

## DEPENDABILITY SHAPING APPROACH OF DEVICES USED IN PRODUCTION PROCESS

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### Abstract

*Paper presents the methodology of shaping dependability of devices used in process with use key performance indicators for increasing Overall Equipment Efficiency (OEE) which are a subject of devices' parameters monitoring under operation. Value of Overall Equipment Efficiency describes the technical state of devices included into production process. Value itself can be different for different production lines even in one industry. For engineers it is important to put all possible effort to increasing values of particular key performance indicators which are building Overall Equipment Efficiency. Values of particular key performance indicators, shows to experienced engineer real technical state of whole production line. Presented in paper selected indicators are connected and have influence for each other, moreover operation parameters of devices' are characterizing production process.*

*Key performance indicators presented in paper represents three the most important aspects of the production process: handling of the process, operators' area of responsibility, management of the process, managers' area of responsibility and optimization of the process, planners' area of responsibility. Only proper cooperation of these three groups of people can benefits requested result. From owners point of view, presented areas have the same importance, problems created in one of them can negatively influence for overall income of whole enterprise.*

**Keywords:** *availability, production process, OEE indicator, synergy effect, constantly improvement*

### 1. Introduction

In production process, issue of dependability of devices and in particular increasing of dependability's value is quality and quantity solution to reach production enterprise's mission. Enterprise's mission is a vision of owners, realize by board of directors, management and all employees. Most effective visions are inspiration for all employees and motivate them to more effective work. The main reason of enterprise's activity is not a profit. The main reason is to find client or better group of clients and convince them to offered product or service. Profit is appearing after that, when satisfied clients bring money, that's how it works. His is the best way to creating addend value of enterprise for owners and shareholders. Without value for client there is no value for owner. Client is a source of long term cash flow in enterprise.

It is not good idea to offer for client bigger value than he is ready to pay. Here we can found expression cost of production. To save satisfy margin, we have to take care about low costs of production or better to constantly decrease these costs with simultaneously taking care about satisfied quality. Production costs are very often most important factors, deciding about competitiveness particular product and particular producer. Production costs and different methods of decreasing these costs are now one of most important issues for highest management of production enterprises. We can find many methods of decreasing costs: in this article we will present method of decreasing production costs due to increasing dependability of devices included into production process.

How to do it? The answer is simple: constantly improvement the process itself, through improvement of process parameters and constantly training of crew. This process shouldn't end. His solution is proved in practice and is universal, so can be implemented in different kinds of industry. This method enriches enterprise managing in engineer's view beside the business view.

Engineers view helps in proper usage of enterprise's resources, thanks to this we can increase production process both for quality and quantity sides. Under valuate and simple activities, as taking care about workshop, cleaning of tools, can benefit increasing of value of dependability of whole production process. Very often some small issues are ignored, but in final have key meaning. Thanks to engineer's view on the stage of taking decision, about needs of production process, managing of enterprise can be much more effective. Thanks to that we can achieve synergy effect in managing process. Both view business and engineering in perfect way are complementary to each other. Thanks to that we can fulfil all needs of production process, raw materials, automation, maintenance and operators. Synergy effect in managing process has influence for shaping competitive position of enterprise on the market.

The dependability problem of devices under operation has been discussed in several publications, for example [1-6]. Paper presents the methodology of shaping dependability of devices used in process with use key performance indicators for increasing Overall Equipment Efficiency (OEE) which are a subject of devices' parameters monitoring under operation.

**Definition**

*Availability* – property of device, shows skill do be on the technical status ready to fulfil required functions in settled circumstances and period of time [4] - Fig.1 and Fig. 3, where: MTBF – Mean Time Between Failure, MTTR – Mean Time To Repair, MTTF – Mean Time To Failure.

*Inherent Availability* is stated in project phase of device and taking into consideration MTBF and MTTR.

*Achieved Availability* from maintenance point of view, includes as well operational maintenance, preventive maintenance and reactive maintenance, excludes organizational delays and purchasing delays.

*Operational Availability* is determine by reliability MTBM – Mean Time Between Maintenance, susceptibility for renovation MMT – Mean Maintenance Time and susceptibility of supporting system MLDT – Mean Logistic Delay Time.

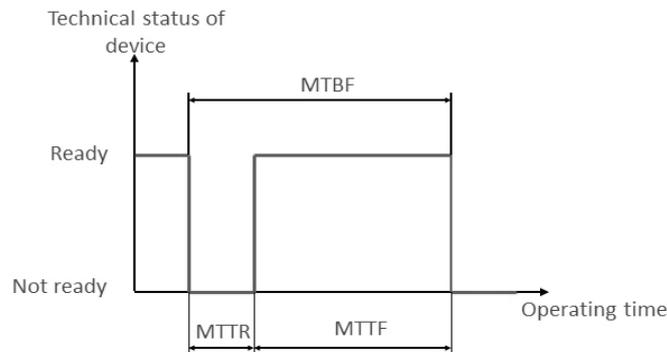


Fig. 1. Chart availability of device

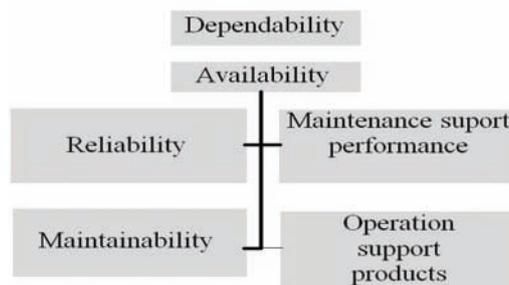


Fig. 2. Dependability of device/ system operator – device [4]

During exploitation process of device there are changes in characteristic  $q$  of device (see Fig. 3.) and we can distinguish phases of brake in, stabilize and accelerated changes of exploitation parameters.

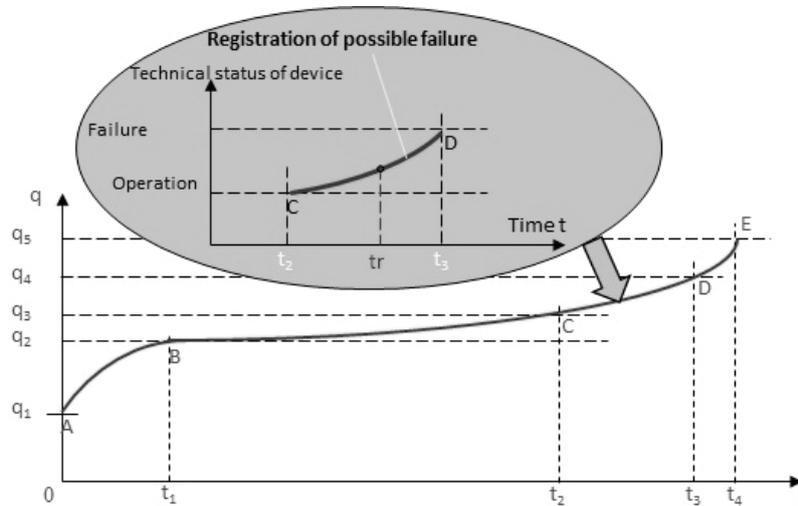


Fig. 3. Characteristic of exploitation parameters [4]

Characteristic of exploitation parameter's changes during operation is most often random and depends on circumstances of operate, that's why very important is to monitor selected characteristic of device to keep availability on required level. Obviously danger of serious devices' failure is growing with time of exploitation. In cycle of exploitation devices passing from state of fitness to state of unfitness. It is important to control this passing and minimization time of rebuilding state of fitness of devices.

Unexpected failures of devices can be reasons of operator's accidents that are why it is important to maintaining these devices in proper way. Predictable and preventive maintenance seems to be good solution help with those activities. Of course not every failure can be eliminated, but reducing number of device's failures will reduce danger of operator's accident.

## 2. Methodology of proceeding during shaping of dependability of devices in production process

Production process example we can present as a scheme presented on Fig. 4. Each production process needs raw material, technology and energy. Process is supported by machines which are a subject of operation and controlled/ steering by operators. In case of decreasing dependability below requested value, we have to start aid activity.

We know from cycle of exploitation, that state of machine's availability is changing form up time to fault in time and maintenance is needed – Fig. 5.

How to control the best moment of transition? One of answers is to use proper methods of maintenance. Overall we can distinguish three methods of maintenance:

- reactive, characterizes by fixing failures,
- predictable, characterizes by predict failures according exploitation time,
- preventive, characterizes by avoiding failures according real state of device.

*Reactive* maintenance is most expensive. Practices depend on fixing what is broken, without any preventive activities generate a lot of not necessary costs. This approach is characterizing that reaction is activate by failure of device or broken part. Fast fixing is always expensive. The reason of his approach is that some enterprises have no data bases with possibility to analyze problems from the past. From other side data base with described past problems can be very valuable to count real costs of maintenance activity.

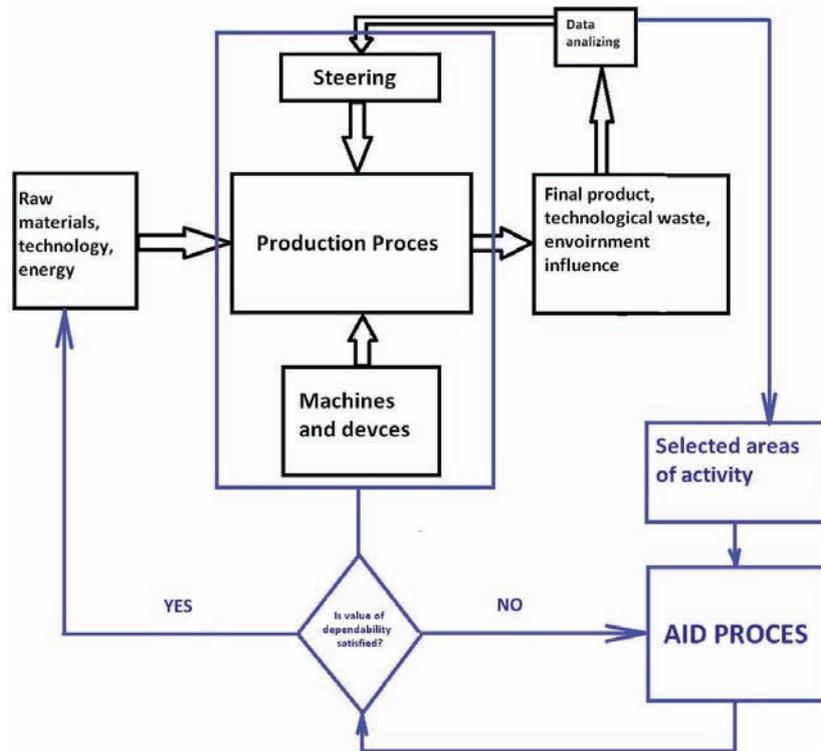


Fig. 4. Scheme of production process included control of dependability value



Fig. 5. Cycle of machine's exploitation example.

Predictable maintenance is depending on device's cycle of life. Thanks to that we can expect work without failure in majority of production time. Setting reasonable form economical point of view schedule of maintenance is a result of knowledge and experience of operators. But there is a question: if replace of some part was really reasonable? If we consider single elements, when we can calculate state of their efficiency, we can say that balance of advantages and disadvantages is positive for us. Problem appears if we have to replace very expensive part or element or if amount of these parts is big. Also we must remember that this solution forces on us time of maintenance job.

Preventive maintenance is depending on real status of the device. Thanks to implementation special monitoring system, we can achieve goal which is only guessing in predictable maintenance. We stipulate real state of device and then we taking decision about scheduling some maintenance task. Of course, special dedicated monitoring systems for particular production line is not a cheap solution, that's why we have consider always economical balance and calculate savings thanks to potential increasing dependability of devices with cost of implementation this system.

If after considering all main methods of maintenance we should establish maintenance in our plant founded only on preventive? Not exactly, experience proves that not everything we can

predict and not everything we can prevent. That's why proper maintenance of machines and devices in production enterprise should be rational combination described above types of maintenance. Of course to find moment of transit machine's state from up time to fault, the best seems to be preventive maintenance. If we constantly monitor technical state of device, we can decide when we replace worn parts, thanks to that we are able to we can cumulate several activities from maintenance in one delay to maximize production time.

Other important thing must be mentioned, is that monitoring of technical state of devices have very big influence for spare parts management. Knowledge about real state of devices can help to create reasonable from economical point of view storage. Too big storage is wasting money and from other side too less can be a reason of unexpected stops of production.

Process dependability can be presented as the set of dependability of particular machines and devices involved into production. In Fig. 6 and 7 examples of selected devices set have been presented, which articulates ability to keep in technical state enable to achieve expected functions in some circumstances and in particular period of time.

If the value of dependability in time  $t_1$  is on satisfied level (Fig.6), production process can be provided in normal way. This value is close to reference value, which we can calculate according key performance indicators delivered by supplier of production line. Time  $t_1$  is an up time in cycle of life time of devices. Problem appears when value of dependability of process is going below satisfied value.

Dependability of Production Process in time  $t_1$  is a congeries includes dependability of particular devices included into process in  $t_1$

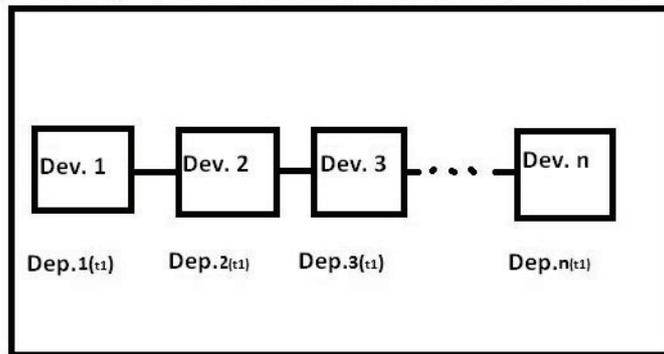


Fig. 6. Dependability of production process in time  $t_1$

Time  $t_2$  is a time of fault of the process down to fault on one or more devices included into production process (Fig. 7). This is the moment for beginning of fixing activities, which will bring value of dependability into satisfy value and process can came back to up time.

Dependability of Production Process in time  $t_2$  is a congeries includes dependability of particular devices included into process in  $t_2$

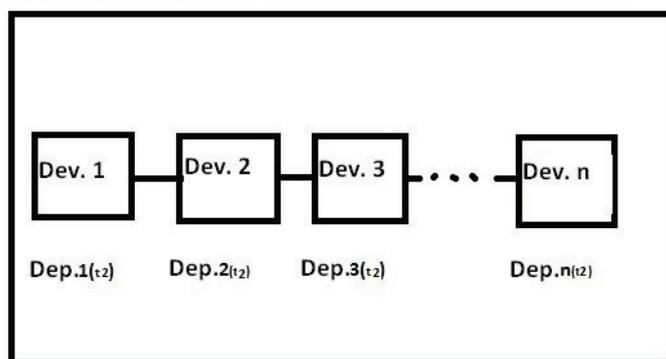


Fig. 7. Dependability of production process in time  $t_2$

### 3. Experiment example

Experiment regarding adjusting activities in area of machines and devices includes into the rolling process. From Fig. 4 we selected blue rectangle, this is area of activity of machines and devices inside production process. Activities presented in experiment, describes situation, when value of dependability drops below expected value. To increase value of dependability of the process, there was designed project of aid and thanks to data base built by monitored parameters, areas of activity were selected. Handling of production process, management of the process and optimization of the process.

The best parameters presented change of value of dependability machines and devices thanks to proposed activities are Overall Equipment Efficiency (OEE). OEE factor has very big influence into constantly improvement process. Calculation is transparent and understandable for all involved into the process people. On first sight there is visible which area should be fixed to increase overall result. Management of the plant can put their effort and attention in area of availability, productivity or quality (Fig.8):

$$OEE = \%PT \times \%SL \times \%Y, \tag{1}$$

where:

%PT- Productive Time,

%SL- Speed Looses,

%Y - Yield in %.

For particular rolling process example the productive time is possible present as on Fig. 8 and express additional via equation 2. Example presents rolling mill with annual capacity about 275 000 [t] and average price for final product 2150 [PLN/t]. Time of experiment duration - 6 months; results were measured in monthly cycles. Value of OEE on the beginning of experiment was calculated on the level of 59.83%. To achieve better OEE value activities described as bellow have been undertaken.



Fig. 8. Productive Time

$$\% PT = RT+GT/AvT, \tag{2}$$

where:

% SL - ratio between real production speed (t/h) to standard speed,

% Y - ratio between amount of final product to raw materials.

#### 3.1. Undertaken Activities - Handling of production process

Activities touch trainings for operators, preparation and implementation new instructions and procedureds in area of machines and devices handling. Very important was proper preparation of tools and equipment involved into process. In addition some motivation trainings were provided to increase operator's morale and convince them how important is their positive attitude. There was organized reference visit in similar production line, achieved better overall results. Regular meetings with operators were scheduled, good possibility for sharing observations and remarks. This last idea benefits fastest in fastest changeovers thanks to better tools bought according operators suggestions.

New procedures were also implemented for maintenance crews. Thanks to them there is possible better control of real technical state of devices. Manufacturing Executive System was implemented, thanks to this system there is possible to monitor production parameters of the process and in advance all reported delays creating data base with full and detailed information about all delays of production line.

The result of described activities was increasing of %PT. Measured results are presented in Tab. 1.

Tab. 1. Influence of %PT for OEE

	Start of Experiment	Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI
Operational delay [%]	16	15,5	15,5	15,5	15,5	15	15
Mechanical Delay [%]	7	7	6,5	6,5	6,5	6,5	6
Electrical Delay [%]	5	5	5	4,5	4,5	4,5	4,5
Others Delay [%]	5	5	5	5	4,5	4,5	4,5
<b>Productive Time [%]</b>	<b>67</b>	<b>67,5</b>	<b>68</b>	<b>68,5</b>	<b>69</b>	<b>69,5</b>	<b>70</b>
Yield [%]	95	95	95	95	95	95	95
Speed Losses [%]	94	94	94	94	94	94	94
<b>OEE [%]</b>	<b>59,83</b>	<b>60,28</b>	<b>60,72</b>	<b>61,17</b>	<b>61,62</b>	<b>62,06</b>	<b>62,51</b>
Daily Production [t]	865	871	878	884	891	897	904
Monthly Production [t]	22922,5	23093,6	23264,6	23435,7	23606,8	23777,8	23948,9
Monthly Difference [t]	0	171,1	342,1	513,2	684,3	855,3	1026,4
Price of 1 ton of product [zł]	2150	2150	2150	2150	2150	2150	2150
Monthly Profit due to increasing Productive Time [zł]		367786	735573	1103359	1471146	1838932	2206718
<b>Annual Profit due to increasing Productive Time [zł]</b>		<b>4413437</b>	<b>8826873</b>	<b>13240310</b>	<b>17653746</b>	<b>22067183</b>	<b>26480619</b>

### 3.2. Undertaken Activities - Management of the process

Activities in this area were proposed to increase production scheduling process. Short orders were eliminated, thanks to that number of changeovers drops down. In advance usage of tools and equipment became more efficient. In simple way this decrease cost of production.

Next activity in this area was better spare parts management. Until now spare parts storage was built according recommendation of their producers, but experience proved that wasn't the good idea. The list of most necessary parts was created according experience of others users of similar equipment.

The result of described activities was increasing of %SL. Measured results are presented in Tab. 2.

Tab. 2. Influence of %SL for OEE

	Start of Experiment	Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI
Average Time of one billet rolling [s]	117,5	117,5	117,5	117,5	117,5	117,5	117,5
Average Gap between billets [s]	26	25	24	23	22	21	20
Average weight of billet [kg]	2400	5	5	4,5	4,5	4,5	4,5
Average Standard Rolling Speed [t/h]	64	64	64	64	64	64	64
Average Real rolling Speed [t/h]	60,21	60,63	61,06	61,49	61,94	62,38	62,84
Productive Time [%]	67	67	67	67	67	67	67
Yield [%]	95	95	95	95	95	95	95
<b>Speed Losses [%]</b>	<b>94</b>	<b>95</b>	<b>95</b>	<b>96</b>	<b>97</b>	<b>97</b>	<b>98</b>
<b>OEE [%]</b>	<b>59,88</b>	<b>60,30</b>	<b>60,73</b>	<b>61,15</b>	<b>61,60</b>	<b>62,04</b>	<b>62,50</b>
Daily Production [t]	865	871	877	883	890	896	903
Monthly Production [t]	22922,5	23082,4	23246,1	23409,8	23581,1	23748,6	23923,8
Monthly Difference [t]	0	159,9	323,6	487,3	658,6	826,1	1001,3
Price of 1 ton of product [zł]	2150	2150	2150	2150	2150	2150	2150
Monthly Profit due to increasing Speed Losses Factor [zł]		343780	695746	1047712	1416048	1776199	2152720
<b>Annual Profit due to increasing Speed Losses Factor [zł]</b>		<b>4125365</b>	<b>8348952</b>	<b>12572540</b>	<b>16992574</b>	<b>21314384</b>	<b>25832641</b>

### 3.3. Undertaken Activities - Optimization of the process

Next considered area was better usage of raw materials. There was analyzing of minimizing technological waste. All operations with influence for that were optimized. Reheating billets, cutting head and tail of material, decreasing of number of cobbles and offer to the clients lengths of produced bars shorter than nominal lengths. The result of described activities was increasing of %Y. Measured results are presented in Tab. 3.

Tab. 3. Influence of %Y for OEE

	Start of Experiment	Stage I	Stage II	Stage III	Stage IV	Stage V	Stage VI
losses due to Furnace operations [%]	2,5	2	2	2	2	2	1,5
Losses due to shear no1 [%]	0,3	0,3	0,3	0,3	0,2	0,1	0,1
Losses due to shear no2 [%]	0,2	0,2	0,2	0,2	0,1	0,05	0,05
Losses due to technology [%]	1,5	1,5	1	0,5	0,5	0,25	0,25
Others factore decreases yield [%]	0,3	0,3	0,3	0,3	0,1	0,05	0,05
Cobbles [%]	0,2	0,2	0,2	0,2	0,1	0,05	0,05
Productive Time [%]	67	67	67	67	67	67	67
Yield [%]	95	95,5	96	96,5	97	97,5	98
Speed Losses [%]	94	94	94	94	94	94	94
OEE [%]	59,83	60,15	60,46	60,78	61,09	61,41	61,72
Daily Production [t]	865	870	874	879	883	888	892
Monthly Production [t]	22922,5	23043,1	23163,8	23284,4	23405,1	23525,7	23646,4
Monthly Difference [t]	0	120,6	241,3	361,9	482,6	603,2	723,9
Price of 1 ton of product [zł]	2150	2150	2150	2150	2150	2150	2150
Monthly Profit due to increasing Yield [zł]		259386	518772	778159	1037545	1296931	1556317
Annual Profit due to increasing Yield [zł]		3112634	6225268	9337903	12450537	15563171	18675805

### 3.4. Undertaken Activities – results discussion

For better understanding proposed activities, in all tables presented results calculated for money.

How we can see increasing %PT up to 3 [%] results additional profit about 6 500 000 [EUR per year]. With %SL the 4 [%] have similar result. Increasing %Y by 3 [%] can profit about 4 500 000 (EUR per year). Of course for better understanding proposed activities all areas were presented separately: in fact all of them were implemented in the same time with additional benefit of synergy effect. Selected areas have interred relations, so activities in one area have positive influence for other areas. Chart on Fig. 9 presents change of particular indicators on all stages of the experiment. Result in not so spectacular but always positive:

- problem was found: too low productivity, too low yield, too big costs of production,
- solution was proposed: areas of activities were selected, improvement activities in selected area have been proposed (handling of production process, management of production process, optimizing of production process),
- comparison of results have been presented: measurement of results before activities, periodical measurement of results, and comparison,
- proposed to monitor system constantly to improve process all the time as crucial.

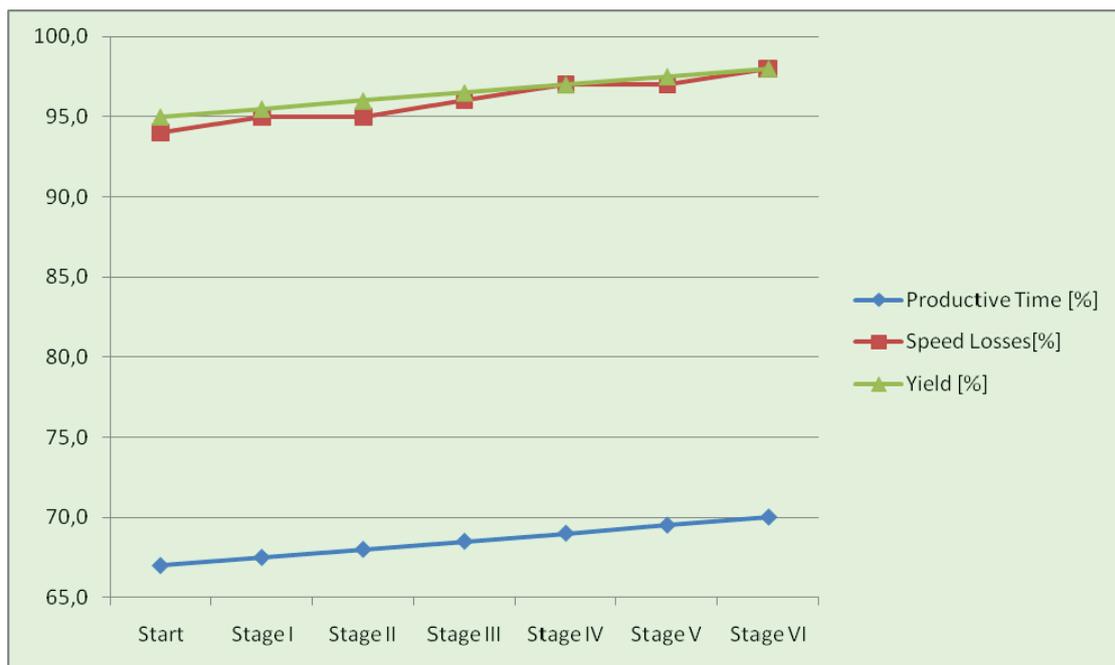


Fig. 9. %PT, %SL, %Y on all stages of experiment

Proposed activities shouldn't be one-shot activities; production process should be constantly monitored and constantly improve. Value of OEE on the end of experiment was calculated as 67.23 [%]. Chart on Fig. 10 presents improvement of Overall Equipment Efficiency.

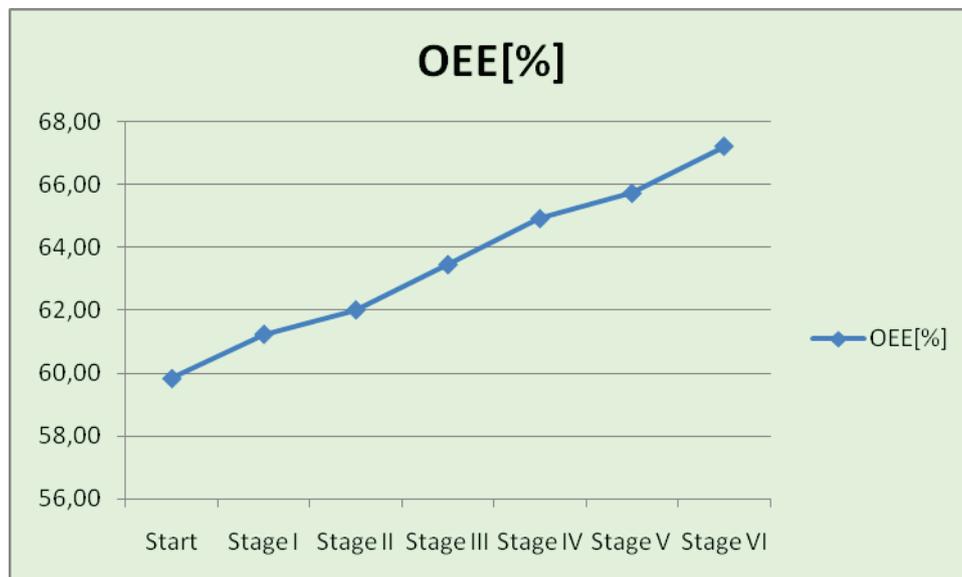


Fig. 10. %Overall Equipment Efficiency on all stages of experiment.

Experiment shows a power of key performance indicators, which with proper measurement and interpretation are very powerful tool in management hand. Thanks to correct focusing on most important problems in production area, management of enterprise can decrease cost of production and position on the market.

Experiment shows that proposed activities were a good idea. Result of particular changes was improvement of indicators which built Overall Equipment Efficiency factor. In the same way dependability of whole process was improved.

Production process is endless, so must be monitor and improve constantly. There is possible that OEE factor is growing but one of indicators is dropping, so very important is not only calculate overall result but all parameters of the process as detailed as possible. If according some unusual value of monitored parameters we can avoid serious failure, which is our advance to competitors which do not have this possibility. Proposed solution can help in better control of production costs.

Another advantage of proposed approach is synergy effect. Activities in different areas have positive influence for other areas of production process.

#### 4. Summary

A weak position on the market is very often a result of too big cost of production. Costs are generated due to not effective usage of enterprise's resources. Examples of not proper usage of resources can be:

- weak technical condition of production line, affects in frequently unexpected delays and failures,
- low level of knowledge and experience of operators, mistakes in management process,
- wasting of raw materials, energy, employees work, etc.

Production process is usually complicated and always should be considered as very complex problem. Very often we can achieve a goal with combination of few activities in different areas. This is effect of synergy. First of all should be calculation of dependability on the beginning, thanks to that we can very easily see the result of proposed solutions.

One of the methods good in present level of dependability is calculation of Overall Equipment Efficiency, presented state of whole production process. Thanks to that there is possible to present effect of particular activities in different areas. In experiment effect was presented as a changing value of OEE in time. We can observe constantly improvement of particular indicators and OEE.

In advance, proposed methodology is universal and can be useful in other kinds of industry and in different systems of transport. Difference is with selected areas and proposed activities. Result can be measured in similar way or in other more fit for considered problem.

### Acknowledgement

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