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

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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%.

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 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 vehicles.
2 Materials and methods

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

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.

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...
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

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\[ P_k(t) = \frac{(\lambda t)^k}{k!} e^{-\lambda t} \]

\[ P_n = \frac{1}{n!} (\mu \lambda)^n e^{-\mu \lambda} \]

\[ P_{pr} = \sum_{n=k+1}^{\infty} P_n = 1 - \sum_{n=0}^{k} \frac{1}{n!} (\mu \lambda)^n e^{-\mu \lambda} \]
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:

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

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

where

- $T_{o,m}$ - the average waiting time for a replacement with $m$ revolving fund aggregates
- $T_{o,m+i}$ - also for $m+i$ aggregates of the revolving fund
- $N$ - the number of units replaced per year
- $C$ - the cost of one circulating unit and its storage per year
- $S$ - the profit received per vehicle-work day
- $K_1$ - the 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;
- $x$ - the current stock of aggregates in the warehouse;
- $\bar{X}$ - the average stock of aggregates in stock.

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

$$\mu = \frac{1}{t_m}$$

where

$\lambda$ - the time distribution density between two successive (adjacent) failures (requirements).

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

The service time can be taken as obeying an exponential distribution law.
\[ f_2(t) = \mu e^{-\mu t}, \quad (t > 0), \quad (6) \]

The average waiting time \( \bar{t}_w \) for a multichannel waiting queuing system can be expressed by the formula:

\[ \bar{t}_w = \frac{\rho^n P_0}{\mu (n-1)(n-\rho)^2}, \quad (7) \]

where \( P_0 \) = \( P_0 = \left[ \frac{\rho^n}{(n-1)(n-\rho)^2} + \frac{\rho^n}{(n-1)(n-\rho)^2} \sum_{K=0}^{n-1} \frac{\rho^K}{K!} \right]^{-1} \rho = \frac{\lambda}{\mu} \)

\[ \chi = \frac{\rho^n P_0}{(n-1)(n-\rho)^2} \quad (9) \]

For specific conditions or its average value, \( \chi \) can be considered as the maximum value of the average waiting time for repair actions for specific considered conditions for organizing repair.

3 Results

For statistical values of \( \rho \), the values of \( n \) are set and the corresponding values of \( \chi \) are calculated for them. As a result, the dependency graph \( n = f(\chi, \gamma, \delta) \) used to calculate \( n \) at various possible variable values \( \gamma, \delta \) 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).
can assume that the average duration of the repair and transportation of one unit $\mu$ (the
auto repair shop) is equal to 5 days (a day there, a day back and three days for repair), and the value $\lambda$ (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 $k$, 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>
<thead>
<tr>
<th>$\lambda$</th>
<th>$\mu$</th>
<th>$\rho = \frac{\lambda}{\mu}$</th>
<th>$P_0$</th>
<th>$\chi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.1</td>
<td>$10^{-4}$</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td>0.2</td>
<td>$10^{-6}$</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>0.03</td>
<td>0.3</td>
<td>$10^{-8}$</td>
<td>0.03</td>
<td></td>
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<tr>
<td>0.04</td>
<td>0.4</td>
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<tr>
<td>0.05</td>
<td>0.5</td>
<td>$10^{-12}$</td>
<td>0.05</td>
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</tbody>
</table>

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

![Function Graph $n = f(\chi, \rho)$]

Fig. 1. Function Graph $n = f(\chi, \rho)$
The graph clearly shows the dependence that as $n$ increases, $\chi$ will decrease, and $\mathcal{C}$ will increase and, accordingly, vice versa.

It can also be seen that the situation will be ideal when $\mathcal{C} \to \text{min}$ and $\chi \to \text{max}$, since $n \to \text{min}$, 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.

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