The impact of lean tools on the growth of overall equipment efficiency (OEE) in vehicle manufacturing

V S Shmatkov¹, A V Shmatkova²

¹ Irkutsk Aviation Plant - a branch of PJSC "Corporation" Irkut ", Novatorov Street, 3, Irkutsk, 664020, Russia
² Irkutsk National Research Technical University, Lermontov Street, 83, Irkutsk, 664074, Russia

E-mail: shmatkov_vs@irkut.ru, annashmatkova@yandex.ru

Abstract. The paper considers the organizational activities allowing to improve the return from the equipment at the expense of reducing timely revealed losses. The analysis of the significance of the effect of the proposed measures on the growth of OEE is carried out. The statistics of losses during the operation of the fleet of metal-cutting high-performance equipment used in the production of vehicles for 10 years is given, an analysis is performed. A method for calculating the motivation fund for bonus payments to interested personnel is proposed.

1. Introduction
For the effective implementation of OEE accounting methodology at the vehicle manufacturing enterprise, the following sequence of actions at the enterprise (10 steps) is proposed:
1. The study of classical technique, proposed by the Institute for Complex Strategic Studies.
2. Adaptation of the classical methodology to the needs and specifics of your enterprise (industry).
3. Experimental testing of the developed methodology at pilot sites, development of a loss classifier.
4. Development of the company's own regulatory documents for accounting and analysis of OEE.
5. Implementation of information systems in order to increase the objectivity of the received data and reduce the time of their collection and processing.
6. Development of a methodology for planning OEE coefficients.
7. Development and implementation of measures aimed at increasing OEE indicators (mainly by reducing organizational losses).
8. Motivation of staff for increasing OEE, incl. through the introduction of progressive forms of labor.
9. Adjustment of regulatory documents (clarification of the classifier of losses).
10. Integration of OEE data into MES systems, etc.

At most enterprises, mastering OEE accounting and analysis methodology is limited to points 1, 5, 7 and partly 8. It should be borne in mind that the use of the classical methodology on one or another equipment, production line, etc. not always possible. For example, it may be necessary to replace the productivity factor, which is difficult to calculate in the production of various products, with different labor intensity and processing cycles in the absence of implemented MES systems at workplaces, this
factor is applied on the conveyor with debugged cycles and a perfect planning system. Possible approaches to increase the objectivity of data on the operation of equipment are discussed in the article “Increasing the objectivity of data on the operation of CNC equipment using a log file (machine protocol) [1]. It is necessary to strive for online monitoring of OEE with the adoption of prompt corrective measures on a “here and now” basis in a standardized manner that is understandable for all involved personnel.

It is important to note that the very fact of accounting for the operation of the equipment allows at once, without any financial investments, to increase OEE by 5-10% by increasing production discipline and increasing personnel responsibility.

2. The main types of losses and corrective measures

The classifier of losses and their subsequent ranking according to their importance is usually compiled on the basis of the results of in-depth analysis when working on machines using a photograph of the working day, this method is more accurate, but very costly, it requires a large amount of labor of employees of the Bureau of Labor and Wages, especially if the equipment is working at the enterprise around the clock. It is possible to take as a basis the recommended classifier of losses with its subsequent updating for the specifics of production. In any case, the most significant losses that we can influence should be monitored, usually the list of such losses does not exceed 10. An example of a list of such losses is given in Table 1 with reference to corrective measures.

According to the information from table 1, it can be concluded that the main losses can be eliminated by the introduction of the main basic tools of Lean production, such as accounting for OEE, 5C, TPM, SMED, while the correction measures must be implemented mainly from left to right, as indicated in the table, thus achieving the maximum effect in increasing OEE. If in principle everything is clear with lean management, we will dwell a little on other corrective measures, they will not be considered in detail in this article. The main difficulty in calculating the load of equipment and scheduling its load, say for a month, is to determine the exact processing cycles, taking into account the performance of all the necessary intermediate operations, taking into account the control of the first part from the batch, especially on night shifts, lying, waiting and other force majeure. Shift is understood as the introduction of progressive forms of labor allowing to organize full-fledged round-the-clock operation of equipment, incl. on holidays and weekends, the most suitable mode is accounting of the timesheet according to the summarized hours worked for each operator separately, etc. taking into account all the requirements of the Labor Code of the Russian Federation. Staff motivation can be both direct and indirect. Direct motivation is understood as payments for a certain period of time (one-time, within a year, etc.) bonuses for achieving a certain level of OEE or reducing certain losses. At the same time, the motivational period may be due to the launch of a new product, a sharp increase in the production plan. Indirect motivation is understood as the share in wages, which depends on the achieved OEE indicators, but for this it is necessary to introduce new methods of calculating wages for machine operators. There is also another good motivator that allows you to increase OEE in certain areas - this is the brigade method of work. Today, there are few enterprises that can boast of a full-fledged transition to the brigade method of work when working on machine tools. Providing foremen with a certain set of functions is fraught with a number of legal and legal restrictions. With processing technology, not everything is so simple. Let's make a reservation right away that the replacement of equipment with an even more progressive one is not considered. Optimization of the processing technology of a part is a very labor-intensive process that requires fundamental knowledge and large resources of specialists. You also need to take into account a number of restrictions due to increased requirements for product quality, life tests, production certification, etc. [2] It will not be possible to obtain a large effect in increasing OEE due to the processing strategy, rather it will allow to achieve a higher stable quality, in some cases an increase in labor intensity is observed. Therefore, decisions must be very carefully weighed. The development of external cooperation in conditions of a decline in production strongly depends on the availability of guaranteed production plans for a long term of 5-10 years. Therefore, if there is a financial opportunity
and confidence in promising launches, then it is better not to load equipment with non-core orders and external cooperation, with the exception of cooperation on a common manufactured product.

Table 1. An example of a list of such losses

| Cipher | Name of losses | Corrective measures (corrective actions) |
|--------|----------------|----------------------------------------|
|        |                | Lean management | Other |
|        |                | Organization of OEE accounting | 5C | TPM | SMED | (PPM WP) | Equipment load calculation | Shift | Organization | Motivation (demotivation) | Processing technology | External cooperation |
| 0.2    | Manufacturing of a part according to the control program (CP) at low feeds | 0.3 | Manufacturing of a part according to CP at high feed | 1 | Preventive maintenance, equipment maintenance by specialists | 2 | Losses due to emergency stops and repairs | 2.1 | Equipment failure or repair | 2.2 | Tool breakage | 2.3 | Other emergency stops (no energy resources, etc.) | 3 | Operator service | 4 | Auxiliary time | 5 | Preparatory and final time | 6 | Organizational losses | 6.1 | No operator | 6.2 | Lack of download from the master | 6.3 | Absence or incompleteness of the service station | 6.4 | There is no blank | 6.5 | Lack of support staff in the workplace | 6.6 | Shift shifts, planning meeting | 6.7 | There is no CP, technical process | 6.8 | Solution of technical issues by services | 6.9 | Downtime due to lack of orders | 6.10 | Unidentified losses | 7 | Losses in the implementation of CP | 8 | Losses during interoperational movements | 9 | Regulated breaks |

| Start | finish |
|-------|--------|
| + | (+) |
| + | + |
| + | + |
| + | + |
| + | + |
| + | + |
| + | + |
| + | + |
| + | + |
| + | + |
| + | + |
| + | (+) |
| + | + |
| + | + |
| + | + |

3. Increasing OEE through Lean Management

5C is a basic tool; without it, the implementation of subsequent tools and the implementation of other organizational measures are impossible. As a rule, the organization of a workplace according to the 5C system allows, without special financial investments, to increase OEE by 3 - 5% by reducing the auxiliary time, preparatory and final time and other unproductive work. At the same time, the
involvement of workers in kaizen is impossible without 5C. The 5C tool is simple and straightforward, at enterprises there are differences only in the assessment of the fifth stage - "Improvement". At our enterprise, we assess the fifth step if two conditions are met: regular audits of workplaces according to the approved methodology with filling in the “5C radar sheet”, see Fig. 1. according to the schedules and participation of workers in the submission and implementation of kaizen proposals. If desired, this fifth level can be supplemented with two more evaluation criteria - labor protection (knowledge of labor protection instructions and their implementation) and fire safety (knowledge of fire safety rules and their implementation). There are two components of success with this tool - the will of the head of the enterprise and motivated staff without administrative "pressure".

### Figure 1. Radar 5C.

TPM - this tool is directly related to the equipment availability ratio. At the same time, this is the case when the growth of losses for equipment maintenance leads to either a significant reduction or prevention of losses associated with emergency downtime in the future. Therefore, this type of loss (codes 1 and 3, see Table 1) must be considered in combination with losses (codes 2.1 and 2.3). Correct implementation of the methods of scheduled maintenance and current repairs of high-performance equipment in modern conditions [3-8] can increase the equipment availability factor to 18%, in terms of OEE (with a loss factor of 0.65, a quality factor of 1.0) will be about 12%.

SME tool is a quick changeover, it is not acceptable for metal-cutting equipment in the aviation industry in its pure form. This tool is well implemented in blank production when working on complex and massive dies, mainly in the automotive industry, where the changeover time is hundreds and thousands of times longer than the part stamping time. Nevertheless, such works on the study of SME in 2014 on metal cutting machines were carried out. A video camera was used for observation. As a result of the subsequent viewing of the videos, the specialists filled out the protocols, the recommended form is shown in Table 2.
Table 2. Result of the subsequent viewing of the videos

| No. | Action | Total time | Time of a separate stage | Internal | External | Changeover phase | Decision |
|-----|--------|------------|---------------------------|----------|----------|------------------|----------|
| 1   |        |            |                           |          |          |                  |          |
| 2   |        |            |                           |          |          |                  |          |
| 3   |        |            |                           |          |          |                  |          |
| 4   |        |            |                           |          |          |                  |          |
| 5   |        |            |                           |          |          |                  |          |
| 6   |        |            |                           |          |          |                  |          |
| 7   |        |            |                           |          |          |                  |          |
| 8   |        |            |                           |          |          |                  |          |

The analysis of the existing changeover ended with the development of changeover improvements; the recommended form is shown in Table 3.

Table 3. The analysis of the existing changeover ended with the development of changeover improvements

| No. p/p. | Operation name | Actual time | Suggestions for improvement | Expected time | Actual received time |
|---------|----------------|-------------|-----------------------------|---------------|---------------------|
|         |                |             |                             |               |                     |

Based on the results of the work carried out, recommendations were made, the main ones are shown in Table 4.

When implementing the above recommendations, it is necessary to take into account:

- batch (seriality);
- relevance of the manufactured product for the future and the development strategy of the enterprise;
- financial feasibility (payback of expensive equipment, machines with interchangeable pallets), etc.

This tool, as applied to high-performance equipment, can also be supplemented with well-forgotten methods from the scientific organization of labor (STO) of the Soviet era, namely, elements of planned preventive maintenance of workplaces (PPMWP). An example of the time schedule for the PPMWP for machine tools is shown in Table 5.
Table 4. Results of the work carried out

| No | RECOMMENDED ACTIONS                                                                                                                                                                                                                                                      | Executor                  |
|----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| 1  | Filming device in conjunction with the last item of the batch. The removal of the part from the device and its control should be carried out after starting the CP of the next batch.                                      | Operator                  |
| 2  | Fill in the operator's report on work with the machine running immediately before the end of the program, and immediately after starting a new one.                                                             | Operator, master          |
| 3  | Prepare fixtures, tools and fasteners in advance before the end of the work on the previous program.                                                                                                              | Operator                  |
| 4  | Use progressive wrenches (ratchet, ring, etc.).                                                                                                                                                                 | Operator, technologist    |
| 5  | Do not unnecessarily clean the machine between changeovers.                                                                                                                                                      | Operator                  |
| 6  | Monitor the safety of the equipment, its completeness. Ensure the safety of removable elements (identify them).                                                                                                   | Operator, technologist    |
| 7  | Participate in the submission of Kaizen proposals for the unification of fasteners of the equipment, simplification of its design.                                                                           | Operator, foreman, technologist |
| 8  | Make the most of the quick-detachable elements of the service station (such as "plugs", etc.).                                                                                                                                 | Constructor               |
| 9  | Provide the ability to install and remove the part on the device outside the machine.                                                                                                                            | Constructor               |
| 10 | It is imperative to carry out external adjusting elements that allow you to configure the equipment on the machine with the installed and pressed part.                                                             | Constructor, programmer   |
| 11 | Indicate on sketches in the technological process and marks on the equipment of the exact location of the clamps, clamps, etc.                                                                                      | Programmer, constructor   |
| 12 | Provide in technological processes with complex equipment of a photo of a part installed and clamped in a fixture.                                                                                               | Technologist              |
| 13 | Make the most of typical lodgements - racks for attaching equipment. Create a catalog of existing overpasses (supplement if necessary).                                                                         | Programmer, constructor   |
| 14 | Unify fasteners. Introduce restrictions on the use of standard sizes of fasteners.                                                                                                                            | Constructor               |
| 15 | Use, where possible, fastening the part to the cradle with bolts, screws, etc. into the holes of the part or technical admission.                                                                               | Programmer, constructor   |
| 16 | Provide storage space for removable elements on the tooling plates. Provide spare parts and accessories - spare pins, nuts, washers.                                                                            | Constructor               |
| 17 | Apply the same type of tool setups, minimize specialized tools.                                                                                                                                                 | Programmer                |
| 18 | The use of modern quick-detachable elements for fixing parts and accessories on the machine table. Availability of rotary tables (replaceable pallets).                                                          | Leading department        |
### Table 5. Example of the time schedule for the PPMWP for machine tools

#### Organization of part launches

| Subject of Labor          | Launch | Ahead of time | Charting | Ahead of time |
|---------------------------|--------|---------------|----------|--------------|
| Nomenclature of parts     | Planning Technician | One month ahead | Master | 5 working days before starting reporting month |

#### Acquaintance with the production, shift task

| Employee service                  | Formation | Ahead of time | Familiarization of the employee | Ahead of time |
|------------------------------------|-----------|---------------|--------------------------------|--------------|
| Production assignment              | Master    | 2 days        | Operator                        | 2 days       |
| Shift job                          | Master    | 2 days        | Operator                        | 2 days       |
| Shift job (replacement option)     | Master    | 1 day         | Operator                        | 1 day        |
| Emergency deficit                  | Master    | 1 day         | Operator                        | 1 day        |

#### Completion of the tool, service station, TD

| Subject of Labor | Responsible No 1 | Responsible No 2 | Request | Completion |
|------------------|------------------|------------------|---------|------------|
| Tool             | Worker           | Master           | 1 day before the start of work (taking into account the availability of the tool according to receipts and tool books) | Head instrumental distribution pantry (IDP) |
|                  |                  |                  | 1 day before the start of work (taking into account the availability of a service station according to the service station issue card) | Head IDP |
| Rig              | Worker           | Master           | List for 1 week                  | Archivist |
|                  |                  |                  | According to the Memo on the formation of request for cutting a workpiece | 1 day before starting work |
| TD (technical process, drawing)   | Master          | -                | List for 1 week                  | Archivist |
| Acquaintance with TD Blank         | -                | -                | -                                | - |
| Blank                          | According to the Memo on the formation of request for cutting a workpiece | |

#### Product control

| Subject of Labor | Notification of employees of quality control department | Control |
|------------------|---------------------------------------------------------|---------|
| Control          | Master (Worker)                                         | 1 hour  |
|                  | Employee of quality control department                   | 0.2…1  |

Control time, h
no more

Control time, h
no more
Within the framework of the PPMWP, it is recommended that the procedures for providing workplaces with the required labor tools be accompanied by one-page instructions (leaflets), an example of such instructions is given in Table 6.

Table 6. Example of instructions

| No | p/p | Executor |
|----|-----|----------|
| 1  |     | Master   |
| 2  |     | Work distributor |
| 3  |     | Toolmaker |
| 4  |     | Storekeeper IDP |
| 5  |     | Toolmaker |
| 6  |     | Toolmaker |
| 7  |     | Operator |
| 8  |     | Toolmaker |
| 9  |     | Tool engineer |

As a result, the implementation of the PPMWP will increase OEE by 5 - 7% by reducing organizational losses. It should also be noted that the impetus for the introduction of this tool can serve as an increase in the workload of production and the formation of "bottlenecks". The tool does not work in low production conditions.
4. Loss statistics

Beginning in 2008, after receiving and launching the last batch of new high-performance equipment, a more in-depth analysis of losses and operational time was started. Statistical data on the achieved components for calculating the OEE coefficients are summarized in Table 7.

| Cipher | Description of works, losses                      | stage 1 | stage 2 | stage 3 |
|--------|---------------------------------------------------|---------|---------|---------|
|        |                                                   | 2008    | 2009    | 2010    | 2011    | 2012    | 2013    | 2014    | 2015    | 2016    | 2017    |
| 0      | Operational time                                  | 46      | 54      | 67.1    | 65.5    | 53.4    | 46.2    | 47.8    | 52.7    | 57.5    | 55.3    |
| 0.1    | Manufacturing of a part according to CP           | 65.8    | 62.3    | 48.2    | 42.5    | 42.5    | 47.5    | 51.8    | 49.6    |         |         |
| 0.2    | Manufacturing of a part according to CP at low feeds | 1.3    | 3.2     | 5.2     | 3.4     | 4.6     | 4.6     | 4.9     | 5.2     |         |         |
| 0.3    | Manufacturing of a part according to CP at high feed |         |         |         |         |         |         |         |         |         |         |
| 1      | Preventive maintenance, equipment maintenance by specialists | 1.2    | 2.0     | 1.2     | 1.3     | 1.8     | 1.2     | 1.0     | 1.2     |         |         |
| 2      | Losses due to emergency stops and repairs         | 7.0     |         |         |         |         |         |         |         |         |         |
| 3      | Service                                           | 1.2     | 0.8     | 1.2     | 1.1     | 0.7     | 0.9     | 0.9     | 0.9     |         |         |
| 4      | Auxiliary time                                    | 20.0    | 14.0    | 9.2     | 7.0     | 9.3     | 9.5     | 12.0    | 11.6    | 11.7    | 11.0    |
| 5      | Preparatory and final time                        | 2.0     | 2.0     | 1.6     | 1.0     | 1.0     | 1.3     | 1.5     | 1.7     | 1.7     | 2.5     |
| 6      | Organizational losses                             | 15.0    | 12.0    | 5.6     | 9.7     | 16.5    | 30.1    | 27.0    | 19.4    | 11.9    | 16.6    |
| 6.1    | Absence of an operator (including on holidays)    | 0.3     | 3.1     | 2.9     | 3.6     | 4.0     | 3.8     | 3.0     | 2.8     |         |         |
| 6.2    | Lack of download from the master                  | 0.0     | 0.2     | 1.0     | 2.0     | 2.8     | 0.8     | 0.7     | 1.8     |         |         |
| 6.9    | Downtime due to lack of orders                    | 0.0     | 0.7     | 2.2     | 15.8    | 17.4    | 13.6    | 7.3     | 10.0    |         |         |
| 7      | Losses in the implementation of CP                | 1.1     | 0.6     | 1.0     | 0.8     | 1.7     | 2.5     | 1.8     | 1.0     |         |         |
| 8      | Losses during interoperational movements           | 0.2     | 0.1     | 0.1     | 0.1     | 0.1     | 0.1     | 0.1     | 0.1     |         |         |
| 9      | Regulated breaks                                  | 10.0    | 7.0     | 6.6     | 7.0     | 5.9     | 4.0     | 2.5     | 2.8     | 2.6     | 2.6     |

The entire presented observation period can be divided into three stages:
- Stage 1 - manual collection and analysis of information according to our own developed methodology;
- Stage 2 - manual collection and analysis of information in accordance with generally accepted guidelines for accounting for OEE [9], development of standard documents of the enterprise;
- Stage 3 - automated collection and analysis of information to improve the objectivity of the data.

From the given data, we want to note some features:
- a sharp increase in accidents in 2009 (cipher 2) with the subsequent adoption of a large set of corrective actions;
- starting from 2011, it was decided to attribute losses not to the organization of work on official holidays, as a result of the increase in losses due to the lack of operators (cipher 6.1). To organize work on these days, the personal consent of the employee is required, which greatly complicates the formation of shift schedules for machine tools;
starting from 2013, there has been a decrease in the load, see losses cipher 6.9 and, as a consequence, a slight increase in the preparatory and final time (cipher 5) due to small launch batches;

- since 2013, in order to prevent accidents, improve the quality of the surface layer of the part and reduce wear, a loss was introduced - the manufacture of a part according to CP at high feeds (cipher 0.3);
- the reduction in scheduled breaks (code 9) was mainly due to the reduction in lunch breaks.

It is important to note that with a constant, say OEE, or its slight decrease over the years, the volume of products removed from the machines increases due to:
- optimization and improvement of technology, namely mechanical processing from year to year due to new strategies, tools and modes, equipment characteristics, etc.;
- planned annual reduction in labor intensity;
- increasing the share of serial work instead of implementing control programs.

5. Development of activities
The recommended form of measures to reduce losses when working on high-performance equipment in the shop (on the site) is shown in Table 8.

Table 8. The recommended form of measures to reduce losses when working on high-performance equipment in the shop (on the site)

| Loss cipher | Description of losses | The amount of losses for the previous period, % | Corrective Action | Performers | Period of execution | The type of document that ends the work | Expected reduction in losses, % |
|-------------|-----------------------|-----------------------------------------------|-------------------|------------|---------------------|---------------------------------------|-------------------------------|
| 1           |                       |                                               |                   |            |                     |                                       |                               |

Below are the most requested and most relevant actions.

Possible corrective measures:
- Organization of multi-station service if necessary;
- Provision of personnel for work in the 2nd and 3rd shifts - accelerated training and transfer of operators from other machines;
- Organization of work on weekends and holidays;
- Preparation and availability of a backup alternative loading of the machine in case of forced downtime, especially after hours and at night;
- Organization of photography of the working day, timing of auxiliary time and preparatory and final time, identification of reserves for revising labor standards;
- Organization of scheduled maintenance and repair of equipment during forced downtime;
- Organization of adjustments and implementation of control programs in the 2nd shift;
- Motivation of personnel for identifying and reducing losses.

Possible corrective actions:
- Application of new forms of payment for operators' labor (refusal from piecework payment).
- Increase in machine load due to the additional volume of transfer of the nomenclature from other equipment, incl. universal;
- Advance launches of promising product series;
• Organization of off-hours and night shifts for specialists of repair services;
• Implementation of procedures for training, testing and certification (recertification) of operators for the right to work;
• Implementation of procedures for the analysis of emergencies and prompt repair of equipment, incl. under warranty. Communication of information to all interested workers and operators. Creation and maintenance of a database on repairs;
• Development and implementation of regulations for scheduled preventive maintenance of equipment, procurement of spare parts and consumables, PPMWP, control of the first part from a batch during off-hours and at night, calculation of equipment load, scheduling of operators' shift, etc.
• The transition to the brigade method of labor.

6. Conclusion
Information on the specific gravity of the tools with which it is possible to increase OEE indicators is summarized in Table 9.

Table 9. Information on the specific gravity of the tools

| No p/p | Tool (correction measures) | Growth OEE, % |
|--------|----------------------------|---------------|
| 1      | Organization of OEE accounting | 5 - 10        |
| 2      | 5C                          | 3 - 5         |
| 3      | TPM                         | 5 - 12        |
| 4      | SMED (PPMWP)                | 5 - 7         |
| **TOTAL** |                      | **18 - 34**   |

In accordance with the data in Table 9, on average, the introduction of these Lean Manufacturing tools will increase OEE by 18 - 34% (on average by 25%), depending on the quality of the activities being carried out.

From practice, at the start of the introduction of lean technologies, OEE usually does not exceed 40%. Consequently, in a short time, it is possible to increase OEE up to 65% only through organizational measures. This value is an average indicator and applies to the entire fleet of equipment, so OEE on individual machines can reach 80% or more, and on machines with a specific unique technology, OEE may not exceed 30%. A further increase in OEE is possible due to:

• stable production load when entering a large-scale debugged production, ideally one product;
• technology optimization;
• the introduction of other forms of work organization, allowing to increase the internal motivation and consciousness of personnel, especially operators.

6.1. Motivation for the implementation of Lean manufacturing tools that increase OEE
We would like to give a simple method for calculating the motivation fund based on the cost of one machine-tool hour [10] using the example of one machine. The lower OEE, the higher the cost of the machine tool hour, and therefore the cost of losses (lost profits), also measured in hours.

Initial data:
1. Achieved or starting indicator OEE1 - 40%;
2. The planned indicator OEE2, to which we strive - 80%;
3. Conventional unit (1 cu) = 70 rubles;
4. The average cost of a machine-tool hour with OEE equal to 40% is 72.83 USD [ ];
5. Fund of the machine tool per month - 720 hours (with 30 days).

Thus, the calculation of losses per month is performed according to the formula:
Losses = \((OEE2-OEE1)/100)\cdot \text{monthly fund of the machine} \cdot \text{machine hour cost} = \((80-40)/100)\cdot 720 \cdot 72.83 = 20,975.04 \text{ USD/ month.}

20,975 USD losses per month from only one machine, with 10 machines this is already 200,000 USD. etc. It is more convenient to operate with a different value, namely, not achieving OEE by one% brings 524.36 USD losses per month from one machine.

Since some of the personnel are involved in the maintenance of more than one machine tool in the shop, I propose the following dependence of the calculation of the share of motivation on lost profits, the data are summarized in Table 10.

| Table 10. The data summarized information |
|------------------------------------------|
| Number of machines | 1 machine | 10 machines | 25 machines | 50 machines | 100 machines |
| % of the increase in OEE (avoidance of losses) | 30% | 25% | 20% | 15% | 10% |

Note: Achievable annual growth of OEE is approximately 10-12%. Thus, with properly planned work, you can reach the average planned OEE indicator of 65% in the third year of operation. And given that the enterprise bears the maximum losses at the very beginning of the journey, with a low OEE, then the share of motivation during this period will be greater. In the future, in the process of achieving the planned OEE, the motivation according to the proposed method decreases, since OEE will increase and the cost of the machine-tool hour will decrease. You should not completely abandon motivation, since the subsequent growth of OEE will be associated with the improvement of more complex processes, where each subsequent percentage of OEE will be given with great difficulty, and it is also not easy to maintain the achieved state.

References

[1] Shmatkov V S, Timokhin R S, Shmatkova A V 2017 Increasing the objectivity of data on the operation of CNC equipment using a log file (machine protocol) Automation. Modern technologies Vol. 71 6 254-259
[2] Karlina Yu I, Kargapoltsev S K, Gozbenko V E, Karlina A I, Leonovich D S 2021 Selection of tools and cutting modes for turning small-sized high-precision parts of micro-wave electronics from beryllium bronze IOP Conference Series: Materials Science and Engineering 1064 012016
[3] Shmatkova A V, Shmatkov V 2018 Organization of scheduled maintenance and current repairs of high-performance equipment in modern conditions Machines and tools 5 36-40
[4] Karlina Y I, Kargapoltsev S K, Gozbenko V E, Leonovich D S, Karlina A I 2021 Automation of preproduction processes for high-precision small-sized parts on CNC machines IOP Conference Series: Materials Science and Engineering 1064 012017
[5] Konyuhov V Y, Gladkii A M, Zott R S 2021 Machine-building enterprise performance and quality improvement tools IOP Conference Series: Materials Science and Engineering 1064 012021
[6] Gladkii A M, Konyuhov V Yu, Galyautdinov I I, Shchadova E I 2020 Suggestions for improving the efficiency of repair activity IOP Conference Series: Materials Science and Engineering 760 012022
[7] Konyuhov V Y, Gladkii A M, Zott R S 2020 Accelerator as an effective replacement of a business incubator in the Irkutsk region Journal of Physics: Conference Series 1582 012045
[8] Lysenko D A, Olentsievich V A, Vlasova N V, Konyukhov V Y 2021 Formation of new principles and models of operation of structural units of the industry under the conditions of implementation of digital technologies IOP Conference Series: Materials Science and Engineering 1064 012025
[9] Overall equipment efficiency 2007 Translation from English (Moscow, Institute for Comprehensive Strategic Studies) p 120
[10] Shmatkov V S, Shmatkova A V 2017 Calculation of economic efficiency and cost of a machine-tool hour when working on high-performance equipment *Machine tools and tools* 12 8-12