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The formalization of the process of servicing trucks at processing points with several stations

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Abstract. Problem. *Today, processing points play a crucial role in the operation of supply chains. The efficiency of such points depends on many factors, including the timeliness of logistics operations, the cost characteristics of such services, and the regularity of vehicle arrivals. Adherence to approved cargo processing schedules (plan-markets) and schedules for the joint operation of vehicles and processing points is not always possible due to several objective factors. That is why this study has sparked the authors' interest in exploring this issue.* ***Goal.*** *Development and justification of a formalized approach to assessing truck waiting times at processing points across several service stations, taking into account the stochastic nature of vehicle arrivals and the relative priorities of their service, aimed at minimizing total time losses in supply chains.* ***Methodology.*** *The apparatus of queueing theory with relative priorities, applied to the formalized description of truck arrival and service processes at processing points with several stations. The study is based on analytical modeling of stochastic request flows and on the evaluation of service waiting time characteristics as a function of arrival intensity and priority structure.* ***Results.*** *The analysis revealed that uneven arrival times and stochastic vehicle servicing result in increased queues, downtime, and schedule disruptions. The formalization of measures to minimize uncertainty involved constructing a model of a queuing system, also known as queueing theory, which takes into account the unevenness of the input flow.* ***Originality.*** *The article proposes a formalised approach to calculating the waiting time for motor vehicle service based on relative service priority.* ***Practical value.*** *The results obtained are of practical importance for optimising the operation of logistics terminals and can be implemented at enterprises in the transport and logistics sector. The perspective for further research is to integrate the proposed approach with enterprise process management systems for dynamic forecasting and adjustment of cargo processing schedules in real time.*

Keywords: *cargo, motor transport, post, priority, processing point, service time, terminal, waiting time.*

Introduction

In today's fast-paced world, the efficiency of truck maintenance is crucial for ensuring the smooth flow of goods and maintaining the competitive advantage of carriers in the transport industry. Research into vehicle maintenance processes at cargo processing points is of great importance, as it directly affects the overall efficiency and effectiveness of logistics operations in the supply chain. The development of optimal strategies and methods to ensure efficient and rapid vehicle maintenance, taking into account the specific features of processing points, is of interest to many researchers. In general, practitioners identify several areas for implementing strategies to improve the efficiency of these processes [1-2]. Practical measures that enhance the efficiency of servicing trucks at transshipment points include developing maintenance schedules, allocating resources effectively, and optimizing workflows. These measures are designed to save money, reduce downtime, and enhance customer satisfaction, ultimately benefiting both companies and consumers. In addition, the issue of optimising resource allocation at cargo processing points is a crucial and relevant concern aimed at preventing the formation of 'bottle-

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necks' and minimising vehicle downtime at these points. By studying these features, implementing a clear service procedure, formalizing 'protocols' for queue behavior and resource allocation, and optimizing truck service processes, it is possible to ensure the smooth and efficient operation of these points.

Analysis of publications

Today, car maintenance processes at cargo handling points are described in numerous scientific studies and publications, but the issue of formalizing these processes, taking into account the stochastic nature of vehicle arrivals and the limited number of service stations, remains insufficiently explored. This issue is mainly considered from the perspective of ensuring the efficiency of logistics processes and optimizing the operation of transport terminals. Research into queue formation processes, service disciplines, request prioritization, and the impact of uneven incoming flows covers various approaches to mathematical modeling, service organization, and analysis of factors determining the time vehicles spend at cargo handling points [1].

The time vehicles spend at cargo processing points is directly affected by queue discipline, which is formed when all service posts are occupied. There may be cases when several vehicles arrive at a cargo processing point at the same time or with a short interval, causing a queue to form. Such vehicles can be serviced in order of arrival (first come, first served) or according to other priorities. The existence of priorities in vehicle servicing at processing points causes additional difficulties in determining the time vehicles spend at these points [2-4].

It should be noted that the priority of vehicle servicing at cargo processing points is a system that determines the order and conditions under which vehicles gain access to cargo handling or undergo customs/technical procedures depending on various factors, such as the importance of the cargo, type of transport, urgency of delivery, or other criteria. During scheduled maintenance or infrastructure upgrades, the priority of service at cargo processing points may be adjusted. The cost of cargo may be a key factor in prioritisation. Goods that are of high economic importance or high value may be given higher priority to ensure their timely delivery or transport. Special cargo processing conditions related to the requirement to comply with special storage or transportation regimes (such as refrigeration, isolation, or regulated processing technology) determine its higher priority during the organization and execution of operations [5, 7]. Priority of service at cargo processing points may be determined not only by the properties of the cargo, but also by the characteristics of the vehicles themselves. These may be vehicles carrying cargo with critical delivery or loading times that require special service: if the freight transport has special technical characteristics or requires specific conditions for unloading or customs control. This may also affect the priority of service at processing points. The form of ownership of such vehicles can also be decisive in determining the priority of service – for example, hired vehicles are serviced first to avoid penalties for non-compliance with the lease terms [6].

The size of the cargo batch is also decisive for queue behaviour at processing points. Small cargo batches can be processed more quickly because they require less time for loading and unloading, and can therefore be given priority over larger cargo batches [7].

Today, scientists distinguish several disciplines, the most common of which are:

- FIFO (First In, First Out) – this is the most common model, where vehicles are serviced in order of arrival at the freight processing point. This is suitable for situations where there are no important priorities;
- LCFS (Last Come, First Served) – In certain situations, vehicles that arrive later may be accepted for service before those already in the queue, particularly if there are special requirements (e.g., increased urgency or emergency conditions);
- priorities by cargo category: some cargoes may have a specific handling sequence depending on their type or nature, regardless of their time of arrival;
- randomised or stochastic models: in some cases, more complex mathematical models are used to determine priority, for example, when the service system has to take into account probabilistic or random factors that affect processing time.

Therefore, the review of scientific works highlights significant theoretical and practical achievements in organizing vehicle servicing at cargo processing points. However, the absence of a unified formalized approach that thoroughly considers queue disciplines, priority mechanisms, and the multifactorial effects on service time justifies further research in this field and emphasizes the need for developing a comprehensive methodology to formalize the service process.

Purpose and Tasks

The purpose of this study is to examine the unevenness of vehicle arrivals, the stochastic nature of vehicle servicing processes at processing points, and, accordingly, the duration of vehicle stays at such points. To achieve this goal, it is necessary to analyse modern methods and approaches for determining the waiting time for service in single-channel and multi-channel queuing systems and to propose a formalised approach to calculating the waiting time for motor vehicle service, taking into account the relative priority in these systems.

Methodology for calculating vehicle wait times at processing points with several stations

In general, the task of processing cargo flows is formulated as follows: during a certain period of time, each cargo flow (source of supply) is characterised by its own parameters – intensity of arrival, service time, carrying capacity of vehicles, etc. At the same time, each destination has its own requirements and characteristics, in particular, processing capacity and number of service posts. [8].

The criterion for efficiency is minimizing the total time spent on both vehicle stay at the destination point and the operation of the points themselves. Optimising this criterion directly reduces the costs of the entire supply chain. It is evident that with a fixed volume of material flow arriving at the point, the number of available mechanisms significantly impacts the total costs associated with vehicle and mechanism downtime [9].

Given the limited processing capacity of processing points and the significant unevenness of vehicle arrivals for servicing, queues of vehicles awaiting processing are inevitable. At the same time, the vehicles in the queue have different technical and economic characteristics. This means that the choice of a particular sequence of vehicle servicing has a significant impact on the overall costs of the process [10, 11].

In such conditions, formalising the process of servicing cargo flows at the processing points boils down to the task of optimising the order in which vehicles are processed [12].

Since the technology for processing a transport unit at the processing points does not depend on the vehicle's position in the queue, the cost of the service itself also does not depend on the order in which the vehicles are processed. Therefore, the objective function of the problem is reduced to minimising the time lost by vehicles waiting for service to begin.

$$\sum_{i=1}^{n} W_i \rightarrow \min , \qquad (1)$$

where W_i waiting time for the start of service for the i-th vehicle in the queue.

Therefore, it is precisely thanks to the determination of a rational sequence of services that the total costs of processing vehicles at cargo processing points are minimized.

The practice of servicing vehicles at processing points also indicates the existence of certain priorities for different cargo flows. Priority is understood as the preferential right to choose to service requests of one class over requests of other classes. Thus, vehicles arriving at the processing points are not serviced in the order of their chronological arrival.

Generally, when a request with a specific priority is received, the vehicle is initially placed at the end of the queue. Before proceeding with its servicing, it is necessary to complete servicing of the vehicle that is already at the station and whose process has been started, serve all vehicles that were already in the queue before the arrival of this vehicle and service all vehicles that arrived at the point after the vehicle under investigation during its waiting time, but had higher priority and were therefore serviced earlier [13].

Thus, during the waiting time for servicing the vehicle under consideration, there is a probability that vehicles with higher priority will arrive and be serviced before it.

To describe the process of servicing cars at cargo processing points, it is advisable to use queuing system models that take into account factors such as the number of vehicles, the number of service channels, and the nature of the queue. Depending on the initial conditions, the most common models for such tasks are M/M/1 or M/M/c, where [14]:

M – Markov process, where the arrival of cars and the time of their service are described by an exponential distribution law).

1 or c – number of service channels (for M/M/1 this is one channel, for M/M/c – several channels).

In this case, we consider objects that require servicing (such as loading, unloading, or performing other logistics operations) to be in demand. These can be trucks with different types of cargo arriving at the processing points. Let

$$k = 1, 2, ..., r, \quad (2)$$

where k – numbers of priority classes of requests coming into the mass service system.

Then the probability distribution function of the service time X_k of the k-th priority request will be as follows

$$G_k(t) = P\left(X_k \le t\right), t > 0, \quad (3)$$

Let λ_k – the intensity of arrival of k-th priority requests, then the load on the k-th priority request processing system will be as follows

$$\rho_k = \lambda_k \cdot M(X_k) = \lambda_k \int_0^\infty t dG_k(t), \quad (4)$$

where $M(X_k)$ is the first moment of the stationary waiting time.

Let W_i – stationary waiting time for k-th priority requests, then for the case when the total load on the service system for all priority classes is less than one, i.e.

$$\rho = \sum_{k=1}^{r} \rho_k < 1, \quad (5)$$

then we obtain the formula for the first moment of steady-state waiting time for k-th priority requests [15]

$$M\left(W_k\right) = \frac{\sum_{j=1}^{r} \lambda_j^2 M\left(X_j^2\right)}{2\left(1 - \sum_{j=1}^{k-1} \rho_j\right)\left(1 - \sum_{j=1}^{k} \rho_j\right)}, \quad (6)$$

Let $\rho = \sum_{k=1}^{r} \rho_k$ – the total load of all priority classes will exceed one. In this case, the service channel will not be able to handle the given flow, and the queue length will tend to infinity. Naturally, it is necessary to add service channels so that the load on each channel is less than one:

$$\frac{\rho}{m} < 1, \quad (7)$$

where m – number of service channels.

The simplest approach is to divide the intensities of Poisson flows of requests with different priorities into m – number of identical service channels.

The next incoming request, with equal probability $\frac{1}{m}$ is placed in the queue and then serviced by one of these service channels.

At the same time, the service time indicators for priority classes will remain unchanged, and only the intensity of requests of different priority types will change.

Then $W_k[\rho, m]$ is the stationary waiting time for k-th priority requests in a multi-channel service system constructed in this way and will be equal to

$$M\left(W_k[\rho, m]\right) = \frac{\sum_{j=1}^{r} \left(\frac{\lambda_j}{m}\right)^2 M\left(X_j^2\right)}{2\left(1 - \sum_{j=1}^{k-1} \frac{\rho_j}{m}\right)\left(1 - \sum_{j=1}^{k} \frac{\rho_j}{m}\right)}, \quad (8)$$

$$k = 1, 2, ..., r.$$

This formalization of the process enables the analysis of the main numerical characteristics of requirements with different relative priorities.

Conclusion

The process of processing cargo flows at the processing points is a key element of the supply chain, and its efficiency is largely determined by the rational management of vehicle queues. The limited processing capacity of the processing points and the uneven arrival of vehicles inevitably lead to queues, which generate additional costs due to downtime.

Since the costs of direct servicing of a transport unit do not depend on its position in the queue, the main criterion for optimisation is to minimise the total waiting time for the start of servicing for all vehicles. It is the determination of a rational order of processing that allows for minimizing the total costs of servicing cargoes at the processing points.

Practice shows that in real systems, priority service is often applied to different cargo flows. Priority gives preferential service rights to requests of one class over others, resulting in vehicles not being serviced on a first-come, first-served basis. When priorities are in place, the waiting time for a specific vehicle depends not only on the vehicles already in the queue, but also on the probability of a vehicle with a higher priority arriving while it is waiting.

Thus, formalizing and optimizing the cargo flow service process, taking into account priorities, are necessary conditions for reducing the overall costs of the supply chain, increasing the throughput capacity of processing points, and improving the quality of logistics services.

Formalising the process of servicing vehicles at cargo processing points enables the consideration of priority classes of requirements and varying numbers of service channels.

In the case of a transition from a single-channel to a multi-channel system, the intensity of vehicle arrivals in each priority class is evenly distributed among several service stations, which reduces the load on individual channels. At the same time, changing the number of service channels does not affect the duration of service for these vehicles of the corresponding priority classes, which is determined by their properties and processing conditions.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Формалізація процесу обслуговування вантажних автомобілів в пунктах переробки з декількома постами

Анотація. Проблема. *На сьогоднішній день пункти переробки відіграють важливу роль в функціонуванні ланцюгів постачань. Ефективність роботи таких пунктів залежить від багатьох факторів, в тому числі від своєчасностосні виконання логістичних операцій, вартісних характеристик таких послуг і регулярності прибуття транспортних засобів до них. Дотримання затверджених графіків переробки вантажів (план-маркетів), графіків сумісної роботи транспортних засобів та пунктів переробки не завжди є можливим через ряд об'єктивних факторів. Саме тому, дане дослідження викликає інтерес авторів до вивчення цієї проблеми.* **Мета.** *Розробка та обґрунтування формалізованого підходу до оцінювання часу очікування вантажних автомобілів у пунктах переробки з кількома постами обслуговування з урахуванням стохастичного характеру прибуття транспортних засобів і відносних пріоритетів їх обслуговування, спрямованого на мінімізацію сумарних втрат часу в ланцюгах постачань.* **Методологія.** *Апарат теорії систем масового обслуговування та теорії черг з відносними пріоритетами, що застосовується для формалізованого опису процесів прибуття та обслуговування вантажних автомобілів у пунктах переробки з кількома постами. Дослідження ґрунтується на аналітичному моделюванні стохастичних потоків заявок та оцінюванні характеристик часу очікування обслуговування залежно від інтенсивності надходження та структури пріоритетів.* **Результати.** *Проведений аналіз показав, що нерівномірність прибуття та стохастичність обслуговування транспортних засобів призводять до зростання черг, простоїв і порушення графіків. Формалізація заходів щодо мінімізації невизначеності проведена шляхом побудови моделі системи масового обслуговування або теорії черг з урахуванням нерівномірності вхідного потоку* **Оригінальність.** *У статті запропоновано формалізований підхід розрахунку часу очікування обслуговування автотранспортним засобом, базуючись на відносномц пріоритеті обслуговування***. Практичне значення.** *Отримані результати мають практичне значення для оптимізації роботи логістичних терміналів і можуть бути впроваджені на підприємствах транспортно-логістичної сфери. Перспективою подальших досліджень є інтеграція запропонованого підходу з системами управління процесами підприємств для динамічного прогнозування та коригування графіків роботи пунктів переробки вантажів у реальному часі.*

Ключові слова: *вантаж, автомобільний транспорт, пост, пріоритет обслуговування, пункт переробки, час обслуговування, термінал, час очікування.*

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