# Assessment of Production Setup and Upgrade Investment Risks

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**Abstract.** Today, investment in the real economy is a widely discussed topic. There are multiple points of view on implementing this mechanism. For Russia, such investment and the mechanism behind are urgent issues, as the country's machinery, equipment, and transports are mostly worn beyond limits. This paper discusses the matter of production system reliability. It also dwells upon the problems lack of reliability may represent. The authors describe a four-stage investment risks assessment method. They thus propose a method for testing the feasibility of financing the setup and upgrade of a production system. The proposed mathematical model will help increase return on investment by taking into account the reliability of process systems.

## 1. Introduction

Investment in the real economy mainly takes form of capital investment; international scientific research on the matter currently focuses on multiple different aspects of it. Some researchers analyze investment chains and how they can fund production setup and upgrades [1, 2, 3]; others discuss the most common production system models [4, 5, 6, 7, 8]; a third group emphasizes the innovation behind capital investment [9. 10, 11]

Russian scientists believe that industrial policies today should seek to upgrade the existing facilities, whereby the quantitative and qualitative characteristics of fixed assets become the single most important factor [**Ошибка! Источник ссылки не найден.**2].

## 2. Relevance

In today's Russia, capital investment is an urgent issue. According to official statistics, 47.3% of the country's fixed assets were worn beyond limits in 2017. Rosstat: wear-and-tear at 60.4% for machinery and equipment, 50.6% for transports in 2017 [13]. Russian economists claim 60% of the equipment the country's economy needs will have to be imported; this exacerbates the problem even further [14].

The situation leads to two extremes. On the one hand, businesses are not willing to fund capital investment; they seek to exploit their fixed assets to the point of depletion. A 2015 study revealed machinery and equipment was aged 13 on average, with 28% of the units being aged 15 to 30, and another 4% being older than 30 years [14]. Another extreme is that when the state or any other source provides the necessary funding, businesses purchase the best (and most expensive) equipment; however, lack of appropriately trained specialists or limited application result in considerable downtime.

 

Setting up and operating a high-performance production system requires reliable and cost-effective solutions. In the market economy, deadlines and requirements to return on investment become ever stricter.

A production system is effectively a flowchart of a company's processes [15]. Fixed assets and means of production constitute its single most important element. Reliability is a key performance indicator. It is defined herein as the ability of a system to operate efficiently over time [16]. Reliability comes down to proper coordination of system components to enable fail-safe operation [17]. Russian researchers believe reliability assessments must be based on cost effectiveness, which is the total cost of running a system as intended and completing the planned objectives [18]. Thus, investment and reliability are two interconnected concepts [19].

## 3. Statement of problem

Running an unreliable system carries excessive costs while also resulting in downtime, non-completion of key objectives and tasks, or even accidents that entail considerable losses and human toll. Less reliable machinery means more machines will have to be made; this is associated with excess consumption of raw materials, excessive capacities, and greater repair and maintenance costs.

A production system can be made more reliable by providing redundant core elements (backups), which will raise the investment in setting up the system, but will also lower the operating costs. This research seeks to optimize the investment in setting up and operating a production system.

## 4. Theory

Define reliability as the probability of fail-safe operation (the probability of survival) [19]

$$P(t) = 1 - n(t)/N, \quad (1)$$

where: $N$ is the number of healthy units at time zero;

$n(t)$ is the number of faulty units at time $t$ since the start of operation.

It is common to make systems more reliable by means of so-called redundancy, i.e. by adding parallel backups for the core components. When the system components work in parallel, the probability of survival is found as

$$P(t) = 1 - \prod_{i=1}^{n}(1 - Pi), \quad (2)$$

where: $Pi$ is the probability of survival for the ith link;

$n$ is the number of links running in parallel.

System reliability and the failure-associated risks comprise a complete group of disjoint events, which can be written as [4]

$$P_н + P_p = 1{,}0 \quad (3)$$

where: $P_н$ is the probability of survival;

$P_p$ is the probability of system failure.

At time zero, the probability of survival (or reliability) is 1 or 100%. As the system keeps running, this probability gradually drops to zero. On the contrary, the probability of failure increases over operating time.

The value of $P_p$ for a unit is proportional to its depreciation (%) per bookkeeping data; for calculations, the depreciation is converted to a decimal fraction.

The setup and upgrade investment risk assessment method is a four-stage process.

Stage 1. Find the occurrence rates of negative events.

Stage 2. Assess the severity of negative events.

Stage 3. Assess the upgrade-related investment risks comprehensively.

Stage 4. Model the process and investment risks in Mathcad [20].

*Stage 1. Find the occurrence rates of negative events.*

Find the occurrence rate of a negative event from the reliability of controls $P_p$. Parallelization improves system reliability as

$$P_p = (1 - P_н)^n, \quad (4)$$

where: $P_н$ is the probability of survival (the reliability);

$n$ is the number of backups in parallel.

However, redundancy means extra investment needed to purchase backups.

*Stage 2. Assess the economic severity of negative events.*

The severity of an event is based on the monetary loss, which is found from the costs of equipment [20]

$$S = \frac{m}{M}, \tag{5}$$

where: $m$ is the monetary loss incurred due to accidents and shutdowns;

$M$ is the costs of purchasing and installing new equipment.

*Stage 3. Assess the setup and upgrade-related process investment risks comprehensively.*

**Process and investment risk assessment** $R$ is a complex function of system reliability, investment, and monetary loss due to accidents and downtime.

$$R = P\, m/M, \tag{6}$$

where: $P$ is the probability (occurrence rate) of a negative event;

$m/M$ is the severity of investment loss incurred due to a negative event;

$m$ is the investment loss incurred due to a negative event;

$M$ is the investment to set up a system.

Transform the equation (6) as

$$RM = Pm = a, \tag{7}$$

where $a$ is a coefficient that links the occurrence rate of a negative event to investment loss; or links the risks and system setup investment.

Figure 1 shows the model (7), which visualizes how greater initial R&D investment reduces the process and investment risks.

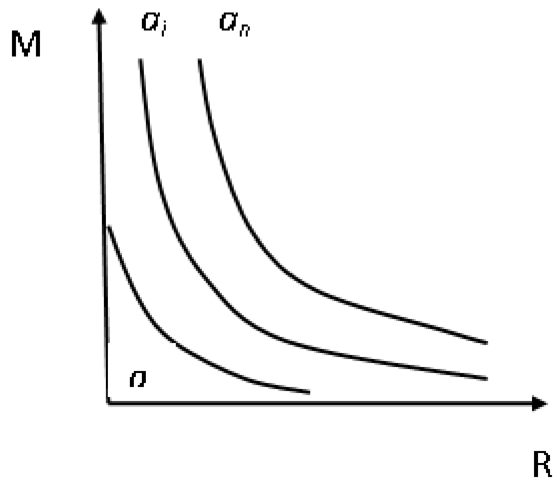


**Figure 1.** How the process and investment risks relate to the system engineering investment.

where $a$ is a coefficient that links the occurrence rate of a negative event to investment loss; or links the risks and system setup investment. The larger a system, the more investment it will need to be set up, the higher will be the curve $a_i$.

*Stage 4. Process and investment risk modeling.*

Given that the mathematical model (7) is a complex non-linear multifactorial model, use Mathcad [9].

## 5. Applicability

The ratio of risks $Ri$ to costs $Mi$ is indicative of how reliability-improving backups affect the return on investment.

$W_i = \frac{Ri}{Mi}$, (risk / rub) (8)

where $i$ is the number of links running in parallel

Costs of equipment repairs can be found from

$S(t) = m(t)M$ (9)

where $m(t)$ is the equipment condition factor. This factor can be found by the equipment condition assessment method proposed by L.S. Bayeva and T.Yu. Pasheyeva; the method is based on attributing one of seven parametric condition levels to each unit of equipment; the levels are based on the residual life (%) and can therefore be linked to the physical wear and tear expressed as a decimal fraction [**Ошибка! Источник ссылки не найден.**].

The probability (occurrence rate) of a negative event can be found as

$P(t) = n / T,$ (10)

where $n$ is the number of failures over time $T$.

Process and investment risks are quantifiable as follows

$R(t) = P(t)\, S(t)$ (11)

The non-linear multifactorial model (12) is computationally intensive for analysis and optimization of process and investment risks association with production setup and upgrades. This is why the authors hereof have developed a Mathcad algorithm for calculating the investment risk minimization parameters [9]. Figure 2 presents the model output.

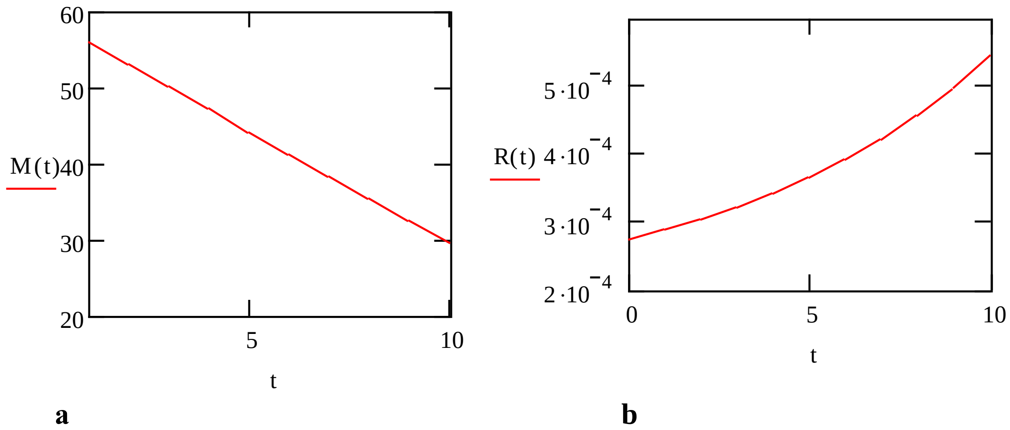


**Figure 2.** Calculating the system risk minimization parameters.

(a) lesser over-time costs

(b) higher over-time survival probability.

## 6. Conclusions

As shown in Figure 2, the $R(t)$, or the risk of system failure, increases over time and follows a parabolic trajectory, whereas the investment losses $M(t)$ drop over time, as the system has been made more reliable thanks to the backups placed when setting up the system.

The processes can be modeled in Mathcad by varying the parameters above to optimize (minimize) both the investment and the risks.

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