Technological Tools For Digital Transformation In Passenger Transportation Systems

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**Abstract.** This article analyzes the main organizational tools of digital transformation in urban passenger transportation systems-"digital services", as well as the quality of functional hardware, software, and software modules of each of them in a technological aspect. Based on the research data obtained during the monitoring of urban passenger transport, it is possible to assess the current state of the transportation system with high accuracy, taking into account social and economic factors, to forecast it in advance for a certain period of time, as well as to make effective management decisions

**Keywords:** digital services, city passenger transport, centralized automated management system, information and payment system, MaaS, hardware and software modules, monitoring model

# INTRODUCTION

The primary organizational tools for digital transformation in passenger transportation systems are "digital services," each of which is technologically implemented through functional hardware-software and software modules. The distinctive features of applying digital technologies are explained by several advantages of information properties converted into digital format:

1) the ability to transmit encoded information using various physical carriers;

2) the possibility of disseminating information by copying it without compromising its quality and accuracy;

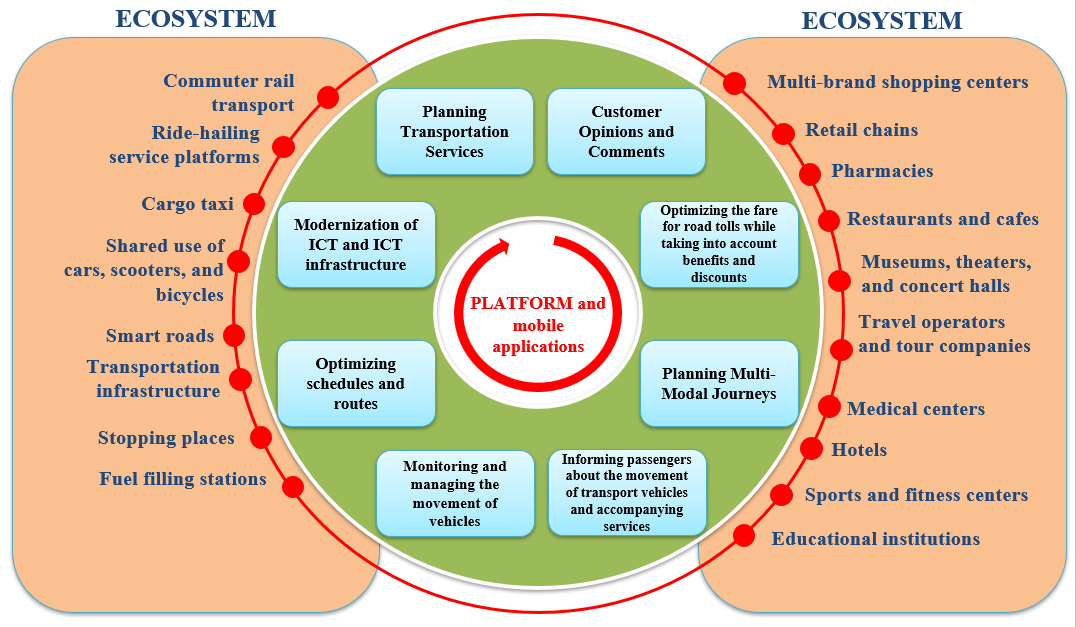
3) the capability to increase information transmission speed multiple times due to higher recording density, and so on.

The development of digital formats for recording large volumes of data and qualitative changes in the process of information transmission has led to the emergence of a new scientific field - "digital economics" [1].

Currently, numerous definitions of the "digital economy" have emerged. Most of them are based on the active implementation of the Internet, mobile information networks, and online work capabilities, which enable the introduction of electronic document management, creation of new business models, restructuring of interaction mechanisms between markets and consumers, and so on. Analysis of these approaches to defining the "digital economy" shows that the listed innovations are merely the result of the "digitalization" process, with each highlighting and emphasizing its significant advantages [2].

Main section. The efficiency, convenience, and safety of regional and urban passenger transport can be enhanced through the application of digital transformation principles to technological and management processes. A digital platform is formed from a typical set of digital services and hardware-software modules, to which regional systems for ensuring population mobility, mobile and external services are connected. This creates an ecosystem (Figure 1) with passengers at its center, surrounded by various services that provide the main target functions (convenience, safety, and efficiency) [3].

Traditional concepts separately consider transport and passenger traffic, road infrastructure, passenger transportation quality (satisfaction), motor transport enterprises, and other objects that play an active role in the formation of the transportation ecosystem. Due to the rapid development and implementation of digital information technologies, new opportunities have appeared in the organization and management of passenger transportation. At the initial stage of developing each service, the target states are described.



**FIGURE 1.** Digital platform for the territorial mobility ecosystem

A modern approach to ensuring citizens' mobility in transport centers on the individual, around whom all services are built to facilitate their transportation from point (A) to point (B). When transitioning to the level of passenger transportation operators, the process should be viewed as the task of transporting groups of citizens who need to move from areas near point A to areas near point B. Proximity is understood in a mathematical sense within space-time (i.e., taking into account positioning and coinciding with passengers' idle time). In the general formulation of the problem, it is also necessary to take into account the transfer point S, as well as the passenger's travel time when switching from one mode of transport to another. In the current situation, where route planning only considers routes with fixed trajectories and schedules, accounting for transfers mainly involves synchronizing the arrival time at the transfer point with the departure time from the transfer point, and assessing the risk of delay and the potential need to modify the travel plan.

In the case of integrated use of MaaS technologies and vehicles with both fixed and flexible schedules, the situation changes significantly, requiring new approaches to solve the problem. In this context, considering regional characteristics is particularly important. The unique aspects of MaaS technology necessitate the implementation of new methods for managing and regulating transportation based on digital systems. The structure of processes in motor transport companies may undergo substantial changes, where the optimization of vehicle movement leads to the need for reorganizing vehicle fleets. The strengthening of the operator's functional role is becoming increasingly evident. This role encompasses ensuring information exchange, planning, accounting for the volume of transport work completed, considering passenger suggestions and complaints, monitoring technological processes at all levels, and more. The operator's functions include: making management decisions at operational and medium-term levels, as well as preparing proposals for executive bodies of state authority regarding strategic management decisions. Thus, the target functions of all participants involved in providing transportation (carriers, operators of the transportation system and road transport infrastructure facilities, regulators, financial service partners, and others) should be aimed at maximizing citizen satisfaction and be aligned with the target functions of passenger services.

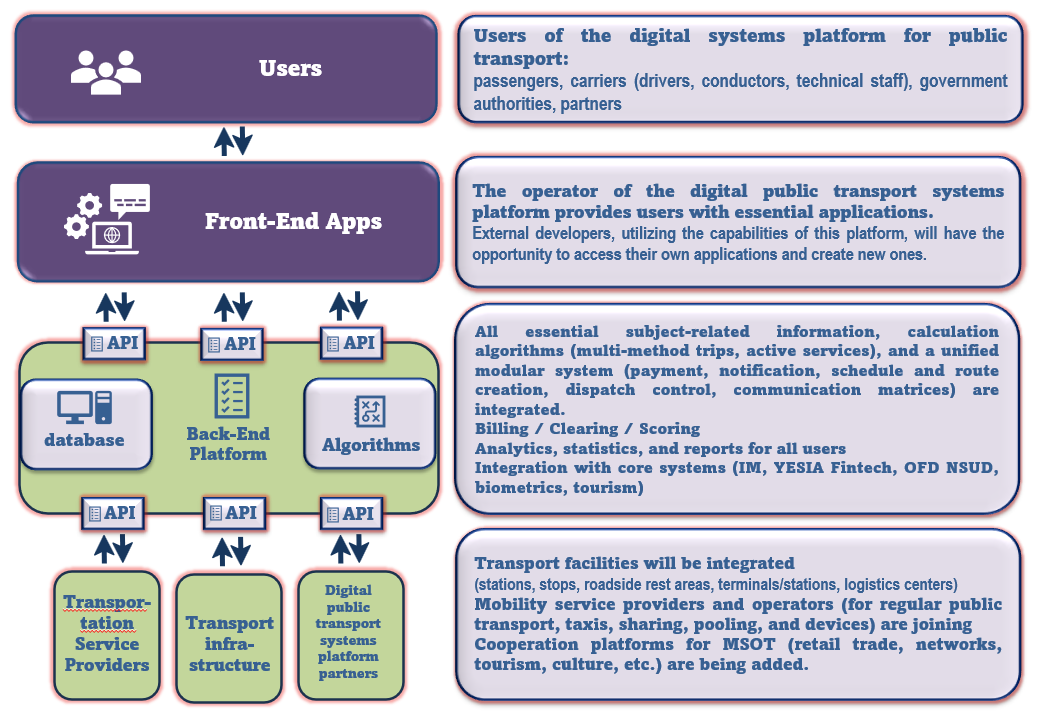
This is precisely the distinctive feature of using digital services: passengers form requirements for their journey, and as a result, the process of providing transportation services should adapt flexibly, taking into account the passenger's wishes and other circumstances.

The concept of a digital transport ecosystem is based on envisioning a modeled system as a set of digital services combined in various configurations to fulfill targeted functions. The center is designed for one or more participants or external partners and comprises functional service modules utilized in various digital services. The division into digital services and modules is largely conditional, but it allows for the creation of a "flexible framework" for designing a regional passenger transportation system.

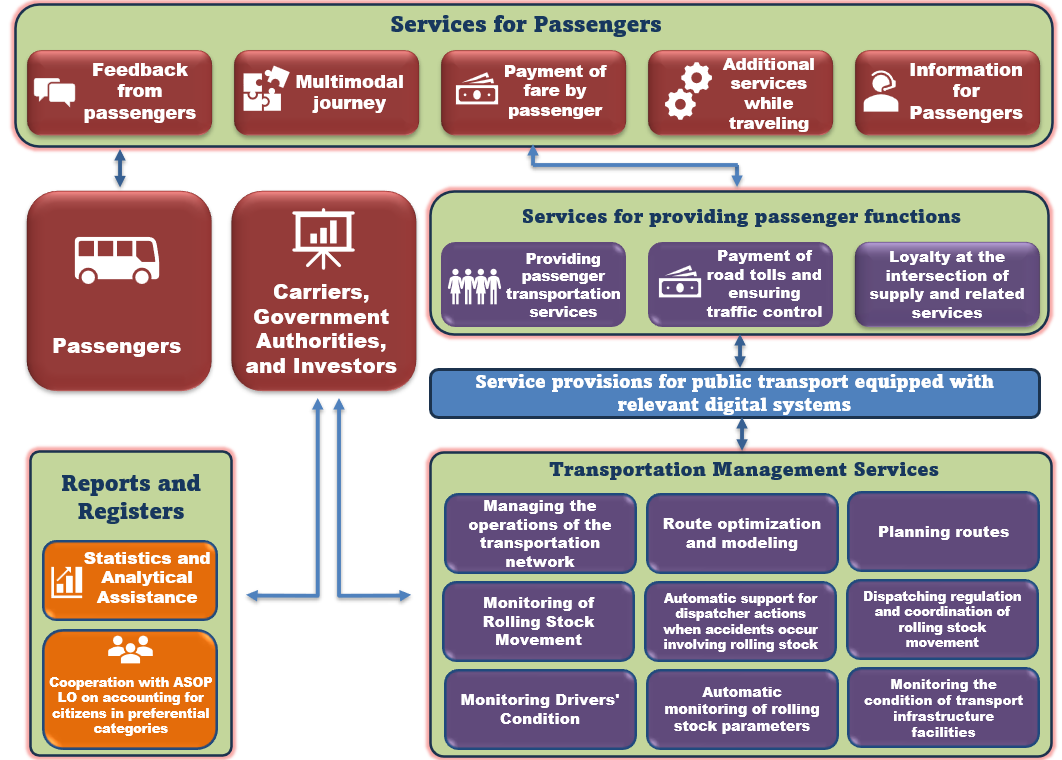
The ecosystem being developed is based on open architecture principles and provides access to a wide range of specialized transport and additional services. The design methodology is founded on a cyclical model, which envisions the gradual development and implementation of digital services in a specific order. This process spans from passenger support functions to those serving carriers and government structures involved in regulating the transportation process. Almost in parallel, with a slight delay in time, the testing and commissioning of services performed in previous stages are carried out. This approach ensures the continuity of development, provides a transition period from the previous generation transport system to a new organizational and technological scheme, and allows for obtaining feedback from users during the design process. Overall, a continuous modernization process occurs throughout the entire life cycle of the system, which significantly extends its lifespan and increases economic efficiency. The opportunity to experimentally develop new solutions in a real environment enables ensuring such an important indicator as citizen satisfaction, particularly from the perspective of considering the opinions of passengers and users.

The success of the concept under consideration and its underlying methods largely depends on the level of analytical description of the objects, their characteristics expressed as criteria, and the methods of interaction between them in the form of targeted relationships and operations performed on the objects. These factors determine the effectiveness of the concept and ensure its practical application. At the same time, there are numerous criteria for passenger travel preferences that travelers should have the opportunity to choose from, and based on which route options are proposed. These criteria include: availability of services for passengers with limited mobility; travel speed; price category; level of service; comfort; safety; number of vehicles; and others.

The technological architecture of the digital platform for ensuring territorial transport mobility of the population (Figure 2) demonstrates an integrated approach to the structure of the transportation system.



**FIGURE 2:** Technological architecture of the digital platform



**FIGURE 3.** Key services for transportation process participants

Within the structure of core services (Figure 3), general services that form the platform's foundation are distinguished. These services include participant registration, administration, information exchange between participants, and intellectual analysis. Other service groups provide the functionality for the information-payment system and the centralized transportation management system.

Three levels of management hierarchy are examined: operational, tactical, and strategic. One of the key requirements when decomposing goals across management levels is to consider not only the higher-level objectives but also the demands of the system's internal elements on the level being analyzed. For each management level, 2 to 3 complex goals are selected that characterize the target state of the chosen level's element. These complex goals are then linked to lower-level objectives according to established interconnections.

In turn, indicators characterizing the degree of achievement are selected for the set goals. Based on the above, a general approach to selecting monitoring parameters is formed:

- identifying the range of stakeholders interested in the activities of the object under study;

- determining the interests and motivations of interested participants;

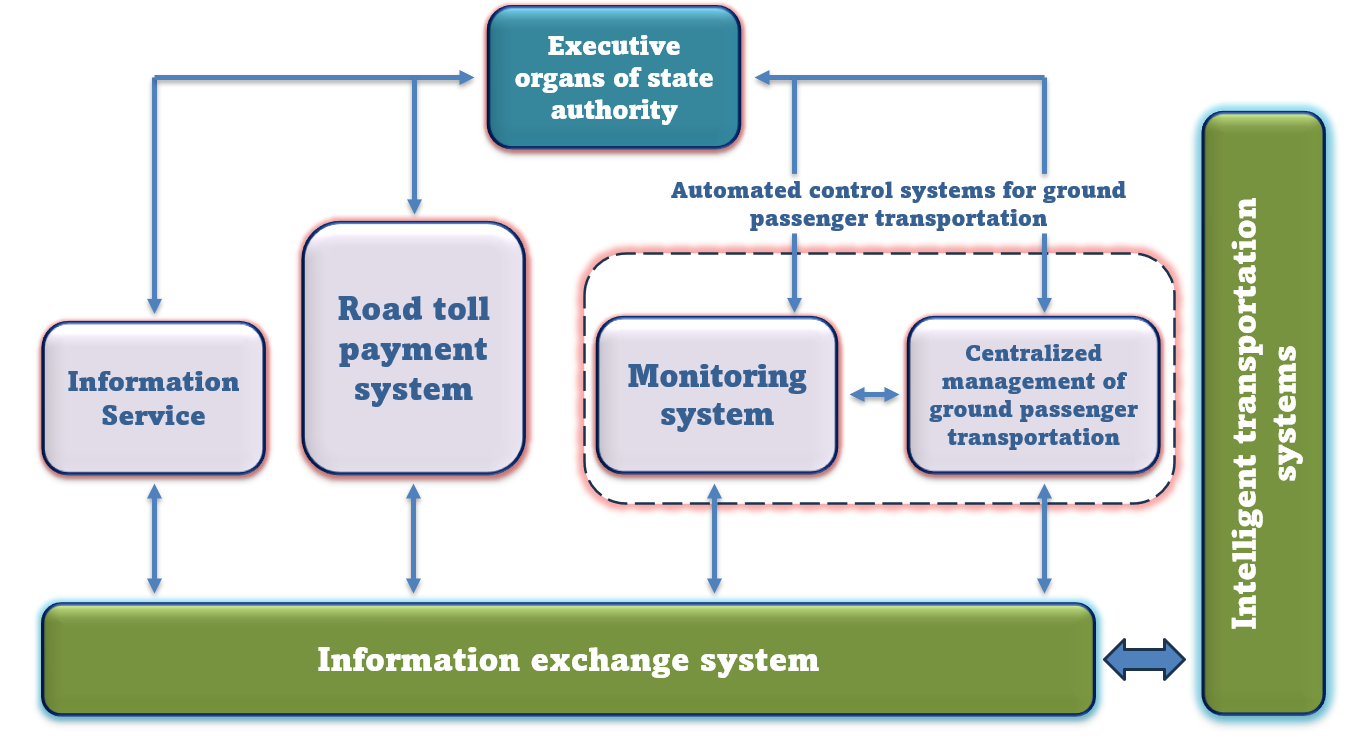
- developing a system of interconnected goals, taking into account different levels, based on incentive factors for stakeholders;

- formulating complex goals.

The functional structure of the passenger transport ecosystem comprises two main subsystems interconnected by external interfaces, forming a unified system (Figure 4):

- "centralized automated management system" - which includes subsystems for comprehensive monitoring and management of passenger transportation;

- "information and payment system" - which provides information services and handles payment and settlement functions for all participants.



**FIGURE 4.** Functional structure of the digital transport ecosystem

The comprehensive service package provides universal, integrated monitoring of the main parameters of centralized management, the system, and individual modules. It offers information and payment functions, as well as analysis for preparing draft management decisions. This includes identifying risks of imbalance and loss of stability, planning routes and schedules, dispatching traffic control, forming and synchronizing multimodal trips implemented according to the MaaS principle, analyzing the volume of carriers' transport operations, and other essential functions. The Center is designed to create systems, each of which is implemented based on several services:

- Automated management of the transport system using MaaS principles;

- Fare payment taking into account multi-zone and multimodal transportation;

- Planning individual journeys for passengers;

- Organizing "flexible routes" for carriers using various modes of transport;

- ensuring synchronization of vehicle and passenger movement trajectories at transport transfer points;

- passenger feedback to the decision-making center for quick and efficient information reception and transmission;

- informing passengers (for example, arrival time of the nearest vehicle, movement options at transfer points, etc.);

- registration and accounting of privileges, tariff schemes, bonuses, and the like;

- compilation of tariff plans (unified tariffs for all types of ground route transport and multimodal travel);

- fare payments (mobile communicators, contactless smart cards, automated cash accounting as basic means of payment.

It can be said that the selection of digital services (particularly their usage options) is determined not only by technological capabilities or third-party experiences, but primarily by the systematized usefulness and efficiency for specific users, taking into account regional characteristics. The uniqueness of the digital transport ecosystem is characterized by the multidimensionality and diversity of its structure, the potential variety in the nature of elements and connections within the system, varying sensitivity to influences, and the asymmetry of potential opportunities for implementing functional and dysfunctional changes. In this context, each element of the system can also be represented as a subsystem. The properties of this subsystem are considered part of the properties of the entire system. At the same time, it is possible to divide the system into relatively independent subsystems (factorization). Additionally, the ability to operate under uncertain conditions and purposefully select algorithms for solving current problems is taken into account. When choosing digital services, mathematical methods of analysis and modeling based on solving multi-criteria optimization problems are utilized [4]. The main indicators that determine and optimize the system's effectiveness are as follows:

- economic efficiency (for carriers and executive bodies of state power);

- transport convenience, assessed by user satisfaction indicators (primarily passengers);

- average travel time per passenger per day;

- KPIs of the activities of government bodies and their subordinate structures

The system optimization methods used in the digital transport ecosystem provide at least the following for the listed indicators:

- assessment of the completeness and reliability of available information;

- analysis of initial requirements reflecting user requests and stakeholder goals;

- analysis of decisions reflecting system behaviors, which should correspond to the target functions of system participants;

- creation of executable models to ensure the system's operation [5].

Digital services that provide the system's target functions are implemented using hardware-software modules. In other words, a mapping is established between the set of digital services used in the design process and the set of hardware-software modules. This allows adapting a specific set of hardware-software modules to the set of digital services selected in the design (Table 1). Through these modules, services are delivered to users via general and specialized telecommunication channels.

**TABLE 1.** Hardware-Software Modules

|  |  |  |
| --- | --- | --- |
| **№** | **Name of hardware-software modules** | **Application** |
| 1 | Dispatcher control panel | Representation of situations in dispatch centers |
| 2 | Passenger display module | Passenger Notification |
| 3 | Mobile applications or messaging platforms | Planning, payment, and notification (on the user's smartphone, tablet, or other specialized mobile device) |
| 4 | Internet portal or website | Using the information resources and administrative functions of the system (Personal computer connected to the Internet) |
| 5 | IRC within the system | Job functions for employee workplaces |
| 6 | Interface for Inter-System Communication | Mobile public communications, specialized communications (for telematics and special purposes) |
| 7 | Special mobile applications | On smartphones and mobile devices (for employees of mobility providers and other participants in the transportation system) |
| 8 | Web access software interfeys | For all participants |

An important component affecting the system's efficiency is the method of selecting hardware components, which is a crucial part of the development methodology. Each hardware-software module has internal software that ensures the implementation of its own operational algorithms and, in conjunction with other modules, provides the target functions of the regional transport mobility system. In particular, an important element of recommendations for selecting hardware-software modules is the concept of transitioning from the currently used special hardware solutions for onboard equipment of passenger vehicles (validators, activators, readers, trackers, etc.) to mass-produced, commercially available mobile devices primarily used by passengers personally. At the same time, a reduction in investment and operating costs will be achieved. Additional opportunities will emerge for the automatic online construction of passenger correspondence matrices, which are necessary for rapid route adjustment and planning, passenger notification, and assessment of transport volume and quality. This assessment will be based on objective indicators from sensors equipped with all modern mobile devices, as well as personal evaluations from passengers (implementing consumer feedback). The use of hardware solutions for mass production allows for easy design of a regional municipal system to ensure population mobility with minimal resource and time expenditures [6].

Mathematical algorithms for monitoring the state of the digital transport ecosystem allow the use of various technological implementations. Depending on the area of activity, parameter monitoring can be fully automatic, semi-automatic, or manual. The most general modules of the system supporting the universal monitoring model are as follows (Fig. 5):

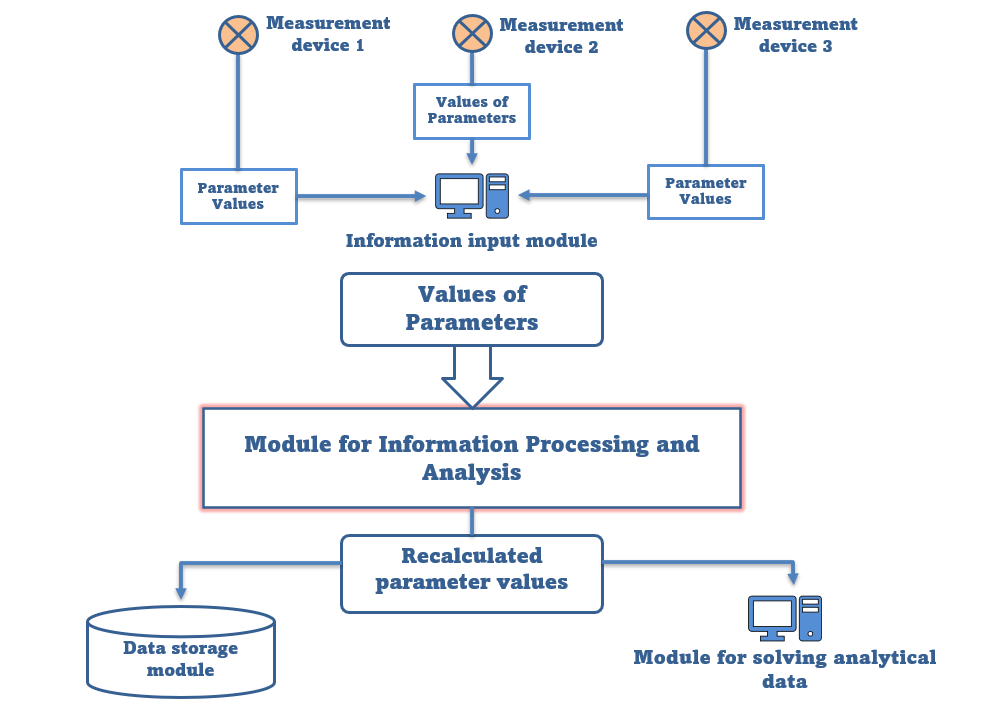
- devices for measuring low-level parameters;

- information input module (it is sometimes advisable to combine parameters measurement and the information input device);

- information processing and analysis module;

- data storage module;

- analytical information output module.



**FIGURE 5.** Conceptual architecture of the monitoring system in the digital transport ecosystem

## CONCLUSIONS

The considered universal monitoring model can be applied to practically all ground urban passenger transport systems and modules. An important advantage of the proposed methodology is the consideration of complexly formed parameters associated with the human factor. In this case, the number of monitoring parameters is minimized. The data obtained during the monitoring allow for a high-precision assessment of the current state of the transport system, taking into account social and economic factors, forecasting ahead of schedule, and making effective management decisions.

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