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SIMULATION MODELING OF GPRS CHANNELS OPERATION IN AUTOMATED DISPATCH CONTROL SYSTEMS

G. Yerkeldesova, A. Turdaliev*
International University of Transport and Humanities, Almaty, Kazakhstan.
E-mail: turdaliev.auezhan@mtgu.edu.kz

Gulzada Yerkeldessova — PhD, International University of Transport and Humanities, Almaty, Kazakhstan
E-mail: erkeldesova.gulzada@mtgu.edu.kz, https:/orcid.org/0000-0001-6527-7180;
Auezhan Turdaliev — D.Sc. (Eng.), Professor, International University of Transport and Humanities, Almaty, Kazakhstan
E-mail: turdaliev.auezhan@mtgu.edu.kz, https:/orcid.org/0000-0003-4092-3507.

Abstract. The article presents a study on the development of simulation models for GPRS channel operation within Automated Dispatch Control Systems (ADCS) for railway transport in Kazakhstan, including High-Speed Railway Transport (HSRWT). The research addresses the optimization of data transmission for navigation and movement coordination of rolling stock, emphasizing the use of mobile communication technologies such as GSM and GPRS. The study develops algorithms for predictive assessment of train location and traffic coordination while optimizing GPRS network resources. A queuing service system (QSS) approach is applied to model GPRS channels, taking into account priority traffic, channel loads, and service delays. Computational experiments conducted using a Delphi-based program demonstrate the adequacy of the developed simulation model, with deviations from experimental data not exceeding 7–9%. The proposed approach improves the efficiency of ADCS and enhances coordination of rolling stock movements. The results have practical significance for further modernization of railway transport systems in Kazakhstan, including the implementation of intelligent digital technologies for high-speed rail transport.

Keywords: GPRS channels, Automated Dispatch Control Systems (ADCS), High-Speed Railway Transport (HSRWT), Navigation data transmission, Queuing Service System (QSS), Traffic coordination, Railway transport modernization

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АВТОМАТТАНДЫРЫЛҒАН БАСҚАРУ ЖҮЙЕЛЕРІНДЕГІ GPRS АРНАЛАРЫНЫҢ ЖҰМЫСЫН ИМИТАЦИЯЛЫҚ МОДЕЛЬДЕУ

Г. Еркелдесова, Ә. Турдалиев*
Халықаралық көліктік-гуманитарлық университеті, Алматы, Қазақстан.
E-mail: turdaliev.auezhan@mtgu.edu.kz

Гульзада Еркелдесова — PhD, қауымдастырылған профессор, Халықаралық көліктік-гуманитарлық университеті, Алматы, Қазақстан
E-mail: erkeldesova.gulzada@mtgu.edu.kz, https:/orcid.org/0000-0001-6527-7180;
Әуезхан Турдалиев — т.ғ.д., профессор, Халықаралық көліктік-гуманитарлық университеті, Алматы, Қазақстан
E-mail: turdaliev.auezhan@mtgu.edu.kz, https:/orcid.org/0000-0003-4092-3507.

Аннотация. Мақала Қазақстандағы теміржол көлігінде, оның ішінде Жоғары жылдамдықты теміржол көлігінде (ЖЖТК) Автоматтандырылған диспетчерлік басқару жүйелерінде (АДБЖ) GPRS арналардың жұмысын модельдеуге арналған симуляциялық модельдерді әзірлеу мәселелерін қарастырады. Зерттеу қозғалысқа қатысатын вагондар мен локомотивтердің навигациялық деректерін беру және қозғалысты үйлестіру процесін оңтайландыруға бағытталған, мұнда GSM және GPRS сияқты ұялы байланыс технологияларының қолданылуы ерекше назарға алынды. Жоба пойыздардың орналасуын болжау және қозғалыс үйлестіру алгоритмдерін дамытуға, сондай-ақ GPRS желі ресурстарын оңтайландыруға арналған. GPRS арналарын модельдеу үшін кезекпен қызмет көрсету жүйесі (QSS) әдісі қолданылып, арнаның жүктемесі, қызмет көрсету кешігулері және басымдық берілген трафик ескеріледі. Delphi тілінде жасалған есептеу тәжірибелері ұсынылған модельдің сенімділігін көрсетті, эксперименттік деректерден ауытқу 7–9%-дан аспайды. Ұсынылған тәсіл АДБЖ тиімділігін арттырады және вагондар қозғалысын үйлестіруді жақсартады. Нәтижелер Қазақстандағы теміржол көлігін, оның ішінде жоғары жылдамдықты теміржолды, интеллектуалды цифрлық технологияларды енгізу арқылы әрі қарай жаңғыртуға практикалық маңызы бар.

Түйін сөздер: GPRS арналар, Автоматтандырылған диспетчерлік басқару жүйелері (АДБЖ), Жоғары жылдамдықты теміржол көлігі (ЖЖТК), Навигациялық деректерді беру, Кезекпен қызмет көрсету жүйесі (QSS), Қозғалысты үйлестіру, Теміржол көлігін жаңғырту

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ИМИТАЦИОННОЕ МОДЕЛИРОВАНИЕ РАБОТЫ GPRS-КАНАЛОВ В АВТОМАТИЗИРОВАННЫХ СИСТЕМАХ ДИСПЕТЧЕРСКОГО УПРАВЛЕНИЯ

Г. Еркелдесова, А. Турдалиев*
Международный транспортно-гуманитарный университет, Алматы, Казахстан,
E-mail: turdaliev.auezhan@mtgu.edu.kz

Гульзада Еркелдесова — PhD, ассоцированный профессор, Международный транспортно-гуманитарный университет, Алматы, Казахстан
E-mail: erkeldesova.gulzada@mtgu.edu.kz, https:/orcid.org/0000-0001-6527-7180)
Ауезхан Турдалиев — д.т.н., профессор, Международный транспортно-гуманитарный университет, Алматы, Казахстан
E-mail: turdaliev.auezhan@mtgu.edu.kz, https:/orcid.org/0000-0003-4092-3507

Аннотация. В статье рассматривается разработка симуляционных моделей работы GPRS-каналов в рамках Автоматизированных диспетчерских систем управления (АДСУ) на железнодорожном транспорте Казахстана, включая высокоскоростной железнодорожный транспорт (ВЖТ). Исследование посвящено оптимизации передачи данных для навигации и координации движения подвижного состава с акцентом на использование мобильных технологий связи, таких как GSM и GPRS. В работе разработаны алгоритмы прогнозной оценки положения поездов и координации движения при оптимизации использования ресурсов GPRS-сети. Для моделирования GPRS-каналов применяется подход системы обслуживания очередей (QSS), учитывающий приоритетный трафик, нагрузку на каналы и задержки обслуживания. Вычислительные эксперименты, проведённые с использованием программы на языке Delphi, продемонстрировали адекватность разработанной модели, при этом отклонение от экспериментальных данных не превышает 7–9%. Предложенный подход повышает эффективность АДСУ и улучшает координацию движения подвижного состава. Полученные результаты имеют практическое значение для дальнейшей модернизации железнодорожного транспорта Казахстана, включая внедрение интеллектуальных цифровых технологий для высокоскоростного железнодорожного сообщения.

Ключевые слова: GPRS-каналы, Автоматизированные диспетчерские системы управления (АДСУ), Высокоскоростной железнодорожный транспорт (ВЖТ), Передача навигационных данных, Система обслуживания очередей (QSS), Координация движения, Модернизация железнодорожного транспорта

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Introduction.

The transport system of Kazakhstan, including railway transport, is an important link of the country's economy. Therefore, ensuring traffic safety, timeliness of cargo and passenger transportation are quite important management tasks of a complex transport process. This task acquires particular relevance in a situation where one of the priority tasks of railway transport development in Kazakhstan is the development of promising high-speed railway transport systems (hereinafter - HSRWT It should be noted that one of the most important subsystems in the data transmission system and HSRWT rolling stock movement coordination are the subsystems of automated traffic coordination based on the use of mobile communication technologies. As a particular example, GPRS data transmission technology can be considered (Akhmetov, 2019: 485).

The basis of the development of an automated system for the HSRWT movement coordination is a communication standard that satisfies the necessary requirements for the operation of the communication system as a whole. Taking into account previous researches in the field of automated dispatch control systems (ADCS) design on railway transport, as well as the results of the work of other authors (Borushko, 2007: 33; Davidsson, 2005: 255; Fay, 2000: 719), it is proposed to use the GSM standard as a mobile communication standard. The use of GSM technology provides information support for the locomotive group through voice transmission, as well as transmission of control messages based on GPRS technology.

Modernization of GSM networks, as well as the creation of networks of the fourth, fifth and subsequent generations, are directly related to the problems of high-quality radio coverage (Borushko, 2007: 33; Davidsson, 2005: 256). The corresponding increase of load, as well as operation in limited frequency bands, necessitates an increase in the controllability of channel resources (CR). The task of assessing the quality of the joint transmission of voice messages and service data packets for HSRWT rolling stock (RS) appears as an accompanying one (Akhmetov, 2019: 485).

Materials and methods.

For the full functioning of ADCS it is necessary to use navigation equipment and on-board intellectual systems (Borushko, 2007: 33), which are installed on the HSRWT means. They provide information on the HSRWT location as well as on operational management decisions. The increase of the amount of HSRWT trains and, as a result, the increase of load on the GPRS and GSM networks requires the use of higher frequencies compared to those commonly used in mobile communication systems. This leads to the need to improve the controllability of CR, and to solve the problems of estimating the existing GPRS system in order to provide the communication subsystem and data transmission for the needs of RWT. For the designed system, there is provided an equal access mode of the HSRWT rolling stock to each of the provided channels. In the ideal case, all users, involved in the HSRWT traffic control system (Borushko, 2007: 34; Davidsson, 2005: 256), should be able to transmit data packets or voice messages. We believe that voice traffic, as of a higher priority, can interrupt the GPRS packets service. In (Borushko, 2007:33; Gapanovich & Rozenberg, 2011: 5) it was proposed to use the term superposition. That is, the superposition determines both the intensity of received packets and those that are re-transmitted, for example, from the accumulator (buffer) of packets. Taking into account the above mentioned, the following such tasks are relevant for prospective HSRWT systems: 1) formalization of navigation data transmission tasks for traffic coordination systems, taking into account optimization of the GPRS network resources use; 2) the task of estimating the capacity and capabilities of the existing GPRS network in Kazakhstan in order to ensure the required quality of service and data transmission speed (Akhmetov, 2019: 485-486).

In (Gapanovich & Rozenberg, 2011: 5; Goldstein & Sokolov, 2010: 300; Mozharova, 2011: 216) it was noted that an important direction for the modernization of existing and in the design of new ADSCs, primarily for HSRWT, are the tasks related to the coordination of the HSRWT trains movement under conditions imposed on solving time constraints.

In (Ning, 2006, 2011) there were analyzed the circumstances that contribute to the imposition of restrictions on the time for solving tasks of RWT RS coordination (including HSRWT). These researches are continuing at the present time, because the task has not lost its relevance.

In (Skalozub, 2013: 100; Arkatov, 2012: 22) the authors conducted a detailed review and analysis of various ADSCs, including the HSRWT. We shoul note that by the analysis of these and other publications (Levin, 2016: 38; Jianjun & Yixiang, 1998) the task of dispatch control and movement coordination in the existing automated dispatch control systems requires the further development of the used mathematical models (Jianjun, 1998).

According to the analysis of a number of publications (Levin, 2016: 38; Jianjun & Yixiang, 1998; Jianying, 2007: 024), it was revealed that a promising direction of the research in this subject area is the organization of assistance in decision making by the driver and the control of the data relevance that are transmitted to mobile means of HSRWT.

Also, as the analysis of the researches showed Jianjun & Yixiang, 1998; Jianying, 2007: 024; Smagulova, 2016: 247; Coll, 1990: 244), there is not well understood the problematics of algorithmization for GPRS channel operation simulation in ADCS, for example, for predictive assessment of the location and coordination of HSRWT traffic, taking into account the optimization of the GPRS network resources use (Akhmetov, 2019: 486).

Therefore, the analysis of previous works in this area confirms the relevance of our research.

The purpose of the work is the development of models and algorithms for automated dispatch control systems on railway transport, including high speed railway transport (Akhmetov, 2019: 486).

In order to achieve the goal of the work it is necessary to solve the following tasks:

- to perform further formalization of the tasks of navigation data transmission for the automated dispatch control system and the subsystem of RS movemnet coordination;

- to improve the algorithm for simulation modeling of the GPRS channel operation in ADCS, in particular, for the predictive assessment of the location and coordination of the HSRWT movement, taking into account the optimization of the GPRS resources use.

Results.

The main technological feature of ADCS in the context of the HSRWT system formation is the need to ensure the control and coordination of the mixed traffic of high-speed, high-speed passenger, cargo (in particular, container or trailer) and other trains. Therefore, the ADCS functions and RWT movement coordination should be linked to the appropriate categories of movement.

The automated workplace (AWP) of the dispatcher (or the client part of ADCS) is a program that is intended for the use on a ordinary PC with access to a public network. There should be noted that the client part of the system can receive information both in real time and retrospectively from the history stored on the database server (DB). Such information, in particular, includes GPS monitoring data on mobile units (MU) of RWT. Data from the database is displayed on an electronic map of the area with reference to a specific MU. This architecture of movement dispatching and coordination system of HSRWT (MDCS) on the basis of the GPS-navigation allows dispatchers by areas of their responsibility quickly to make decisions necessary to eliminate conflict situations.

A distinctive feature of data transmission systems for geographically distributed ADCS is, first of all, the use of wireless communication channels - radio channels, satellite and mobile communication channels, see fig.1.

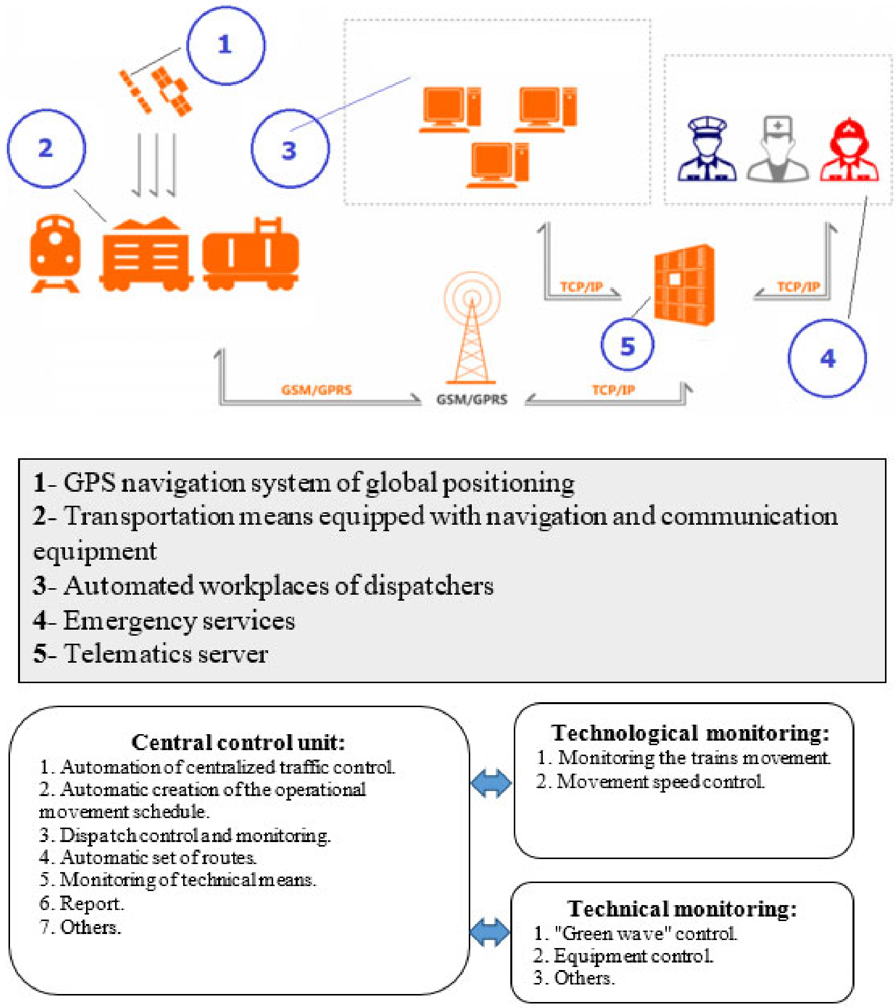

Fig. 1. Scheme of information exchange of the automated dispatch control system and HSRWT movement coordination system (Akhmetov, 2019: 486)

The technology of MSCS exchange information provides for the use of navigation signals from GNSS satellites. Signals are received using special GPS/GSM receivers. Further, the signals are processed and the navigation data in the WGS-84 coordinate system (latitude, longitude, time, etc.) are obtained from the processing results. In this system there are used receivers with a frequency of information update at least 5 times per second (5 Hz), since they provide the necessary accuracy in calculating the location of the RWT object on the map.

Navigation signals are received at a frequency of 1227.6 MHz using GNSS Navstar/GPS. Or at a frequency of 1200 MHz for GLONASS. The use of GPRS technology on RWT has led to a significant increase of the transmission capacity of data transmission channels (Akhmetov, 2019: 486; Borushko., 2007: 35; Smagulova, 2016: 247; Coll, 1990: 244).

If EDGE technology is used (Fay, 2000: 719; Gapanovich, 2011: 5; Goldstein, 2010: 300; Mozharova, 2011: 216), which is not very different from GPRS, it can also be implemented on existing networks. Modernization of MDCS at the implementation of EDGE will entail the need to solve other problems. This, in particular, relates to issues that relate to changes in coding schemes, as well as to the modernization of software on network components.

In connection with these features of modern ASDUs functioning on RWT, the task of communication subsystem optimization with respect to such parameters as time, cost and reliability of message delivery has a particular importance. The fig. 2 shows the structure of the navigation data acquisition subsystem. The scheme has a hierarchical structure, the elements of which are MU of RWT, the railway dispatcher's AWP, the railway dispatcher's AWP for Kazakhstan, message commutation centers (SSGN) and communication channels. At the top level of the hierarchy is the dispatcher's AWP of the corresponding dispatcher zone (DZ), and the lower level of the hierarchy is represented by the MU.

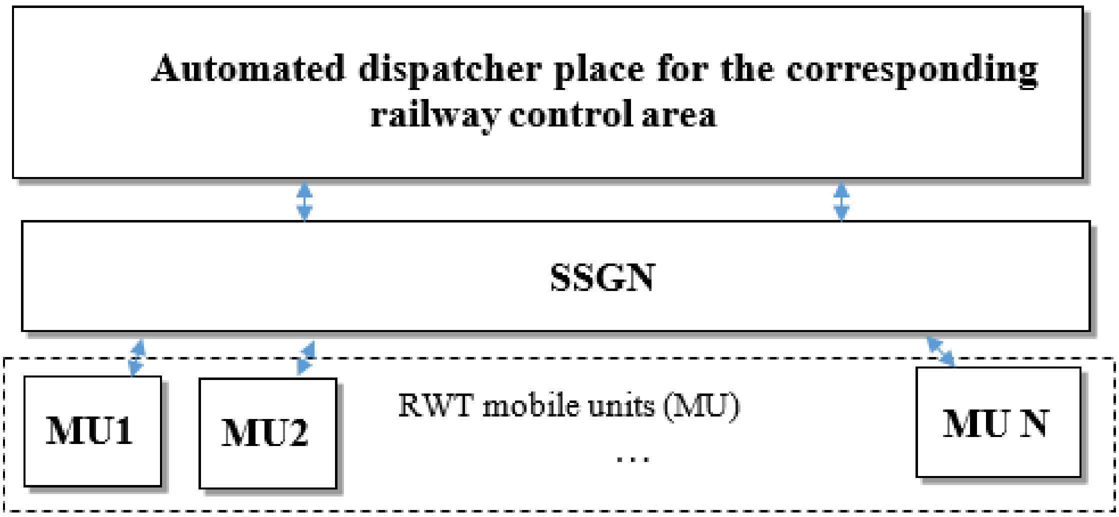

Fig. 2. Structural diagram of the navigation data collection subsystem for ADCS (Akhmetov, 2019: 487)

The main data flow in the subsystem shown on Fig. 2 consists of the results of received navigation information coming from the MU to the upper level - AWP for the dispatcher zone (DZ). In addition, the system can also transfer other information, for example, control actions in case of conflict situations on railway. The peculiarity of the MU movement coordination system is the binding to time and a given time of the data relevance. The fig. 3 shows the procedure for data collection from the MU.

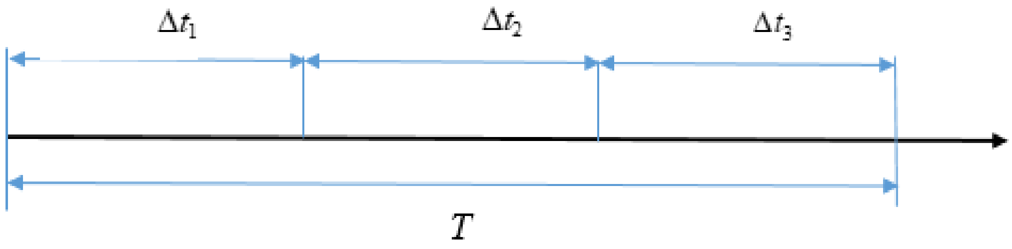

Fig. 3. Scheme of time intervals for linking navigation data collection process (Akhmetov, 2019: 487)

The figure describes the periods: $\Delta t_1 -$ data collection; $\Delta t_2 -$ data processing; $\Delta t_3 -$ control message sending; *T*– the period of time during which the data is relevant (time sufficient for decision making on the MU movement coordination).

Optimization of data collection and transmission subsystem for ADCS is proposed to be implemented according to one of the following three criteria:

1. optimization according to the message delivery time. This criterion implies prompt delivery of messages or transfer of information maximum per unit of time with available communication channels (CC);
2. optimization according to the message delivery cost. This parameter provides that the cost of sending a message will be minimized for existing CC;
3. optimization according to the transmission reliability. The third criterion provides that the probability of an error during data transmission is minimized.

The GPRS system, as well as any communication network, is modeled by a queuing service system (QSS). Accordingly, in the calculation of the capacity the are used formulas that correspond to the selected model of QSS.

Discussion.

Since the GPRS system uses the packet commutation mode, then in our case we will use the queuing-based QSS model (Coll, 1990: 250) for modeling.

In the modeled subsystem it is proposed to use statistical information. That is, we use data that characterize the flows in the GPRS transport network. And, moreover, there is adopted a limit on the memory size in the nodes of the GPRS system. It is possible to simulate the operation of a GPRS switch using QSS - $M/G/1$ (i.e., the Poisson flow at the input, then the general distribution law for operation time, one server unit, the buffer size is infinite).

The average delay value for the protocol block (PB) in this case can be calculated from the Khinchin-Polacek dependence (see (Smagulova, 2016: 247; Coll, 1990: 244)):

$$\bar{t}_q = \bar{q}/\lambda = \bar{t}_a \cdot \left(1 + p \cdot \left(\frac{1 + C_a^2}{2 \cdot (1 - p)}\right)\right), \quad (1)$$

where $\bar{q}$ – average queue length in QSS;

$p = \lambda/\mu -$ QSS load intensity of the type $M/G/1$;

λ, $\mu -$ the intensity of the receipt and service of packages in the QSS, respectively;

$\mu = 1/\tau$; $\tau -$average size of PB;

$\bar{t}_a$ – average service time;

$C_a^2 = D(t_a)/(\bar{t}_a)^2$ – quadratic service time modification coefficient.

In the course of maximum capacity calculations of the data transmission subsystem for ADCS, it is necessary to take into account the fact that as the scale of the development of the HSRWT system in Kazakhstan increases, the amount of MU equipped with these devices will increase accordingly. Consequently, the value λ. will increase. This, in turn, makes the task of control automation over the value $\bar{t}_q$ actual as the traffic increases over the GPRS channels used by RWT.

Because the GPRS node serves packets, for its modeling there can be used a relation $M / D / 1$ (since the maintenance time is a constant value).

Then the expression (1) takes the following form:

$$\bar{t}_q = \bar{t}_a \cdot \left(1 + p \cdot \left(\frac{p}{2 \cdot (1-p)}\right)\right). \qquad (2)$$

For calculations according to the equation (1), except for intensity λ (taken as the amount of PB per unit of time) and according to the average length of the PB (bits per block), the parameter C_a^2 is required. In turn, the capacity of the GPRS transport network is determined by the requirements for quality of service indicators, in particular, by the delay parameters (Smagulova, 2016: 249; Coll, 1990: 252).

Let consider the process of GPRS channel modeling as a QSS with one serving channel, see fig. 4.

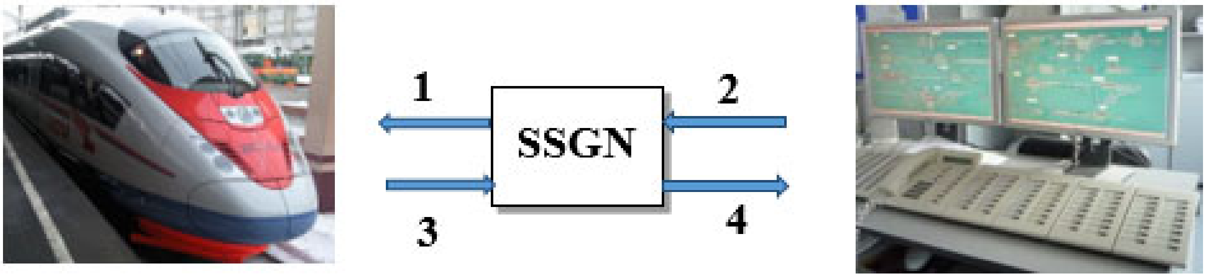

Fig. 4. Scheme for SSGN channel simulation on RWT (Akhmetov, 2019: 488)
1, 2 – control messages for MU; 3, 4- navigation information in ADCS

Let introduce the following notations: τ – time of application servicing in QSS (adopted distribution law - $f(\tau)$). Applications are alternately served in the received order, and the time spent in the queue does not exceed τ^e with its own distribution law $\varphi(\tau^e)$. For different applications, the value τ^e is independent. As a result of simulation, we will track such parameters: 1) serviced orders; 2) rejected; 3) average waiting time in the queue. You can also make a forecast for free channels. The work of the QSS is considered in the time interval $[0, T]$. Applications submitted outside this interval, are not considered. This also applies to applications whose service began in the specified interval, but was not completed. We believe that the application was rejected, if inequalities are true $t^{st} < T$, $t^{end} > T$, where t^{st}, t^{end} – the time of the beginning and end of the application service, respectively. The fig. 5 shows a step-by-step block diagram of the algorithm for simulation modeling of GPRS channels operation as part of the ADCS data transmission subsystem. The steps of the algorithm are described below (Points: P1 – P20 on Fig. 5.):

1. Generation of random values of the moments t_j of the applications receipt in the system.

2. Application control, which arrived at the moment t_j, in the interval $[0,T]$. If this condition is not satisfied, then go to step 19.

3. Verification $t_j < t_{j-1}^r$, where t_{j-1}^r – the moment of release of the service channel from the previous application. If the condition is false, then go to step 8.

4. Generation of random queue length values for the distribution law $\varphi(\tau^e)$.

5. The calculation of the upper limit t_j^e for the waiting interval $[t_j, t_j^e]$ of the application in the queue.

6. Control of $t_j^e < t_{j-1}^r$. If the condition is true, then go to p. 14.

7. Generation of service starting time of the j application $t_j^{st} = t_{j-1}^r$ and transition to the step 9.

8. Generation of service starting time of the j application $t_j^{st} = t_j$.

9. Generation of the time period τ when the channel is busy according to the distribution $f(\tau)$.

10. Calculation of time t_j^r for the j application (SSGN channel release).

11. Control of $t_j^r < T$. If the condition is false, then go to step 14.

12. Increasing the counter value of the served requests - m.

13. Calculation of waiting time $(t_j^{st} - t_j)$ for service of the j application.

14. Increasing the counter value of the amount of applications $\overline{m}$ that were rejected (Akhmetov, 2019: 488).

15. The calculation of the intensity of packages receipt and their service.

16. Calculation of $\bar{t}_q$.

17. Control of the condition $\bar{t}_q < T_q$ where T_q – the size of the maximum delay in the GPRS channel. In case of a channel overflow, it is necessary to switch to another service channel (SSGN) - step 18.

18. Switching to another service channel.

19. Assessment of simulation modeling results of the SSGN channel.

20. Compilation of channel (channels) employment forecast estimate (Akhmetov, 2019: 488).

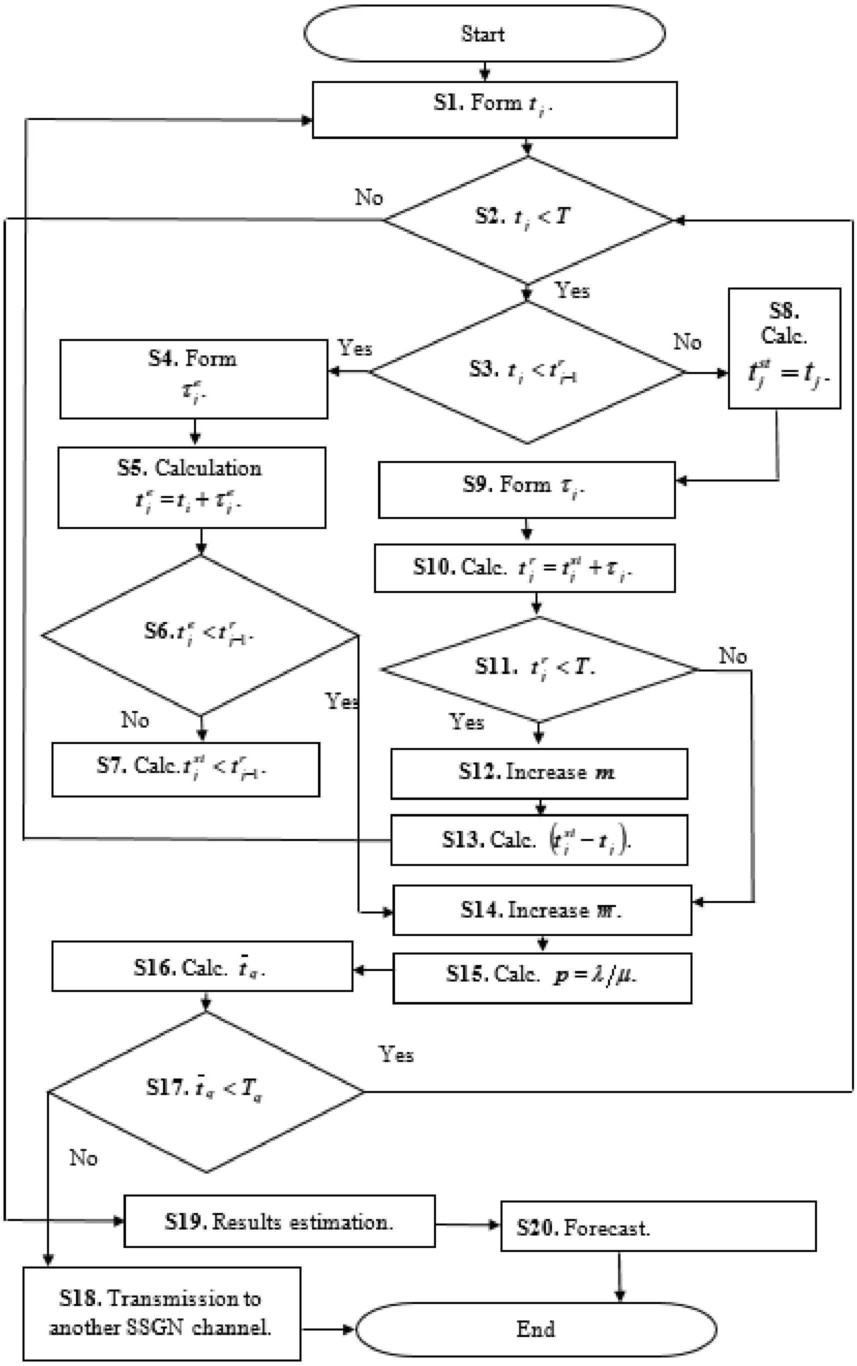

Fig. 5. The block diagram of the algorithm for the simulation of the GPRS channels operation as a part of the ADCS data transmission subsystem (Akhmetov, 2019: 489)

In order to test the effectiveness of the algorithm for simulation modeling of the SSGN channel, there was written a corresponding program in Delphi language, with the help of which computational experiments were implemented.

The fig. 6, 7 show examples of the results obtained during computational experiments. These results allow in subsequent researches to talk about the possibility of tasks automatization on RS movement coordination and dispatching. Computational experiments were performed on a PC with an i7 processor.

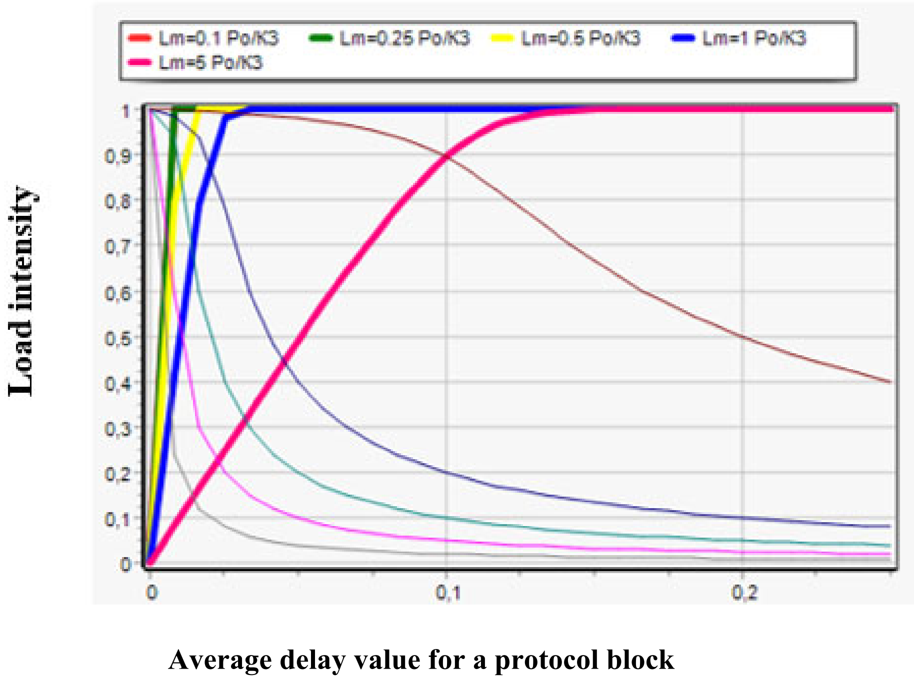

Fig. 6. The results of the algorithm testing (Akhmetov, 2019: 489)

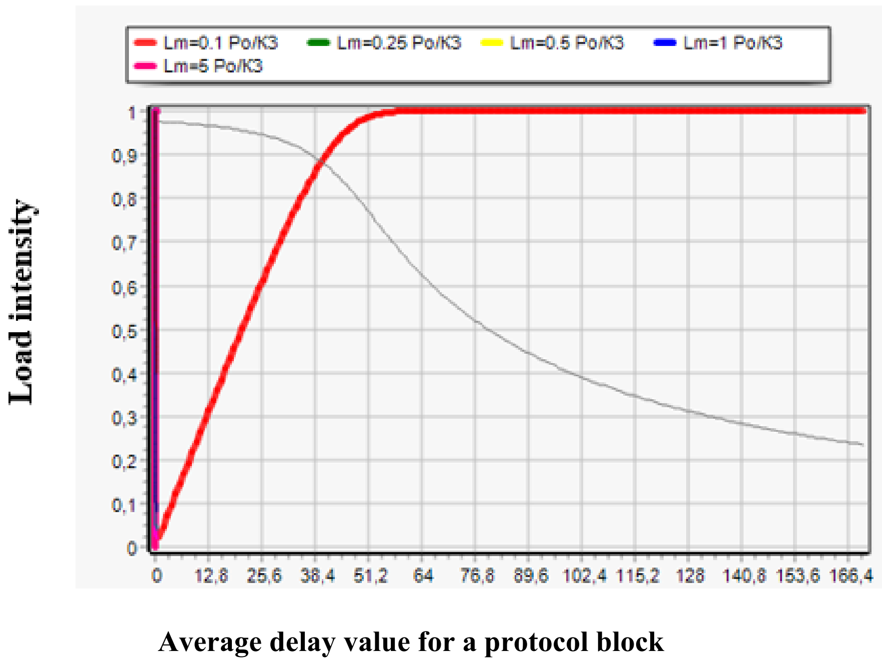

Fig.7. The results of the algorithm testing (Akhmetov, 2019: 489)

Therefore, during the simulation modeling there was confirmed the expediency and prospects of GSM technology use for information data exchange organization in the system of railway transport movement coordination in the Republic of Kazakhstan, including the prospects for the development of HSRWT systems. There is considered the technology of information data exchange in the system of transport means movement coordination, are described the main characteristics of the components of the data transmission system. During the research, there was solved the problem of estimating the GPRS network capacity on the basis of the mathematical apparatus of queuing systems. The developed simulation model for navigation data collection has an acceptable adequacy; the deviation from the experimental data does not exceed 7–9%.

In our opinion, the advantage of the proposed approach is the fact that the developed algorithm for solving simulation problems of the SSGN channel allows, in general, an increase in the efficiency of ADCS and RS movement coordination (Akhmetov, 2019: 489).

Conclusion.

The conducted research demonstrates the relevance and necessity of developing advanced simulation models for GPRS channel operation within Automated Dispatch Control Systems (ADCS) on railway transport in Kazakhstan, particularly in the context of High-Speed Railway Transport (HSRWT). The integration of mobile communication technologies, including GSM and GPRS, into ADCS provides a reliable foundation for the real-time coordination of rolling stock movement, ensuring safe, timely, and efficient transportation. The developed simulation model, based on the queuing service system (QSS) approach, allows for predictive assessment of data transmission processes, including the prioritization of voice traffic, optimization of network resource usage, and minimization of delays in information delivery.

Computational experiments conducted using the Delphi-based software demonstrate the practical applicability and adequacy of the proposed algorithms, with deviations from experimental data remaining within 7–9%. The results confirm that the proposed approach can significantly enhance the operational efficiency of ADCS by providing dispatchers with accurate, timely, and relevant navigation and control data. This improvement, in turn, facilitates more effective coordination of mixed traffic flows, including high-speed passenger, cargo, container, and trailer trains, which is critical for the modernization of Kazakhstan's railway infrastructure.

Moreover, the research highlights the importance of systematic optimization of GPRS network parameters, taking into account message delivery time, cost, and reliability. Such optimization ensures a balanced and efficient utilization of communication channels, even under increasing traffic loads associated with HSRWT expansion. The study also underscores the need for integrating intelligent on-board systems, real-time GPS monitoring, and data analysis tools to support decision-making processes for train movement coordination.

The developed models and algorithms can serve as a foundation for further modernization of ADCS in Kazakhstan, including the implementation of EDGE, 4G, 5G, and subsequent-generation networks, which will enhance the scalability and flexibility of railway communication systems. In addition, the proposed methods contribute to the improvement of automated traffic management for HSRWT, enabling predictive scheduling, timely response to conflict situations, and enhanced safety standards.

Finally, the research outcomes have broader implications for the development of intelligent railway systems in Kazakhstan. They support the country's strategic goals of improving transport efficiency, integrating with international transport corridors, and adopting digital technologies to ensure competitiveness on the global stage. The findings of this study can be applied not only to HSRWT systems but also to conventional railway networks, contributing to the creation of a unified, intelligent, and resilient transport infrastructure. Future work will focus on extending the simulation models to include multi-modal transport coordination, integration with AI-based decision support systems, and further validation under real-world operational conditions, ensuring sustainable development of Kazakhstan's railway transport sector.

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