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LEAN MODEL FOR CONSTRUCTION PROJECT EFFECTIVENESS MEASUREMENT

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Abstract: Construction industry and construction activities are considered to be one of the major sources of economic growth, development and economic activities. This fact shows significance of construction activities and their continuous improvement. Construction activities are closely related with effective use of people, machines, materials etc. Poor and work-shy machinery management will result with bigger project costs, project delays generating unnecessary waste. In order to manage better overall machinery this paper shows a model based on a lean manufacturing tool to improve and visualize your construction project management state.
Keywords: lean management, OEE, construction project planning

1. INTRODUCTION

Lean methodology has many tools for optimization and continuous improvement of many business activities. Some of them are widely known as powerful tools for continuous iterative optimization of current and future business activities. Many sectors use lean tools in order to enhance their productivity; such is the construction sector. The construction industry is a knowledge-based industry: It relies heavily on knowledge input by the different participants in a project team. In fact, as construction is a project-based industry, most of its knowledge is generated in projects. Then, capturing, sharing, and utilizing the combined knowledge of the current workforce is essential to avoid losing vital corporate knowledge assets. This means construction companies need to capitalize learning outcomes in each project to continuously improve organizational performance [1]. The lean approach has limitations in construction projects, but the combination of lean and agile should be a solution. Based on the results of correlation analysis in one research it was concluded that the implicit usage of lean and agile elements can help coping with project complexity [2]. Therefore lean tools should be used in construction activities as widely as possible to achieve greater business results.

The construction projects involve various risk factors which have various impacts on time objective that may lead to time-overrun. It was proven in research by Usama Hamed Issa research of lean implementation on construction techniques that project time has been reduced as a result of using lean construction techniques. It was concluded that the impacts of risk factors decrease as time increases due to using lean construction techniques [3]. Efficient lean techniques provide the future projects a higher level of knowledge when starting up, which can support making decisions quickly. Furthermore, it also assists in reducing the cost and improving the quality. When lean construction managers implement a lean tool, they unintentionally facilitate the knowledge creation. Therefore attentions should be paid to keep new knowledge recorded and to build a more holistic and efficient knowledge management system [4]. Continuous improvement must have a strong local adaptation in order to really work. Standardized tools copied directly from Lean literature are no guarantee for success. Basically, there are four lean categories of implementation; education in how to do thing, simplifications of operations or developing a "common sense" approach, close involvement with the unions, close collaboration (both formal and informal) leaders and employees [5]. Therefore lean tools should be improved and modified to achieve and carry out expected benefits of each tool.

Every management decision on construction site has its consequence on effectiveness of people, machinery and overall stage of construction site improvement. Therefore precise metric for measuring effectiveness of people, machinery and production should be brought in the management decision process to avoid waste. A Number of management techniques has been developed over the years to manage the manufacturing. Overall Equipment Effectiveness (OEE) is a novel technique to measure the effectiveness of a machine and it truly reduces complex production problems into simple and intuitive presentation of information [6]. OEE is a "best practices" way to monitor and improve the effectiveness of manufacturing processes (i.e. machines, manufacturing cells, assembly lines). OEE is simple and practical. It takes the most common and important sources of manufacturing productivity loss, places them into three primary categories and distils them into metrics that provide an excellent gauge for measuring for where you are and how you can improve [7]. There

have been many studies on process if implementation OEE in industrial manufacturing, but there is shy try of implementation OEE on construction site machinery. Various parameters of OEE contribute to overall OEE in a different manner and have significant effect on improving the performance. An excel sheet can be used as simplest tool to measure and monitor true data collection. OEE is an important performance measure for effectiveness of any equipment, careful analysis is required to know the effect of various components [8].

2. MEASURING EFFECTIVENESS

Effective management of construction machinery minimizes waste of people, machines, materials and reduces overall project time. In order to distinguish effective from noneffective construction machinery management, there should be installed proper metric method with accurate results. In lean methodology there is such tool, it is called Overall Equipment Effectiveness and it represents current state of machine availability, performance and work quality. This tool was designed for purpose and requirements of industrial manufacturing, but it can be modified for use in construction site management. OEE is a measurement method that is commonly used by companies on their way towards a Lean production where in specified it is a percentage number that is usually defined by multiplying the calculated availability rate, performance rate and quality rate. It is a measure of how well equipment of lines are utilizes in relation to their full potential [9]. This tool was rarely used outside industrial manufacturing ambience, but it has great potential for use in non-industrial manufacturing environment such as construction sites. The three primary strata of construction project management are Time, Cost and Quality; these three pillars should always work hand in hand to underwrite success to projects. Advice is that this triangle must include sustainability/performance as the heart of these pillars; with each pillar serving a sustainability objective [10]. Time is key parameter in every project and seeking for optimal usage of available resources is key of success. If construction machinery is not used properly overall success will be poor, generating unnecessary costs and waste.

Overall Equipment Effectiveness

OEE is a method for measuring machine/cell/line effectiveness in order to achieve full potential of asset in production environment. It gives feedback for upgrade production and determines where equipment is losing time. There are many ways to calculate OEE, here is a general view of this lean tool. OEE is the product of three percentage factors: availability, performance efficiency and quality rate.

$$\text{Availability} = \frac{\text{Actual Production Time}}{\text{Planned production Time}} \quad (1)$$

$$\text{Performance} = \frac{\text{Current Run Rate}}{\text{Ideal Run Rate}} \quad (2)$$

$$\text{Quality} = \frac{\text{Good Product}}{\text{Total Product}} \quad (3)$$

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (4)$$

OEE is a great tool for showing where the biggest time losses are during production. It can be broken down into downtime losses, speed losses, and quality losses so that it can be shown where the biggest time losses are. OEE is a good way for looking at a single machines performance but it doesn't say anything about if the machine makes a profit or not. This tool is good for continuous improvement and it can identify problems on several levels [11].

Key indicators of construction machinery effectiveness

The unit price of construction work consists of the sum of supplier's entire costs (material, wages, statutory payments, machinery, energy, management and operational costs of the company) and a reasonable profit [12]. Machinery costs on construction site are defined by overall operating hours, however to measure if operating hours were effective there should be appropriate metric tool for measurement of key indicators. Key indicators to define effectiveness of construction machinery must be defined such as effective working hours, delays due to inadequate maintenance, preventive and corrective maintenance, adverse weather conditions, shortage of work and so on. Many construction companies track this key indicators on daily basis but they fail to recognize full potential of such data. If you put this quantitative and qualitative indicator in appropriate metric tool, such as OOE you can get reliable data on how you manage your asset and detect "bottleneck" activities.

3. MODELLING OEE FOR USING IN MEASURING CONSTRUCTION MACHINERY EFFECTIVENESS

OEE has shown its strength in industrial and manufacturing environment, but putting this tool in unpredictable environment such as construction sites can be a challenge. Construction machinery generates big operative costs, so their efficient work is irrefutable necessity. OEE is potential tool for tracking effectiveness of equipment on several basis with the objective of identifying problems on various levels. To form OEE which could be used

on construction machinery and equipment, it is necessary to identify and modulate this tool. Key indicators which should be tracked on construction equipment are:

» Planned working hours – it refers to construction site working time schedule for day, month or even year.
» Effective working hours – this indicator refers to equipment value-adding activities. Measuring this indicator gives us ability to calculate costs per hour and effectiveness per day or month.
» Work shortage – this indicator stands for unused working time when equipment was out of job due to lack of job or poor planning of activities. This indicator refers to equipment value-adding activities. It gives us ability to calculate how well supervisors manage with given construction equipment expressed in time unit.
» Adverse weather condition – this data indicates the availability of equipment due to weather conditions.
» Maintenance – this indicator shows availability of equipment and it is composed of preventive and corrective maintenance. It gives us ability to calculate equipment reliability in order to determine unreliable equipment.
» Fuel consumption – this data shows how well equipment is used. It indicates skill level of equipment operators.

Construction machinery is high valuable, their planned or unplanned delays are expensive, and so they have to be managed properly with full care. Machinery is bearer of main operative activates, however they can be stumbling-stone in fulfil project demand if their full potential is not reached. All key indicators should be tracked through machinery log files in order to see bottleneck of machinery processes and activities (see table 1). Many civil organizations seek to measure key indicators of their machinery, but in lack of skills and proficiency they fail to utilize this data for improvement of their core business. Machinery log files should be updated on daily basis to prevent poor management of machinery, these log files should be carried out for all equipment that generates value. Log files are simple tools for measuring key indicators of equipment, they could be simply tracked on piece of paper for each machine. Entering data to log files should be obligation of machinist, maintenance teams and construction supervisor, while inspection and control of machinery log files should be obligation of machinery management personnel. This valuable data tracked by machinery log files can be analysed through modified OEE toll. The modified OEE tool should be starting point for iterative process of improvement business activities closely linked with success of project demands.

Table 1 – Machinery log file for tracking key indicators

Machine type: Excavator							**Asset code: 4073339**	
Day	Planned working hours	Effective working hours	Work shortage	Adverse weather condition	Maintenance	Maintenance description *P – PREVETIVE *C - CORRECTIVE		Refuel (litres)
1	10	5	4		1	P	lubrication	182
2	10	4	1	5				
3	10	6	3		1	P	antifreeze fulfil	
4	10	2			8	C	fuel pump breakdown	
5	10	5	5					211
6	10	3	5	2				
7	10	7	3					
8	10	8	2					302
9	10	3	6		1	P	fulfil of hydraulic oil	
10	10	9			1	P	lubrication	
Total	**100**	**52**	**29**	**7**	**12**			**695**
Average	**10**	**5.2**	**2.9**	**0.7**	**1.2**			**13.37**
Nominal fuel consumption in effective working state = 23 litres per hour								

Overall machinery effectiveness model

Starting point for tracking data about machinery activities can be piece of paper or excel worksheet (e.g. see Table 1). It doesn't matter how data is collected as long as you track key indicators through machinery log files. Collected information's through log files can be transformed into pragmatic improvement solutions only if you have effective model for analysis of those data. OEE is an effective tool for such analysis but it should be transformed to meet conditions of construction site machinery. In previous chapter it was mentioned that OEE was firstly designed for manufacturing environment where machines and equipment have different production tasks than equipment on construction sites. To transform OEE for construction equipment needs, we have to examine each component of basic OEE. OEE consists of three main components, these are availability, performance and quality. Each one of them tells us different information on new level. Overall Machinery Effectiveness (OME) should have all three components as OEE to carry out equally metric as basic OEE (see Equation. 5).

$$OME = Availability \times Performance \times Quality \quad (5)$$

$$Availability = \frac{Planned\ working\ hours - (Adverse\ weather\ conditions + Maintenance)}{Planned\ working\ hours} \quad (6)$$

$$Performance = \frac{Effective\ working\ hours}{Planned\ working\ hours - (Adverse\ weather\ conditions + Maintenance)} \quad (7)$$

$$Quality = \frac{Average\ fuel\ consumption}{Nominal\ fuel\ consumption} \quad (8)$$

$$Planned\ working\ hours = Effective\ working\ hours + Work\ shortage + Adverse\ weather\ conditions + Maintenance \quad (9)$$

$$Average\ fuel\ consumption = \frac{Overall\ fuel\ consumption}{Total\ working\ hours} \quad (10)$$

All three components of OME bring out overall look on effectiveness of construction machinery and pinpoint biggest problems on machinery. Availability tells us how much planned and unplanned downtimes happened on equipment, performance tells us if construction supervisors manage properly with equipment due to planned working hours and quality indicates if machinist on the equipment is working value add job. It is important to say that nominal fuel consumption stands for machine fuel consumption when machine is working value-adding activities. Value-adding activities on construction sites are defined as activities which are chargeable due to signed contract. These activities should be optimized in order to generate more profit.

Visualisation of OME model on construction equipment

It is very hard to distinguish adding and non-value-adding activities. In order to minimize non value-adding activities you have to locate them with proper metric methods and solve them with pragmatic solutions. Described OME model in previous chapter track down decisions on several levels, where you can locate non-add value activities and pinpoint department or personnel who generates waste. If availability of machine is poor then responsible personnel for such state is maintenance department. If performance is poor then construction site supervisor doesn't plan proactively tasks for machinery. If machine work quality is poor than machine or equipment operator doesn't work well. To describe full potential of OME, it is shown in table 2 how this tool should work if you use it right.

Table 2 – Overall Machinery Effectiveness of excavator during 13 months

Machine type: Excavator											**Asset code: 4073339**	
Month	Effective working hours	Work shortage	Adverse Weather conditions	Maintenace	Planned working hours	**OEE**	**Availability**	**Perfrormance**	**Quality**	Total fuel consumption	Average fuel consumption	Nominal fuel consumption
11-2016	92	56	0	40	188	33%	79%	62%	68%	1432	15.57	23
10-2016	89	67	0	36	192	34%	81%	57%	74%	1511	16.98	23
09-2016	63	57	0	60	180	26%	67%	53%	73%	1058	16.79	23
08-2016	39	119	0	16	174	16%	91%	25%	71%	638	16.36	23
07-2016	82	55	0	40	177	35%	77%	60%	74%	1405	17.13	23
06-2016	73	56	0	51	180	32%	72%	57%	78%	1313	17.99	23
05-2016	79	64	0	56	199	31%	72%	55%	78%	1412	17.87	23
04-2016	55	88	0	42	185	24%	77%	38%	80%	1009	18.35	23
03-2016	79	62	0	54	195	37%	72%	56%	90%	1642	20.78	23
02-2016	62	67	6	45	180	32%	72%	48%	94%	1339	21.60	23
01-2016	46	29	3	33	111	38%	68%	61%	93%	980	21.30	23
12-2015	74	41	0	24	139	50%	83%	64%	95%	1613	21.80	23
11-2015	195	7	0	36	238	70%	85%	97%	86%	3842	19.70	23

Table 2 present OME tool used on excavator during 13 months, where you can see overall picture of excavator usage. In table 2 we can see that general problem of poor OEE is inadequate maintenance and management with excavator where generally speaking half working time excavator was in downtime or work shortage. Excavator is big machine which has big purchase price, small letters maintenance costs and this machine should be used more on predicted construction site or it should work on construction site where it is more needed. If machine performance is poor then maybe machine or equipment should be allocated to another construction site where it can generate more add value activities. We can also see that excavator in table 2 has big problems with downtimes where we can pull down two clues, one of them is that maintenance department doesn't work its job properly, and other one is that machine is too old and it should be put in expenditure. Overall look on table 2 tells us to investigate poor OEE and initiate improvement of machine effectiveness.

OME doesn't just follow individual effectiveness of equipment, it also follows overall effectiveness of construction site. OME is based on lean tool, so it locates all construction asset that generates waste. Generally speaking this tool could help middle management to carry out many decisions which are closely related with

making more profit and less waste. In table 3 it is show how monthly OEE report for one construction site could look like, where we can see which equipment is effective in its job. It should take into account that smaller machines cannot have same effectiveness as big, the effectiveness evaluation of smaller machines should be done with great care. In table 3 it is shown that smaller machines have almost 100% availability but they have poor performance ratio. This data doesn't mean that this machines should be allocated to another construction site, it means that this equipment is used for supporting activities which are unpredictable.

Table 3 – Overall Machinery Effectiveness for 1 month on construction site

Construction site code: 309												Month: 11-2016	
Asset code	Machinery type	OEE	Availability	Performance	Quality	Effective working hours	Work shortage	Adverse weather conditions	Maintenace	Planned working hours	Total fuel consumption	Average fuel consumption	Nominal fuel consumption
4840900	Generator	3%	100%	4%	63%	8	172	0	0	180	20	2.50	4.00
4840437	Generator	5%	100%	6%	90%	10	170	0	0	180	18	1.80	2.00
4910222	Water pump	4%	87%	5%	100%	8	148	0	24	180	8	1.00	1.00
4634160	Vibratory roller	16%	96%	34%	49%	58	114	0	8	180	169	2.91	6.00
4120345	Compressor	23%	98%	36%	65%	64	113	0	3	180	292	4.56	7.00
4634152	Vibratory roller	13%	94%	18%	73%	31	139	0	10	180	136	4.39	6.00
4842073	Generator	24%	98%	45%	54%	80	97	0	3	180	214	2.68	5.00
4073185	Wheel excavator	56%	92%	80%	77%	132	34	0	14	180	1623	12.30	16.00
4073339	Excavator	35%	78%	66%	68%	92	48	0	40	180	1432	15.57	23.00
4080122	Backhoe loader	45%	90%	70%	72%	113	49	0	18	180	652	5.77	8.00
4021844	Track loader	38%	93%	58%	70%	97	71	0	12	180	613	6.32	9.00
4411005	Cracksealing machine	13%	100%	28%	45%	50	130	0	0	180	45	0.90	2.00
4080187	Backhoe loader	59%	81%	88%	82%	128	17	3	32	180	843	6.59	8.00
4073142	Excavator	46%	88%	75%	71%	118	40	0	22	180	1501	12.72	18.00
4120183	Compressor	16%	99%	27%	60%	48	130	0	2	180	145	3.02	5.00
4040260	Grader	53%	82%	84%	77%	124	23	23	10	180	1423	11.48	15.00

Generally speaking Overall Machine Effectiveness (OME) is a tool which can lead to agile decision making about organization asset. This tool brings precise metric and objective decision making on several levels.

OEE has shown significant role in overall improvement of industrial organizations putting them rapidly towards lean transition. Lean tool as OEE is worthy in every aspect, but in this paper it is shown that this tool could be used also in other environment which is drastically different than manufacturing environment. The report shown in table 2 and Table 3 doesn't show just how OME tool works, it also represent simple example of visual management where all information about value-adding and non-value-adding activities are easily put out on excel worksheet. This visual management brings out all personnel included in process optimization real state of current activities, simultaneously marking weak points on severe levels. Probably the most inexplicit parameter in measuring and calculation of OME is work Quality of machines. Machine work Quality is very difficult to measure because if try to involve all factors that have correlation with work quality you would have excessively too big database. This could lead to needles recording of data, what could ultimately lead to puzzling import and monitoring of data into machinery log files. Therefore if we know how much does some machine has average fuel consumption we can have perception on labour standard of some machinist. It is simple to compare average fuel consumption and nominal fuel consumption, but it is hard to define nominal fuel consumption for each machine. Machine nominal fuel consumption should be objective data for 100% effective work, however this data can be difficult to define. Many manufactures gives data about minimum, average and maximum fuel consumption what is starting point for setting nominal fuel consumption for each machine or equipment.

OME could be used as visual decision-make tool for presentation of machinery effectiveness as shown in table 4. You can easily see all relevant data about asset usage. Table 4 is example how excel worksheet can be great tool for presentation of Overall Machinery Effectiveness data, and doesn't allow you to overlook significant information about machinery effectiveness. Visualisation of gathered information is important step to determine your weak spots in order to figure out way of their minimization or even elimination. Figure 1 shows pragmatic feedback between supervisor and middle management, while director have view of real time business activities.

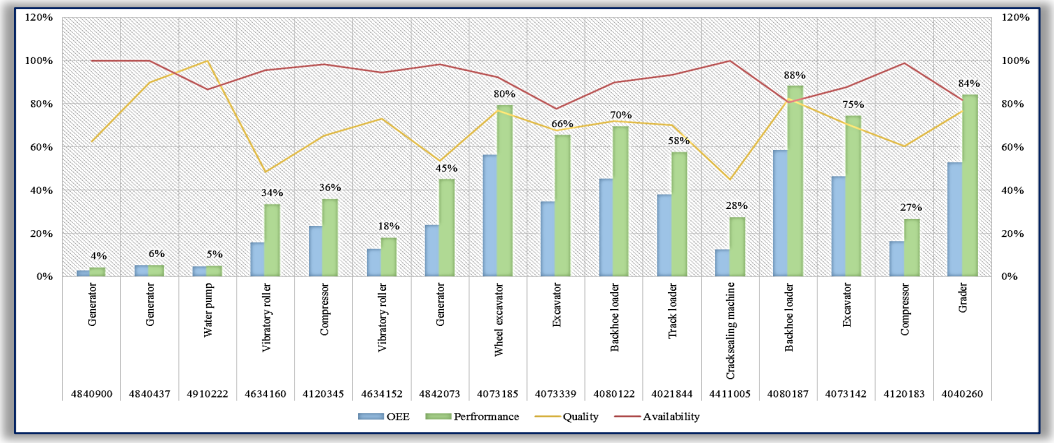

Figure 1 – Visual presentation of Overall Machinery Effectiveness

Improvement of construction equipment effectiveness

Effective construction asset is an important factor to carry out successfully project. Gathered data shown in table 4 indicates that construction equipment effectiveness is most influenced by work shortage where equipment under consideration is not managed properly. Construction management is very difficult and complex job where skilled engineers and supervisor can face up with various problems and risks. In order to improve equipment performance construction companies should adopt lean tools to recognize and improve adding-value activities. Cornerstone for improvement of observed construction site in table 4 is probably value stream mapping of every activity connected to asset management. Value stream mapping (VSM) is great tool for analysing current state and designing future improved state. VSM shouldn't be the only lean tool implemented on this construction site. In order to develop better asset management on construction site lean tool as "kaizen" (continuous improvement) should be also implemented where employees on all levels of a company should work together to achieve incremental improvements on project activities. Lean tools as VSM and "kaizen" would brought proactive decision making on construction site where asset management would became standardized work. The benefits of standardized work include documentation of the current process for all shifts, reductions in variability, easier training of new operators, reductions in injuries and strain, and a baseline for improvement activities.

4. CONCLUSION

Measuring effectiveness, regardless whether it is about add value and non-add value activities is very tough and comprehensive job. Lean production and its tolls have shown their full strength in past decades, therefore every organisation should use potential of this tools and try to find path how to adopt this principles into their core business activities. Measuring machinery effectiveness is a complex job that can be done by presented tool in this paper. Overall Machinery Effectiveness (OME) is an easy tool for in time auto track of machinery work data. It is shown that this tool doesn't just pinpoint add value and non-add value activities, yet it gives solutions for future proactive activities. In future steps consideration should be given to find maybe correlation of OME with project profit or even delays. This tool could be cornerstone for continuous improvement of business activities on all levels. However lean methodology has learnt us that process of improvement never ends, so it would be wise to find path how to expand this tool in order to gather better information about you asset usage. This tool has great potential for apply on all machinery which can carry out needed data for calculating OME.

Note

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