Using redundancy methods to build a maintenance and repair system in Burundi

Juvenal Bigirimana[1] and *Alexey* Pavlov[1*]

[1]MADI, Manufacture and repair of vehicles and road machines Department, 125319, Moscow, Russia

Abstract. The purpose of this paper is to ensure the maintenance and Repair system's functioning in Burundi using redundancy methods, which include the organization of warehouse stocks of repair kits (units, repair kits) formed on the basis of the received results from studies on the damageability of structural elements of buses in Burundi. This approach will simultaneously ensure that all maintenance and repair requests are met when first needed, reduce vehicle downtime while waiting for repairs, and thus increase the efficiency of using ground transport and technological means. For the practical implementation of the task, a methodology for the strategy's optimization for managing the stocks of circulating units in the conditions of Burundi on the basis of an analysis of various sources of literature and a method for size's calculation of the circulating fund of units, spare parts and materials using modern mathematical models were developed. Costs of its creation, maintenance and replenishment in the context of Burundi were also estimated. As a result, it was shown after calculations that in the example of the OTRACO vehicle transport company it is possible to reduce the probability of bus downtime due to gearbox failure to 5%. The proposed method of redundancy with repair kits, especially in the conditions of Burundi, has an invaluable property; when it is implemented, the technical condition of buses, even despite the long service life, has a clear tendency to be improved.

1 Introduction

In line with the national strategy for planning and management of the transport sector and its action plan 2018-2027 [6], the objective of the transport sector in Burundi is to make its full role as an important tool for economic and social development by offering quality transport services. services both at the national, sub-regional and regional levels. The most voluminous tasks need to be solved in the transport sector using ground transport and technological facilities, as it happened historically and geographically [1]. In this strategy, the purpose of using road transport is to ensure the mobility of people and goods in the country and in the region [12-13]. The operation of vehicles in the conditions of Burundi is characterized by a large flow of requests for repairs, which, given the almost complete practical absence of a maintenance and repair system, as well as the organization of the supply of spare parts at the present time, leads to a significant increase in the downtime of

* Corresponding author: 89037628407@mail.ru

vehicles waiting for repairs [2]. The ground transport and technological facilities park's operation can be more efficient if unplanned downtime is significantly reduced. And this task has a real practical solution to the fulfillment conditions, which will be considered in this paper. Why is it necessary to solve the problem of establishing the optimal volumes of the working capital of units and repair kits of parts, taking into account the different brands of the park used on the basis of the principles of complete redundancy.

2 Materials and methods

2.1. Optimization of the inventory management strategy for circulating aggregates in the conditions of Burundi

The working capital of units at a vehicle transport company can be formed in two ways: through their repair on their own or through the use of a centralized repair system at vehicle repair companies; through the purchase of new units and kits of parts or spare parts. The authors of [8,14] discussed some methods of spare parts management. Both ways are practically feasible, but as experience and the results of our own research show, in the conditions of any country, including Burundi, it is more profitable to plan a system for redundant units and sets of ground transport and technological facilities with the condition of creating an effective system for repairing failed units and parts on specialized repair companies. In [5], according to the author, non-compliance with the requirements for the level of service (Service Level Agreement -SLA) in terms of the technical readiness factor leads to additional losses due to the reduction factor when calculating the mileage of locomotives, the analysis showed that the losses of the technical readiness factor up to 60% are determined by long downtime waiting for maintenance and repair and unscheduled repairs. Due to in-house planning and logistics management of service locomotive depots, downtime while waiting for repairs can be halved.

In [4], V.I. Karagodin proposed to consider a car service station as a multi-phase queuing system. To optimize the inventory management strategy for circulating units (repair kits), it is advisable to use probabilistic methods for calculating the circulating fund, based on the theory of queuing. A characteristic feature of queuing models is the assumption that units removed from the machine are immediately sent for repair. This is very beneficial in Burundi as the aim is to optimize the park of ground transport and technological facilities where reducing their downtime while waiting for repairs is one of the methods to improve the efficiency of their operation. Using the reservation system, it is possible to dismantle the unit of vehicle which is out of line and send it directly to the auto repair shop, and install a reserved unit (new or pre-repaired) on this vehicle so that it is returned to operation as soon as possible.

According to V.I. Karagodin, the units, in accordance with their technological routes, are sent to specialized workplaces, where one or more technological routes can be executed at one workplace [3]. The unit sent to the auto repair shop becomes a requirement in need of repair at the auto repair shop and thus forms an incoming flow of requirements, which for the conditions under consideration is considered the simplest. The demand for the products of car repair enterprises and technical services of vehicle transport enterprises is the need for repairs of cars and their components, in the case of objectivity and validity of this need, it must be fully satisfied, to mean that in our case, the need for repairs of units and cars must be fully satisfied.

The point is that in order to meet the urgent need for repairs, it is necessary to have a stable volume of an irreducible fund of circulating units (repair kits), which is created both through the purchase of new units and fit units repaired in advance by auto repair shop from

decommissioned ground transport and technological facilities. This should be planned, considering that each supplier has the possibility of late delivery of the order (gap risk) [7]. This is discussed in more detail in [10-11]. Thus, the quality of technical service to customers is ensured in accordance with the definition that states in [9] that quality is a measure of the performance felt by customers. According to the queuing theory, cars and the working capital of aggregates are considered as a multi-channel system, in which the aggregate (repair kit) is considered as a service channel when the task is formalized, and can simultaneously satisfy only one requirement for replacement. The channel is considered occupied from the moment the corresponding serviceable circulating unit is withdrawn from the warehouse until another unit arrives in its place.

However, if [6] developed the idea of adapting the schedule of vehicle maintenance operations as much as possible in accordance with the evolution of their wear, this entails the need for the availability of spare parts. With regard to the spare parts management process, Thiebaul Hubert set the classic goal of maximizing service and minimizing inventory, which has the effect of maximizing the effect at a minimum of costs [15].

2.2. Methodology for calculating the size of the revolving fund of aggregates and the costs of its creation, maintenance and replenishment in the conditions of Burundi

An application for car repair is not always received at the very beginning of the shift when the team is working, but maybe in the middle or at the end of the shift. Then, for each period of time (0, t), both zero claims and k claims can arrive, which affects the random process of receipt of claims for repair, and is described by the function X(t), which determines the number of claims entering the system for a period of time (0, t).

In the theory of queuing, the simplest flow of requirements (or stationary Poisson flow) is considered and studied, to mean that a flow which has the properties of stationarity, ordinarity and no aftereffect, and if there is a simple flow of customers, then the number of customers in a time interval (0, t) obeys Poisson's law:

$$P_k(t) = \frac{(\lambda.t)^k}{k!} e^{-\lambda t} \quad (1)$$

where $k -$ is the number of requirements.

For a Poisson customer flow, the probability (P_n) that there are n customers in the queuing system at any time is expressed by the formula:

$$P_n = \frac{1}{n!} \quad (\mu\lambda)^n . e^{-\mu t} \quad (2)$$

where $\mu -$ average duration of repair and transportation of one unit (intensity of service flow);

$\lambda -$ the average number of requirements for the replacement of units arriving per unit of time (intensity of the flow of requirements);

If there are k units in the circulating (exchange) fund (for example, gearboxes), then a downtime of cars with gearbox failure will occur when the number of faulty gearboxes (the number of replacement requests in the system) n > k. Then the downtime probability P_{pr} at any time will be equal to the sum of the probabilities P_n for all n > k:

$$P_{pr} = P_i(t) = \sum_{n=k+1}^{\infty} P_n = 1 - \sum_{n=0}^{k} \frac{1}{n!} \quad (\mu\lambda)^n . e^{-\mu\lambda} \quad (3)$$

If the number of machines that need to have replacement units of the same type is greater than the number of circulating units in stock, then these machines will queue up and wait for units to be replaced.

It is known from the theory of queuing that the queue will grow indefinitely if the following inequality holds:

$$\frac{\lambda}{\mu} > n$$

Experience has shown that the creation of turnaround units (sets) will require additional costs for their acquisition and storage. Compensation for these costs is possible only when making a profit by reducing the downtime of vehicles with an increase in the number of circulating units in stock. Then, the feasibility of increasing the number of reverse gearboxes in stock is determined by the function:

$$[(T_{o,m} + T_{o,m+i}).S.N - Ci] \rightarrow max$$

where $T_{o,m}$ - average waiting time for a replacement with m revolving fund aggregates
$T_{o,m+i}$ - also for m+i aggregates of the revolving fund
N – number of units replaced per year
C – the cost of one circulating unit and its storage per year
S – profit received per vehicle-day of work

The optimal margin X_0 corresponds to the minimum of the function:

$$C_{\Sigma} = C_d + C_{st} = K_1 (v_t - x) - K_2 \bar{X}] \rightarrow min$$

where K_1 – loss of vehicle transport company due to the shortage of this unit in the warehouse;
K_2 – the cost of maintaining and maintaining one unit for time T;
C_d, C_{st} – respectively, the loss of vehicle transport company due to shortages and storage costs;
x – current stock of aggregates in the warehouse;
$\bar{X}$ – average stock of aggregates in stock.

The average duration of repair and transportation of one unit μ, which is the reciprocal of the average service time, was determined by the formula:

$$\mu = \frac{1}{t_m} \qquad (4)$$

where t_m - the duration of the turnover of the unit under repair; this is the time from the moment a serviceable unit is issued from the warehouse on demand until the moment when a new or repaired unit arrives at the warehouse together with it.

As already mentioned above, failures (requirements for the replacement of units) form the simplest flow that obeys the Poisson law

$$\lambda = \text{const}, \quad f_1(t) = \lambda \, . \, e^{-\lambda t}, \quad (t>0), \qquad (5)$$

where $f_1(t)$ - time distribution density between two successive (adjacent) failures (requirements).

The service time can be taken as obeying an exponential distribution law:

$$f_2(t) = \mu \, . \, e^{-\mu t} \quad , \quad (t>0) \quad , \tag{6}$$

where $f_2(t)$ - service time distribution density. The average waiting time $\bar{t}_w$ for a multichannel waiting queuing system can be expressed by the formula:

$$\bar{t}_w = \frac{\rho^n . P_0}{\mu(n-1)!(n-\rho)^2} \quad , \tag{7}$$

where P_0 - the probability that there will be no turnaround units in the warehouse.

$$P_0 = \left[\frac{\rho^n .}{(n-1)!(n-\rho)} + \sum_{K=0}^{n-1} \frac{\rho^K .}{K!}\right]^{-1} , \; (\rho = \frac{\lambda}{\mu}) , \tag{8}$$

n - the number of requests entering in the system.

Based on the specific conditions for the organization of repair and restoration work, one can set the limit value of the average waiting time, at which the inequality takes place:

$$\bar{t}_w \leq t_w^{lim}$$

If we designate a mulyiplication $\bar{t}_w \, . \, \mu$ through χ, then formula (7) will look like:

$$\chi = \frac{\rho^n . P_0}{(n-1)!(n-\rho)^2} \quad , \tag{9}$$

The obtained value of χ for specific conditions or its average value can be considered as the maximum value of the average waiting time for repair actions for specific considered conditions for organizing repair.

3 Results

Having statistical values of ρ, the values of n are set and the corresponding values of χ are calculated for them. As a result, the dependency graph

$$n = f(\chi, \boldsymbol{\rho})$$

used to calculate n at various possible variable values **λ**, $\boldsymbol{\mu}$ and t_w^{lim} is presented in figure 1, and the dependence values are presented in table 1.

In the form of initial data, the corresponding parameters of the OTRACO vehicle transport company were taken as a basis. Currently, the total number of buses in the organization is 100 units, which include three models: TOYOTA COASTER - 44 pcs; ISUZU FRR - 31 pcs; ISUZU MV 123 - 25 pcs. It is necessary to calculate how many units (repair kits) should be reserved (for example, a gearbox) in the warehouse as an unloaded reserve so that the probability of bus downtime due to gearbox failure does not exceed 0.05. The value of such a probability, usually used as an admissible one in calculations by the methods of queuing theory of the required stock of reserved items, is the value 0.01. But taking into account the economic conditions of Burundi, its technological equipment and the availability of qualified human resources, it can be assumed that the necessary volumes of redundant units for organizing warehouse storage are provided taking into account the achievement of the probability of demand during maintenance and repair of at least 95% of the need from the first requirement, therefore, in our case, the probability of bus downtime due to the lack of a unit will be 5% (0.05).

Also in the conditions of Burundi, based on the insignificant distances between the provinces, the transportation time to the auto repair shop is taken as 1 day, and therefore we can assume that the average duration of the repair and transportation of one unit μ (the average time required to transport the gearbox from the vehicle transport company, where it left out of line, to the auto repair shop and back, taking into account the repair time) will be equal to 5 days (a day there, a day back and three days for repair), and the value λ (intensity of the flow of requirements) in our example, we take the value 0.2 for TOYOTA COASTER, 0 .21 for the ISUZU FRR and 0.22 for the ISUZU MV123, given the difference in their failure rates. In accordance with expression (3), let's check at what value of k, the probability of bus downtime will not exceed 0.05. The results showed that only with k=2, the probability of idle bus ISUZU FRR and ISUZU MV123 will not exceed 0.05, it will be $P_{pr} = 0{,}035$ for ISUZU FRR and -0.007 for ISUZU MV123. But, the probability of downtime for TOYOTA COASTER buses will not exceed 0.05 at k = 3: it will be $P_{pr} = 0{,}019$.

Then it can be assumed that in the OTRACO, in order to ensure the probability of claiming at least 95% of the need from the first requirement during maintenance and repair, it is necessary to have at least 7 gearboxes in stock in which, 3 gearboxes for TOYOTA COASTER, 2 gearboxes for ISUZU MV123 and 2 for ISUZU FRR.

Table 1. Dependency values in the function n = f (χ, **ρ**)

	λ	***μ***	$\rho = \frac{\lambda}{\mu}$	n	P_0	χ
Possible values	0.1	4	0.025	1	0.975	0.026
	0.2	5	0.04	2	0.961	$4.002.10^{-4}$
	0.3	7	0.043	3	0.958	$4.356.10^{-6}$
	0.4	9	0.044	4	0.957	$3.82.10^{-8}$
	0.5	11	0.045	5	0.956	$2.994.10^{-10}$
	0.6	12	0.05	6	0.951	$3.498.10^{-12}$

P_0 we calculate in accordance with (8), and χ according to formula (9).

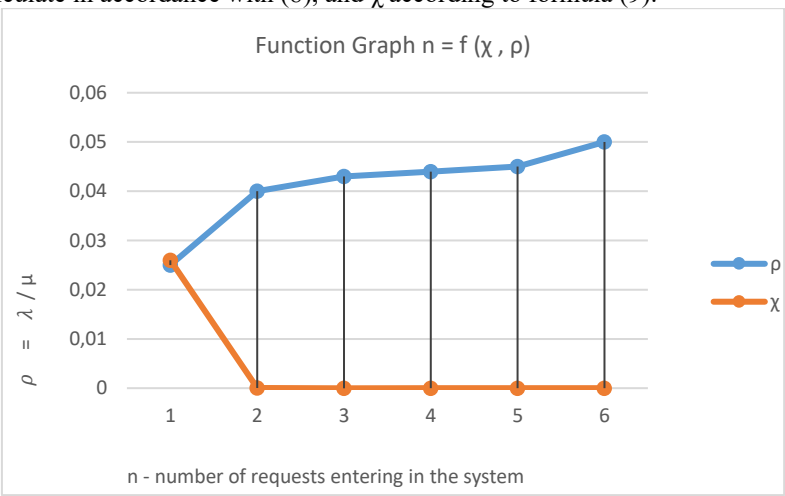

Fig. 1. Dependency graph n = f (χ, **ρ**)

The graph clearly shows the dependence that as n increases, χ will decrease, and **ρ** will increase and, accordingly, vice versa.

It can also be seen that the situation will be ideal when **ρ** → min and χ → max, since n → min, this is the solution to our problem.

4 Conclusion

Based on the results of this work, it can be concluded that the system of complete redundancy is the most effective way to reduce the downtime of vehicles for the conditions of Burundi. Using the example of the OTRACO company with 100 buses of 3 different brands, it is demonstrated that, provided that it is necessary to ensure the probability of service during maintenance and repair of applications from the first requirement of at least 95%, if there are 7 gearboxes in stock, no mean 3 gearboxes for TOYOTA COASTER, 2 gearboxes for ISUZU FRR and ISUZU MV123 buses.

References

1. J. Bigirimana, A. P. Pavlov, Analysis of the factors influencing the formation of supply and demand on the market of automobile technical service under conditions of Burundi, M. transp, MADI, Moscow, Russia, **3-2**,78, 125-132 (2022), DOI 10.33979/2073-7432-2022-2(78)-3-125-132
2. J. Bigirimana, A. P. Pavlov, Development of a methodology for organizing maintenance and repair system for the conditions of Burundi, Transp, MADI, Moscow, Russia, **4,** 5-11 (2022), DOI 10.15593/24111678/2022.04.01
3. V. I. Karagodin, R. A. Khapugin, Technology of centralized repair of hydraulic hammers according to technical condition, Transp, MADI, Moscow, Russia, **3**, 45-53 (2021), DOI 10.15593/24111678/2021.03.06
4. V. I. Karagodin, V. O. Malyutin, E. Yu. Faddeeva, A. A. Ivakhnenko, New approach to the modeling of processes for maintenance vehicle service, MADI, Moscow, Russia, **6**, 66, 184-193 (2015), DOI 10.12731/wsd-2015-6-18
5. I. V. Pustovoi, Key performance indicators of information-dynamic model for management of service and maintenance carried out on locomotives, bill USUC, **2**,38, 77-84 (2018), DOI 10.20291/2079-0392-2018-2-77-84
6. R. Elodie, Health management of industrial vehicles and fleet maintenance optimization: taking into account operation constraints and mission planning, UGA, Grenoble, Alpes, France, 263 (2019)
7. F. Hamdi, Optimisation et planification de l'approvisionnement en présence du risque de rupture des fournisseurs, EMAC, France, 155 (2017)
8. L. Hongtao, T. Feng. The research and application of spare parts coding system, IEEE, WARTIA, 1287-1289 (2014)
9. H. Kashif Understanding the role of information and communication when moving from industrial management techniques to a quality culture: QMI (Quality Management Implementation) in three multinational organizations, UVHC, France, 491 (2020)
10. A. A. Martel, W. Klibi, reengineering methodology for supply chain networks operating under disruptions, 241-273 (2013)
11. J.T. Mentzer, J.T. Mentzer, W.de Witt, J.S. Keebler, Defining supply chain management, JBL, **22**, 2, 1-25, (2001)

12. J. B. Ntunzwenimana Stratégie nationale en matière de planification et de gestion du secteur du transport et son plan d'actions 2018-2027 au Burundi.
13. Plan national de dévéloppement du Burundi. PND Burundi 2018 -2027 *[Ressource électronique]. – URL:*https://presidence.gov.bi/strategies-nationales/plan-national-de-developpement-du-burundi-pnd-burundi-2018-2027/
14. A.A. Seyed, Common weight linear optimization approach for multicriteria ABC inventory classification, ADS, **2015 (**2015)
15. H. Thibault Prévision de la demande et pilotage des flux en approvisionnement lointain, ECP, Paris, France, 156 (2013)