG	3

Source: authors according to [3]

Basal variant is the worst variant which can be theoretically or practically achieved (*Table 4*).

1. Relative (the lowest value in the criteria matrix for a given criterion),
2. Absolute (the lowest theoretically possible value).

Table 4. Basal variant

Criterion	Basal value
GDP	10104
TGR	2875
NSE	11781
NP	563081
RN	241.75
AG	0

Source: authors according to [3]

4.2.3. Normalization of criteria matrix

If we know the ideal and basal variants, we simply normalize the criteria matrix. All values in the criteria matrix will be in the interval <0,1>, the ideal value of the criteria matrix will then be represented by the number 1 and the basal by the number 0. An important feature of this normalized criteria matrix is that it is completely independent of the units [1,2].

If we mark the basal value for criteria j as D_j and the ideal value for criteria j as H_j then the normalized criteria matrix (r_{ij}) arises from the initial criteria matrix (y_{ij}) as follows:

$$r_{ij} = \frac{y_{ij} - D_j}{H_j - D_j}. \quad (2)$$

In our case, to normalize the criteria matrix the following steps must be performed:

Having a criteria matrix for maximizing criteria, we add lines with the ideal and basal variants (*Table 5*).

Table 5. Adjusted criteria matrix with auxiliary lines with the ideal and basal variants

Variant \ Criterion	GDP	TGR	NSE	NP	RN	AG
Bratislava	43063	8255	49420	628686	241.75	3
Trnava	20078	5651	13136	563081	360.87	3
Trencin	15823	8921	11781	598819	508.52	2
Nitra	14841	2875	14301	704752	517.99	2
Zilina	15826	4320	13390	698274	593.54	2
Banska Bystrica	13215	3968	12525	652218	733.89	0
Presov	10104	4258	13120	809443	715.43	2
Kosice	14109	6369	14744	780000	371.88	2
H_j	43063	8921	49420	809443	733.89	3
D_j	10104	2875	11781	563081	241.75	0
$H_j - D_j$	32959	6046	37639	246362	492.14	3

Source: authors according to [3]

$$r_{i1} = \frac{y_{i1} - 10104}{32959}, \quad r_{i2} = \frac{y_{i4} - 2875}{6046},$$

$r_{i3} = \frac{y_{i6}-11781}{37639}$, $r_{i4} = \frac{y_{i7}-563081}{246362}$, $r_{i5} = \frac{y_{i9}-\frac{24175}{100}}{\frac{49214}{100}}$, $r_{i16} = \frac{y_{i10}}{3}$.

According to the above formulae we set up the required matrix (*Table 6*):

Table 6. Normalized criteria matrix

Criterion / Variant	GDP	TGR	NSE	NP	RN	AG
Bratislava	1	0.890	1	0.266	0	1
Trnava	0.303	0.459	0.036	0	0.242	1
Trencin	0.174	1	0	0.145	0.542	0.667
Nitra	0.144	0	0.067	0.575	0.561	0.667
Zilina	0.174	0.239	0.043	0.549	0.715	0.667
Banska Bystrica	0.094	0.181	0.012	0.362	1	0
Presov	0	0.229	0.036	1	0.963	0.667
Kosice	0.122	0.578	0.079	0.881	0.264	0.667

Source: authors

5. Conclusion

In order to accomplish all steps of the multi-criteria evaluation of variants the above mentioned procedures should be followed by the determination of criteria weightings.

This step can be made using the Saaty pairwise comparison method. This method is able to determine final values of the vector of weights of individual criterion.

Subsequently, the most appropriate variant for the multimodal logistics object location in the Slovak Republic can be determined. One possible approach is to multiply the normalized matrix by the vector of weights indicated by Saaty method. But this article does not deal with this part of the multi-criteria evaluation of variants issue.

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