Handling equipment reliability effect on grain terminal risks

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Abstract. This article presents the servicing vehicles process simulation modeling results at the grain terminal in order to assess the risks additionally arising from sudden failures of loading and unloading equipment. Two types of trucks incoming flow are considered: simple random and presupposing preliminary on-line registration. The Weibull distribution and the transition to the parameters of the general totality were used to estimate the equipment recovery time. The regression models of downtime were obtained and the magnitude of the increase in risks was determined depending on the cars’ input flow intensity.

1. Introduction

Russia is one of the largest grain exporting countries. Grain delivery from storage to the port for export is carried out mainly by the ground transport. The crops export flow is formed in the south of the Russian Federation.

In this regard, for several consecutive seasons, the problem of servicing automobiles - grain carriers at the port terminals in the Southern Federal District of the Russian Federation does not cease to be relevant. The processes’ seasonality at agricultural enterprises has an uneven effect on the transport and logistics structure of the region as a whole, as well as its individual elements. In a limited time, a significant number of grain trucks arrive at the port for unloading grain. Federal roads, intercity roads, technological facilities and terminal equipment, communications and data processing facilities, as well as personnel, are experiencing increased stress.

Earlier studies allowed us to analyze the grain crops flow to the terminals of the Rostov Region, the procedure for servicing grain cars, the effect of the terminals’ organization on the service parameters, and to assess risks depending on the type of cargo flow entering the terminal [1-5].

To increase the terminal’s throughput during the peak periods, maintenance and repair of existing equipment or the purchase, installation and testing of the new terminal equipment is required. To make the effective decisions in this area, it is necessary to assess the terminal risks with different strategies and, in particular, the impact of possible technological equipment failures on the car service.

2. Risk assessment

In this paper, the risk $R$ was considered as consequences of an undesirable event $A$ and defined as the product of damage $D$ and probabilities $P(A)$ occurrence of an undesirable event [6]:

$$ R = P(A) \cdot D. \tag{1} $$

Damage $D$ equal to the product downtime $T_d$ for the cost of one hour of work $C$. Equipment downtime $T_d$ is composed of downtime for organizational reasons and downtime $T_r$ due to sudden
failures. Probability $P(A)$ is obtained as a result of the arrival flow simulation of the grain carriers to the terminal and the flow of the terminal equipment sudden failures. The simulation was carried out for two types of incoming streams: simple random (SR-stream) and preliminary on-line recording (POR).

For input SR-stream time interval between the cars $\Delta t$ has an exponential distribution:

$$F_{SR}(\Delta t) = 1 - \exp(-\lambda(x) \cdot \Delta t).$$

where $\lambda(x)$ - is the flow rate, $x$ – is the month of the year. The flow rate during modeling was made dependent on the month of the year, the share of the terminal in the total volume of grain export and the car’s carrying capacity, such as grain crops and was based on two seasonal regression models [5].

For input stream with POR time interval between the cars $\Delta t$ is deterministic and equal to the maximum normalized value of the service time of one grain carrier in the terminal $\Delta t = \max\{t_{\text{norm}}\}$.

The normalized service time $t_{\text{norm}}$ may be increased considering the equipment recovery time after sudden failures [5].

As a probability distribution for the recovery time $t_r$, Weibull three-parameter distribution were selected:

$$F(t_r) = 1 - \exp\left(-\left(\frac{(t_r - c_r)}{a_r}\right)^b\right)$$

where $a_r$, $b_r$, $c_r$ – are the scale, shape, and shear parameters, respectively, determined by the maximum likelihood method for a small volume sample $n_r = 5-15$. To go from the statistical estimates of the distribution parameters obtained from the small samples $a_r$, $b_r$, $c_r$, the FISP method [7-10] was applied to the parameters of the general totality.

Risks of $n$ sudden failures during maintenance $t$, consisting of $m$ service time intervals can be determined by the formula:

$$R(t) = \sum_{i=1}^{n} C_{Ri} + \sum_{j=1}^{m} F_j(t)D_j(t),$$

where $F_j(t)$ – is the probability distribution on $j$-th service interval, $D_j(t)$ – is the rejection function, $C_{Ri}$ – defines the repair costs, determined in accordance with the methodology described in [9].

To assess risks using the formula (3), simulation modeling was used, the enlarged algorithm of which is presented in the flowchart (Figure 1). When modeling the car service at all posts, the methodology from [5] was used. The process was cyclically repeated until a predetermined number of equipment failures appeared. The source data for simulation were: grain arrival rate $\lambda(x)$, damage from downtime $D_j(t)$, the Weibull distribution parameters $a_r=50.2$, $b_r=2.1$, $c_r=60$, obtained during the statistical evaluation of empirical data on the restoration of truck unloaders, repair costs $C_{Ri}$, normalized service time $t_{\text{norm}}$. Car arrival process simulation was carried out for two types of flows.
The terminal equipment failures’ effect on the total risks of the grain terminal arising from the car servicing was assessed using the grain terminal example with an export flow of about 5% of the total grain export in Russia this season.

The terminal has a series-parallel functional structure. On the structural-logical diagram of the terminal, presented in Figure 2, the following conventions are adopted: 1.1 and 1.2 – the checkpoints at the entrance and exit, respectively; 2 – the post express grain analysis; 3.1 and 3.2 – the vehicle weighing points; 4.1 and 4.2 – the wheat unloading posts; 4.3 – the barley unloading post; 4.4 – the post unloading sunflower.

Automobile unloaders with a mechanical drive of a travel type are installed at the grain unloading posts (Figure 3). Repair of such equipment, depending on the type of failure, lasts on average from two hours to several days.
During the year, grain carriers come to the terminal with the following crop ratio: 78-80% wheat and 10-11% each of sunflower and barley. The nominal carrying capacity of grain carriers is 30 tons. Failure of the truck tipper at the posts 4.1 or 4.2 will lead to a stop of a more intensive flow of grain carriers than at the posts 4.3 or 4.4.

For the POR flow, it was found that the recovery of unloading equipment after sudden failures increases the risks by 3%, and the average service time at the terminal by 80-110%.

The total equipment downtime and the risks that arose in connection with this in the absence of failures and sudden failures at the first wheat unloading post with flow rate were determined for the SR stream $\lambda =0.05 – 0.15$, which corresponds to 8-235 serviced cars per day. Figure 4 shows the total equipment downtime depending on the intensity $\lambda$ in one of the simulation cycles. Blue dots correspond to downtimes without failures of unloading equipment, red dots correspond to failures. The average daily downtime of one car, depending on the input SR flow intensity, obtained as a result of modeling, has a rather large scatter. Statistical analysis of average downtime values made it possible to obtain the quadratic regression models with acceptable correlation coefficients $kor=0.94-0.95$ (figure 4).

The average daily downtime due to sudden failures of the truck tipper at one of the posts receiving wheat, with a high flow rate, increase compared to downtimes without equipment failures up to 9%. At low flow rates, failures do not have a clear negative effect on total equipment downtime.
Figure 4. The results of modeling and statistical processing of total downtime of equipment and vehicles

$$y = 62218x^2 - 9519.4x + 1100.9$$

$$kor = 0.95$$

$$y = 67577x^2 - 11431x + 1184$$

$$kor = 0.94$$

Figure 5. The increase in risks per day from the intensity of the flow and the corresponding month of the year

$$R/\text{Day}, \text{ mln rub}$$
Risk increase $R(t)$ depending on flow rate $\lambda$ due to the truck tipper failures is shown in Fig. 5. A positive logarithmic trend starts with $\lambda=0.51$, which corresponds to 74 - 75 cars arriving for service per day. Figure 5 also shows the months of the year to which this flow rate corresponds according to the statistical analysis results of the seven-year grain export flow [5]. It is important to note that in the summer and autumn seasons, mainly relevant to $\lambda>0.115$ additional risks from the equipment downtime after sudden failures may exceed 1 million rubles per day.

3. Summary
The servicing cars’ process simulation at the grain terminal made it possible to assess the increase in risks during sudden failures of unloading equipment at one of the posts with the well-known law of recovery time distribution. The resulting increase in risk is 3% in the stream with preliminary online recording and reaches 9% in the case of a simple random stream in peak months.

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