вила (технические требования) формирования каталога всех объектов модели, координат точек и параметров линков.

Например, для каждой станции разработки *ЦМПР* организуются отдельные хранилища типа: «станционные парки», «изолированные секции», «стрелочные переводы», «светофоры», «граничные точки», «линки», «вагонные замедлители» и др. Вводится признак направления (лево, право) при перечислении точек, определении направления показаний светофоров и в других необходимых случаях. Атрибуты объектов хранилищ позволяют четко идентифицировать каждый объект и получать данные, используемые при решении задач автоматизированного управления подвижными объектами.

Навигационные подсистемы спутникового позиционирования, включающие в свой состав *ЦМПР*, уже разработаны в комплексе МАЛС для нескольких сортировочных станций.

Это создает хорошую основу для реализации интеллектуальных станционных систем с автоматизированным управлением поездными и маневровыми маршрутами. При этом используется техническая база МАЛС, которая дополняется программным обеспечением интеллектуальной системы.

Главной составляющей частью такого программного обеспечения является имитационная модель оперативной работы станции, позволяющая осуществлять прогноз поездных и маневровых передвижений на заданный плановый период, оценивать результаты работы при различной очередности выполнения операций и принимать оптимальные решения. При этом *ЦМПР* дает возможность определять все расстояния намечаемых передвижений по любым маршрутам, а значит, и время их выполнения, что, собственно говоря, и становится основой оптимизации выполнения станционных технологических операций.

Таким образом, разработка в составе МАЛС спутниковой системы позиционирования, включающей в себя *ЦМПР*, обеспечивает решение не только задач по безопасности движения, но и автоматизации оперативного управления работой станций.

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DIGITAL MODELS OF STATION TRACK DEVELOPMENT

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ABSTRACT

In order to use automatic control of train and maneuvering routes it is necessary to position moving objects (locomotives, maneuvered trains, rail cars) at station tracks in real time mode. So there is a need for tools of satellite navigation, intelligent systems based on digital models of station tracks. The article describes approaches of that problem, methods of database development, needed for simulation of system elements as a selection of different types, as well as methods of solution of equations describing trajectories of the axis of rail tracks.

ENGLISH SUMMARY

Background.

Intelligent station control systems (ISS) are intended to considerably enlarge the range of tasks solved automatically from within the set of tasks which refer to technological process and are usually solved in «manual» mode by operational personnel – station and maneuver dispatchers, assistant station-masters, duty yardmasters, tower men, shunting masters.

The existing MALS and GALSR systems provide possibility of automated control of arriving and of breaking down of the trains, as well as of safe maneuvering operations. But the decisions on the priority and timing of train and maneuvering operations are still made by station staff. Station automatic control systems give more data for human decision making, while there are thousand and more decisions made at large stations daily.

One of prerequisites of automatic control of train and maneuvering routes is real time positioning of moving objects (MO) (train and maneuver locomotives, cars) at station tracks. It is necessary so to provide ISS with technical basis of MALS, equipped particularly with subsystem of satellite positioning of MO. Digital model of track development or gridiron of the station (DMTD) constitutes one of the independent elements of the mentioned subsystem.

Objectives. *According to studies and practical expertise, if coordinates are determined by establishing link between satellite and a moving object, then the accuracy of measuring constitutes about several meters. The mentioned level of precision is sufficient for road navigators. But the normal distance between station tracks is about 4–5 meters, and the distance at the points of tracks joining is even less. So such positioning system causes risks of fixing of a MO at neighboring track and not at the correct one, which is not acceptable, particularly according to safety requirements.*

In order to increase accuracy a method of determining of coordinates of MO under so called differential mode is used. Such mode provides for signal reception not only on board of MO, but also by base reference station (BRS) with known geodetic coordinates. In that case, taking into account special mathematical apparatus, precision of determining of coordinates of a MO increases by 8–10 times and becomes acceptable for the objectives of station technological processes' control, as well as for automation of decision making on priority setting and timing of train and maneuver operations. So it is necessary to study processes of organization of such mode of positioning, and to offer relevant equations for its designing and computation, and finally to propose a method of automatic data reception for building of DMTD using locomotives as MO with repeatable trajectories while they are moving by different station tracks.

Methods. *The authors use mathematical apparatus, methods of mathematical statistics and standard Excel statistical and economical software.*

Results. *The necessary components for realization of navigational system of positioning at rail stations are shown in fig. 1.*

Any moving object (e. g. maneuver locomotive at track # 4 in fig. 1) using the proposed mode of positioning could be fixed with sufficient accuracy at different moments of its moving along station tracks. Such moments for instance are illustrated by point 1 with geodetic coordinates X_1 and Y_1, by point 2 (X_2 Y_2), by point 3 (X_3 Y_3). Those coordinates of maneuver locomotive (MO) should be linked to coordinates of station infrastructure.

Coordinates of station tracks and of their joining points together with allocation of switches, isolated joints, limit columns, color light signals and other technological objects should be reflected in DMTD. Substantially DMTD is a basis of geodetic (coordinates) and technological (objects) interrelated data, presented in form of tables and mathematical dependencies that provide decision of management problems.

The tracks of the station and all infrastructural components are represented in DMTD as a database of a set of points of different types, as well as of equations describing trajectories of track axis.

Three types of points are used.

1. Border points. Those points are limits for allocation of MO on the station tracks or the sections there-of (isolating joints of isolated sections of tracks, station borders with adjoining legs, v-blocks of dead-end sidings, derailing switches). This type of points includes also the blades of switches as during maneuver mi-passage a MO should pass over the joint of frame rail to ensure blades' transfer to another position. Temporary border point can be placed at the track point till which the MO can go during track repair works.

2. Track points are represented by two types of points. First one is a projection of track column on the axis of a straight track. The second type is a point to describe coordinates of tracks and possible routes of MO along the sections with isolating switches. To increase accuracy the trajectories of the axis of such track can be described by some sections, allowing therefore using of more simple mathematical dependencies. It is similar for describing of MO moving in curves.

3. Special points describe coordinates of different devices of station infrastructure.

Trajectories of station tracks within the limits of border points respond to equations $Y = f(X)$.

It is possible to use traditional geodetic survey to create digital spatial model of a station. But it requires an increased volume of geodetic works and considerable expenditures. Reduced costs of development of DMTD are ensured by data on location of MO if they are positioned according to fig. 1.

An idea if automatic surveying for development of DMTD is based on the use of locomotives as of MO with repeatable trajectories passing along different station tracks. Navigation antenna is fixed in the center of the top of locomotive edgewise. High frequency cable (1.6 GHz) connects antenna to navigation receiver in the driver compartment. The receiver does measurements with assigned discretion and transmits data to processing block. The coordinates received are stored in special data storage device for every track section necessary for DMTD.

For instance the fig. 2 shows stored data on n points of a certain track section # 5. The volume of sampling from n points within constraint zone a (fig. 2) is determined by the methods of mathematical statistics taking into account admissible probability of limit error and dispersion level (root-mean-square deviation) of coordinates of different points as compared to population mean value.

Using data on n points and real curvature of station tracks, the geometry of their axis lines could be predicted with accuracy (sufficient for practical purposes) using polynomial not higher than of degree 3:

$$Y = f(X) = a_0 + a_1X + a_2X^2 + a_3X^3. \qquad (1)$$

Factors a_0, a_1, a_2 and a_3 can be defined with the help of the method of leastsquare if the condition of minimization of the sum of squares of root-mean-square deviations (dispersions) for n points is respected:

$$S = \sum_{i=1}^{n} (Y_i - a_0 + a_1X_i + a_2X_i^2 + a_3X_i^3)^2 = \min, \qquad (2)$$

where Y_i, X_i – are current coordinates of n points, received through field survey.

Using of standard tools of Excel statistical and economic software permits rapid obtaining of the values of searched factors.

For practical purposes it is useful to present within DMTD station curved tracks between border points as a set of their sections. Every section is defined through border and track points. The number of track points for each section depends on track geometry. More is curvature then more track points are used.

To define discretization (points of location) of the points the authors introduce mathematical criterion, which explicitly (by single-value solution) determines maximum distance L between the points at the track section dependently on the curvature radius R of that section:

$$L \approx 2 \sqrt{R^2 - (R - \Delta)^2}, \quad (3)$$

where Δ – maximum admissible distance of computed points from real geometry of a track section with known curvature.

For DMTD adopted for MALS and GALSR systems criterion $\Delta = 0{,}3$ м. According to (3), for instance, if R = 2000 м then $L \approx 70$ м, if R = 1000 м then $L \approx 50$ м.

Then a track section between border or between border and track, or between track points (including the sections with different curvature which is characteristic of the areas in front of switches and of approaching tracks) can be represented as track sections $A_1 \ldots A_i \ldots A_N$, determined by set of border and track points 1, 2 ... i, (i+1), ... (N–1), N (fig.3).

Such station track sections are called links.

An example of presentation of station tracks and structures (for a limited sector of a station) by points of different type and by links is given in fig.4. Within DMTD the points are identified with coordinates, and the links are identified by values of factors a_0, a_1, a_2 a_3 in equations of a type (1). Using those factors the length of each link can be calculated.

As fig.4 illustrates, the number of points and links for large stations can be rather considerable. That fact explains why a special attention during development of DMTD is paid to organization of data storage. There are special requirements (technical specifications) concerning development of catalogues of all the oblects of a model, point coordinates, links' parameters.

There are separate data storages for each station (e. g. «station shed», «isolated sections», «light signals' etc.). The index of direction (to the left, to the right) is introduced for enumerating of points, definition of signals of light signals etc. The attributes of the objects of storage permit to clearly identify each object and to receive data which are further used to solve problems of automatic control of moving objects.

Conclusions. *Navigation subsystems of satellite positioning, containing DMTD, have already been developed within MALS system for some freight yards. It is a good foundation for realization of intelligent station systems with automatic control of train and maneuver routes. The technical base of MALS is completed by software of intelligent system.*

The main component of the software consists of simulation model of operations of the station which permits to forecast train and maneuver dislocations for assigned planned period, to assess the results of work with different priority of separate operations and to make optimum decisions. The DMTD allows defining of all the distances of future movements by any routes and therefore the time necessary to fulfil them. It constitutes a basis of optimization of station technological operations.

The development within MALS of a satellite system of positioning, including DMTD, contributes to safety maintenance as well as to automation of operational management of stations.

Key words: railway, station, track system, track development, gridiron, digital model, intelligent system, routing control.

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