WASTE ELIMINATION OF MUCKING PROCESS OF A PETROLEUM STORAGE TUNNEL THROUGH THE VALUE STREAM ANALYSIS

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ABSTRACT

Construction firms are getting smarter and more effective by significantly improving their performance level at the job site. Particularly, cycle time which represents the time needed to complete one set of operation has been an important measure of productivity. In this study, cycle time of a petroleum storage tunnel which has many reiterative operations is investigated. With the aid of value stream analysis based on flow process chart, non-value adding activities of mucking-focused process are identified. Value stream mapping is then applied to simplify the current process as well as to remove crucial wastes of the process. Finally, this study suggests a scheme to improve the mucking process, which ultimately shows that applying the 'to-be' mode to the real site can improve the cost and average effectiveness by 9.6% and 17.7%, respectively.

KEY WORDS

value stream analysis, flow process chart, tunnel construction, mucking process

INTRODUCTION

Construction firms do not focus on working harder anymore, but rather attempt for working smarter, being aware of the fact that they can get the same or more output from less input while maintaining reliability of the work process; in other words, they should be effective. However, most traditional efforts have focused more on the 'efficiency of production' (in other words, productivity which is simply an average production divided by time or resources while disregarding the variation of the production rate and resource usage) than on 'effectiveness' that indicates the stable use of resources and a stable production rate by nurturing relationships and improving reliability involved in the construction processes (Mun 2002).

Lean construction which tries to manage and improve construction process with minimum waste and maximum value is the most popular approach for productivity improvement (Best and Valence 2002). Lean construction firstly concerns the

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combined effect of dependence and variation since their interactions highly affects the time and cost (Howell 1999). High variation in process easily increases the time and cost of project while decreasing reliability and manageability of the process. In this sense, Koskela (1992) emphasized systemic process simplification as an important function of lean construction in view of the fact that uncomplicated process seldom has much variation such that it can be more flexibly modified to improve the current performance by enhancing the level of reliability in process management. As such, construction firms require contributing their time and effort to the last minutes and seconds in obtaining more effective process which concerns work flows by simplifying process and so lowering variations of the complicated process. Moreover, they are forced to improve their performance where projects are usually time-constrained; in other word, together with a simplified process, it is indispensable to make a remarkable reduction of cycle time which refers to the time span required to complete one cycle of an operation.

This research aims to achieve a productivity improvement of tunnel construction project in terms of systematic process simplification as well as cycle time reduction through value stream analysis. On the basis of the actual site observations and real data collected, this paper performs the value stream mapping to find non-value adding works and then suggests the critical areas for improvement. Finally, this paper provides the useful implications from a real case application in how to seek ways to implement the lean principle for the future applications in this problem domain.

THEORETICAL BACKGROUND

VALUE CATEGORIZATION METHODS

The outcome of productivity improvement can be represented by the quality of cycle time. According to Plenert (2007), cycle time can be used to evaluate the degree of overall achievement among many views of the project performance, and improving cycle time can lead to reduced costs, reduced inventories, and increased capacity. Moreover, even a small reduction of cycle time can make a remarkable advance in a whole project, since cyclic operation usually constitutes most of tunnel construction projects. Thus reduction of cycle time can be a major factor of work flow control, and it must be managed significantly in lean construction approach.

However, if not properly equipped with the systematic value management concept, construction firms can often tend to consider only how long each activity took individually. Accordingly, they do not well identify how valuable the quickly performed activities are as well as how significant the delayed/wasted activities are toward the succeeding activities. Without consideration for value flows at a glance, however, reducing cycle time is apt to be mystified. One of key objectives of lean construction is to decrease unnecessary activities, while not decreasing value of the project. To reduce cycle time, therefore, it requires defining values of each activity and simplifying the problematical process.

In this regard, Koskela (1992) categorized construction activities into four classes; processing, moving, waiting, and inspection. He further categorized them into Value Adding Activity (VAA) and None Value Adding Activity (NVAA). Then he asserted that only the processing activity is VAA while the others are NVAAs; thus, moving, waiting, and inspection should be minimized. Carreira (2004) also defined VAA as ‘anything that causes the product to become a more complete product,’ and NVAA as ‘an activity that does not cause the product to reach a more complete state.’ More specifically, Choo and Tommelein (1999) divided NVAA into two additional classes; Non-Value Added but Necessary (NVAN), and Non-Value Added and Unnecessary (NVAU). NVAN is essential, but does not add any values. We investigate the value process of a tunnel with this categorization. NVAU’s of a tunnel operations are to be removed for its valueless nature such that the cycle time can be reduced while maximizing the valuable activities and simplifying the current process.

VALUE ANALYSIS METHODS

As the construction process analysis methods, flow process chart is effective, but even simple technique for indentifying activity’s value (Lee et al. 1999). It enables to find activity type, working time, and value type of each activity; all of which are visually described by many figures so that users can recognize work flow and each activity’s value at a glance. This research uses flow process chart along the activity steps.

Along with the flow process chart, Value Stream Mapping (VSM) identifies lean improvement opportunities based on the NVAAs (Plenert 2007). It concerns value stream for finding wastes of construction process, which involves two basic steps; current state mapping and future state mapping. In the first step, current state mapping is performed to comprehend the logic of the process and to find non-value adding efforts – so called, wastes. The schemes to remove wastes and make the process more effective can be figured out with current state map. Following that, future state map is shaped to set a target goal of the schemes, and to identify changes that are required to improve current state to the desired future state (Plenert 2007). Future state mapping shows an improved value stream of the current process. According to Rother and Shook (1998), the term ‘value stream’ refers to ‘activities’ flow’ that is required by successors in production process. In other words, it represents resource supplying activities to users or customers. VSM creates a visual description of interrelated value streams with many symbols, as depicted in table 1. These symbols are to be understood intuitively, and can be modified for better description (Mun 2002).

Table 1: Symbols of Value Stream Mapping (Mun 2002)

Symbol	Meaning	Symbol	Meaning
	Value Adding Activity		Information flow between workers
	Non-Value Added but Necessary		Work flow between activities
	Non-Value Added and Unnecessary		Reiterative work

OUTLINE OF A CASE PROJECT

This research targets the productivity improvement by managing values and removing key waste factors. To demonstrate the proposed methods, a large-scaled storage tunnel project is selected. The case tunnel is developed for the purpose of storing petroleum that amounted to 1,650 barrels. The length of the tunnel is 5.2 kilo-meters, and its cross section is 18 meters wide and 30 meters high. The tunnel is divided into four stories each of which is 7.5 meters in height. Each story is sequentially excavated until the lowest story is fully excavated. With this sequential process, total constructing length reaches approximately 20.2 kilo-meters. The case tunnel project consists of three basic works; blasting, mucking, and reinforcing. After the blasting the rock, many refuse rocks and stones (so-called, mucks) are produced. They should be promptly moved out from the underground work site through mucking process. Following that, reinforcement work to strengthen the inner surface of tunnel is performed. These series of works constitute the basic and reiterative cycle of tunnel excavation which consumes almost 80 percent of the whole time of the project.

Of the repetitive work cycle of tunnelling, the mucking process is the most time-consuming work above all else. Moreover, the mucking process generates common/recurring types of wastes and non-value adding works, mostly due to the uncooperative work patterns among the equipments. This work is typically carried out with several heavy vehicles reiterating mucking process; a loader, a backhoe, and four dump trucks. Actual work procedures of mucking process are summarized as follows:

1. After the blasting dust is cleared off, the loader is put into the site.
2. The loader loads mucks onto dump trucks, and the dump trucks carry them to open storage yard out of tunnel in real time.
3. The backhoe is put into the site to do scaling, while the loader and the dump trucks are waiting outside near the work area.
4. While the backhoe is on standby, the loader stacks scraped mucks onto dump trucks, and the dump trucks carry them.
5. The loader comes out from the site, and the backhoe gets into the site to load remaining stones onto trucks and to finish the work.

In a different way from this basic work procedure, only a backhoe is used occasionally to load up with mucks when the loader is out of work site or temporarily used for other work. In this situation, the work procedure is simplified as follows:

1. After the blasting dust is cleared off, the backhoe is put into the site.
2. The backhoe loads dump trucks up with mucks, and the dump trucks carry them in real time.
3. The site is finished by a backhoe only.

In the second procedure, scaling is not additionally required because the backhoe can do scaling in the intervals between loading works; while fully loaded truck leaves and empty truck comes into the site, the backhoe can scrape mucks down little by little. With this time-keeping works, no vehicles have to wait. However, it was observed that the second procedure is rarely appeared than is the case of the first one.

VALUE ANALYSIS

The mucking process begins with a loader's entrance, and finished by an inspection of excavated tunnel distance. To compare each process, this paper evaluates value flows for not only basic loader-and-backhoe-work process, but also backhoe-only-work process. Furthermore, each process is divided into more details to draw out NVAAs.

VALUE ANALYSIS OF LOADER-AND-BACKHOE-WORK

Loader-and-backhoe-work has 28 individual activities in detail. In this process, loading and dumping mucks are considered to be the VAAs. Despite the fact that scaling of surface and clearing of debris for securing working space are the processing activities, they are defined as the NVAN because they are not actually value-added in the face of a mucking process. Carrying mucks to a storage yard and inspection are also considered necessary, but not value-added.

Since loader and backhoe were used in this mucking process, they were put into the work site by turns due to their different functions. This explains why many entering and waiting activities which are NVAU activities are unreasonably occurred. Loader waits for dump trucks when a fully loaded truck is switched to an empty truck or when there are no dump trucks on queuing line. Similarly, each dump truck waits for its turn to load mucks when a loader is busy. Loader and dump trucks' total waiting time can be gauged from table 2; which account for 3 hours 45 minutes for loader[1] and 4 hours 19 minutes for dump trucks.

[1] This is calculated as the sum of loader's each waiting time; 02:38 + 00:50 + 00:17. The waiting time of dump trucks is also estimated by a similar way.

Table 2: Flow Process Chart of Loader-and-backhoe-work

Activity	Activity type	Working Time (Hr:Min)	Value type
Loader's entry	‣	00:06	⇒
Clearing debris	●	00:12	□
Dump trucks' entry	‣	00:35	⇒
1st loading by loader	●	01:41	○
Loader Waits for next work	▼	02:38	⇒
Carrying mucks to storage yard	‣	16:27	□
Dumping mucks	●	00:08	○
Dump trucks wait	▼	01:23	⇒
Backhoe waits	▼	00:16	⇒
Backhoe's entry	‣	00:05	⇒
Scaling by backhoe	●	00:45	□
Loader waits	▼	00:50	⇒
Dump trucks wait	▼	02:35	⇒
Loader's re-entry	‣	00:03	⇒
Dump trucks' re-entry	‣	00:32	⇒
2nd loading by loader	●	00:14	○
Loader waits	▼	00:17	⇒
Carrying mucks	‣	01:12	□
Dumping mucks	●	00:01	○
Dump trucks wait	▼	00:15	⇒
Backhoe waits	▼	00:34	⇒
Backhoe's re-entry	‣	00:04	⇒
Final loading by backhoe	●	00:05	○
Carrying mucks	‣	00:11	□
Dumping mucks	●	00:00	○
Dump truck waits	▼	00:06	⇒
Backhoe waits	▼	00:00	⇒
Inspection of digging distance	■	00:20	□
The sum of each activity		31:35[1]	28
VAA		02:09	6
NVAA		29:26	22
Actual total working time		**06:34**	

●:processing, ‣:moving, ▼:waiting, ■:inspection, ○:VAA, □:NVAN, ⇒ :NVAU

BACKHOE-ONLY-WORK

Backhoe-only-work comprises ten activities, showing a very simple work process. Backhoe's loading and trucks' dumping activities are considered to be VAAs. Whether or not each activity creates value was determined by the

[1] Working time represents a cumulated time of each activity. As each activity's working time occurs independently, the sum of each activity (31: 35) does not mean the time of whole mucking process.

same way of loader-and-backhoe-work case. The biggest difference of this work process is that there is a significant increase in the loading time. While the total loading time of a basic work process (loader-and-backhoe-work) is 2 hours, backhoe-only-work consumes 3 hours and 46 minutes for loading as shown in table 3. Moreover, as backhoe's loading time increases, so does the waiting time for dump trucks, which in turn significantly boosts up the time for NVAA. This is mainly because backhoe's bucket capacity is far insufficient compared to loader's, which slows down the loading speed. Moreover, since a backhoe moves slower than a loader, it can't convey mucks in a swift manner.

Table 3: Flow Process Chart of Backhoe-only-work

Activity	Flow	Working Time (Hr:Min)	Value
Backhoe's entry	‣	00:15	⇒
Clearing debris	●	00:25	□
Dump trucks' entry	‣	00:12	⇒
Loading by backhoe	●	03:46	○
Scaling by backhoe	●	00:45	□
Backhoe waits	▼	00:36	⇒
Carrying mucks and returning	‣	18:45	⇒
Dumping mucks	●	00:09	○
Dump trucks wait	▼	10:45	⇒
Inspection of digging distance	■	00:20	□
The sum of each activity		35:58	10
VAA		03:55	2
NVAA		32:03	8
Actual total working time		**06:35**	

●:processing, ‣:moving, ▼:waiting, ■:inspection ○:VAA, □:NVAN, ⇒ :NVAU

COMPARISON OF TWO WORK PROCESSES

Figure 1 shows the effectiveness of the two work procedures associated with different equipment fleets. Here, the effectiveness is calculated by considering clearing, loading, scaling, dumping, and muck carrying as purpose of each vehicle, and by determining how much these works account for a part of the whole operation time of vehicles.

In the case of loader-and-backhoe-work, it was found that the effectiveness of loader or backhoe was quite lower than that of dump trucks. This is due primarily to the insufficient number of dump trucks compared to the work capacity of a loader. In other words, the effectiveness of dump trucks could be fairly high because they performed work just in time without having a queue line when arriving on the site, whereas a loader often had to wait for dump trucks to arrive. In the case of a backhoe, it had to be on standby before scaling while a loader was operating for its work, and even after the scaling was completed, it had to wait again for a loader so that final loading could be finished.

In backhoe-only-work, on the contrary, backhoe's effectiveness was found to be well above that of dump trucks. This is because a backhoe continuously performs loading while at the same time doing scaling by the use of extra time for which dump trucks take turns. However, insufficient bucket's capacity retarded loading work, which subsequently led to an increase of the waiting time of dump trucks.

By comparing the two mucking types, it can be found that the NVAA time of backhoe-only-work is higher than that of loader-and-backhoe-work. However, the actual working time of loader-and-backhoe-work was 6 hours and 34 minutes, which was almost the same as the case of backhoe-only-work. This is because the waiting time of dump trucks that has dramatically increased the NVAAs degrades the effectiveness of trucks, but they have a little impact on the actual work time. In the end, although the case site utilizes a high-performing loader, its work efficiency is very poor as it recorded the same work hours compared with using only a backhoe. This implies that a loader was ineffectively used in the site.

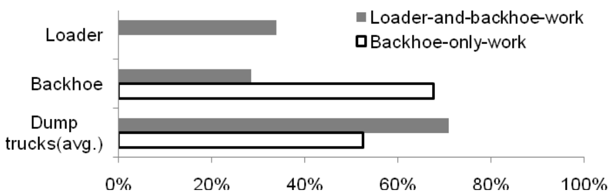

Figure 1: Effectiveness Comparisons of two different work processes

VALUE STREAM MAPPING

CURRENT STATE MAPPING

In what follows, Value Stream Mapping was performed to find the cause of aforementioned ineffectiveness and to reduce the cycle time by unravelling the problem areas. First, current state mapping was used to illustrate the current status, making it easy to understand the entire mucking process.

The entire mucking process can be largely divided into five stages: preparation, 1st handling, scaling, 2nd handling, and finishing. The handling stages, in particular, include key activities of mucking process; loading and dumping activity. These activities are the only ones which add value in mucking process. Figure 2 represents the current state of mucking process. Based on this, we investigate the critical wastes frequently found at the job site and suggest alternatives, summarized as follows:

1. Loading, an important VAA among mucking process is often stopped due to scaling, which is a NVAN activity. This interrupts the flow of loading, thereby making the process complicated, and the switching between loader and backhoe causes an increase of entry and exit of equipments as well as the waiting time. Accordingly, it is necessary to consolidate separate loading works and to simplify the process while

assigning equipments in an efficient manner.

2. All stages in mucking process are on the critical path and thus every stage only can be started when preceded stage is finished. This makes the process inflexible in variations; when a predecessor is delayed, a successor has to wait for the predecessor’s completion.

3. The number of dump trucks put into the site does not well match with loader's capacity, causing a significant increase of loader's waiting time. A suitable number of dump trucks needs to be decided based on the loader's efficiency, dump trucks' capacity, and hauling distance to a storage yard.

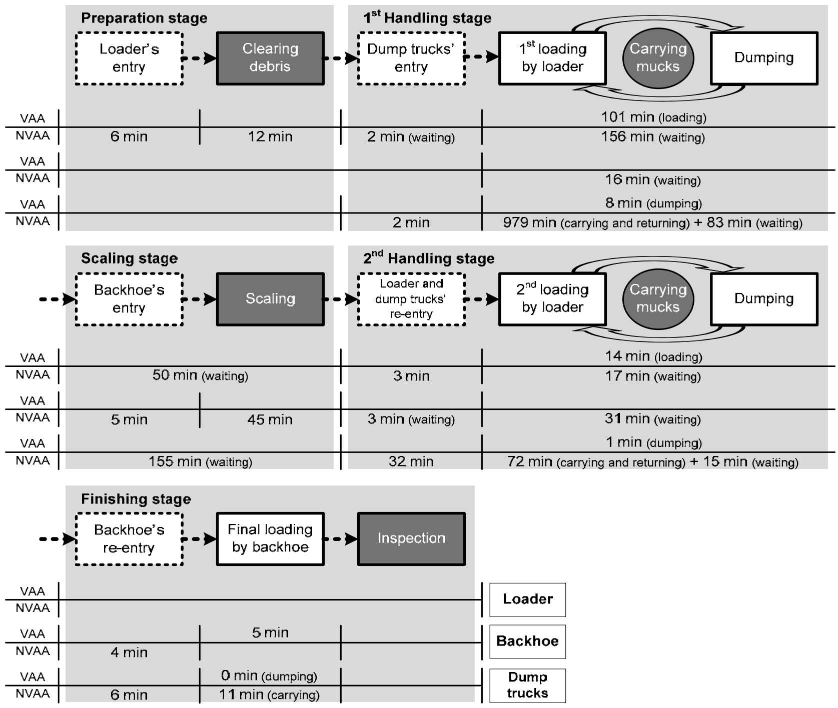

Figure 2: Value Stream Map of Current State

FUTURE STATE MAPPING AND IMPROVEMENT PLAN

The future state mapping was developed to suggest key improvements for the current state to reduce wastes while maintaining flow production of value adding activities. While designing a scheme that enables scaling without causing interruptions to loading work, it can be noted that the site actually has a large cross section. The cross section at the site is very open with 18 meters width, making it easy for equipments to do their work and to move around. As such, if a loader, a backhoe and dump trucks are assigned properly in this work zone, the equipments can overlap at once for use. When a loader and backhoe can be put into the site at once, a backhoe can do scaling without interrupting loader's work, which in turn ensures uninterrupted work flow and minimized waiting time for one another.

To decide whether this improvement plan can be actually applied to the site, a series of job meetings with field managers and engineers was convened. Total four participants who were actually engaged at the site as an owner's representative, superintendents, inspectors, and subcontractors were attended. As results, it was concluded that when loader's loading is completed at around 70 to 80 percent, a sufficient work space can be secured for a backhoe to do scaling, and that if a backhoe driver is skilful to a certain degree, concurrent work between two equipments can be valid. Mapping the improvement plan generates the 'to-be' state where a loader and a backhoe are put into the site at once, as shown in figure 3.

In future state mapping, loader's loading process which was initially divided into two stages in its current state is consolidated into one, simplifying the process at the handling stage. The NVAU works in the existing process such as backhoe's entry (5 min), loader's re-entry (3 min), dump trucks' re-entry (32 min) and backhoe's re-entry (4 min) were eliminated, while scaling (45 min), an NVAN, was performed at the same time with loading, a VAA; thereby, reducing the cycle time. Based on this, the total cycle time was estimated again: showing a 394 minutes in current state mapping and 333 minutes in future state mapping. All together, 'to-be' model can lower the cycle time by 61 min (or 15.5% decrease) from current state mapping. Considering that the mucking process is reiterated 5,050 times in this case project, a total of 308,050 minutes can be reduced as a whole. This translates to 214 days when a workday is based on 24 hours. Moreover, variation of the process is expected to be reduced due to the simplified procedure. When overlapping between handling and scaling stage, scaling work can be started by supervisor's direction according to the progress of handling work. This helps backhoe to reduce the waiting time for entry and deal with contingencies in work process.

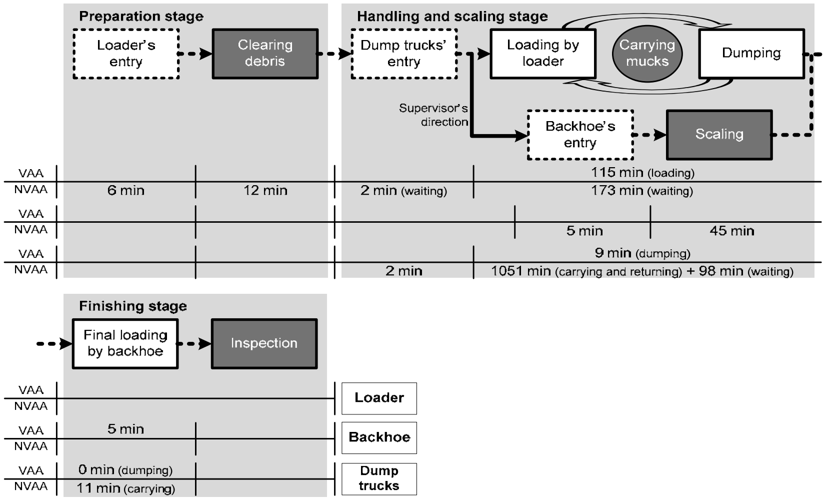

Figure 3: Value Stream Map of Future State

MODIFYING THE ACTUAL SITE

To evaluate the improved process through a future state mapping, this study attempts to implement the 'to-be' process to the actual mucking process. For this purpose, the following instructions were discussed and prepared for the case project:

1. The site is divided into left and right, and a loader does loading on one side first and then proceeds to another.
2. Because scaling takes about an hour, a backhoe is put into the site about an hour before a loader completes loading.
3. Backhoe's scaling should be performed within a boundary such that it does not intrude into loader's work scope, and as such, a backhoe driver needs to have an adequate level of work proficiency.

Based on these instructions, the improvement plan was applied to the actual site. The authors observed that the total cycle time dropped to 356 minutes. While this is an improvement of 38 min. (9.6%) from a current state mapping, it took 23 min longer than was anticipated by a future state mapping. This is presumably due to the slight time differences caused by actual work conditions plus other additional time caused by a backhoe and loader's lack of experience in moving around the space.

In addition, reduced cycle time is of great importance since it is directly related to construction cost. Monthly equipment costs of the case project are \$23,000, \$31,700, and \$30,000 for a dump truck, a loader, and a backhoe, respectively. Since the equipments are used 24 hours a day and 25 days in a month, the unit equipment costs are estimated at \$0.64, \$0.88, and \$0.83 for every minute for a dump truck, a loader, and a backhoe, respectively. Altogether, total equipment cost for a minute amounts to \$4.27. As a result, 38 minutes of reduced cycle time in actual application can make \$162.26 of cost-saving even in a cycle of the mucking process; hence, the amount of total saving reaches $819,313 in the whole tunnelling project.

Table 4: Improvement of cycle time and equipment cost in one cycle

	Cycle time	Equipment cost	Cost saving	Improvement rate
Current state	394 min	$1682.38	-	-
Ideal plan	333 min	$1421.91	$260.47	15.48%
Actual application	356 min	$1520.12	$162.26	9.64%

Figure 4 shows the effectiveness of equipments. Those of all equipments were found higher than the existing effectiveness. In particular, backhoe's work efficiency improved greatly, and this is because backhoe's timely entry was made possible through simultaneous loading and scaling. Moreover, the waiting time of loader and dump trucks during scaling is eliminated, improving their work efficiency as well.

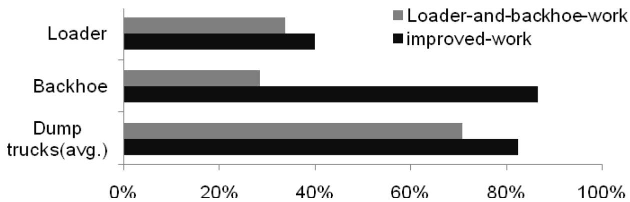

Figure 4: Effectiveness of Current and Improved Work Process

CONCLUSION

This research targets the productivity improvement of tunnel construction by maximizing VAAs and removing key waste factors involved in the value stream flow. This paper focused on process simplification and cycle time reduction. In this study, the actual tunnel construction site was applied as a case study to ascertain whether the mucking process, which consumes almost 80 percent of the whole tunnelling cycle time, can be improved through the value stream analysis.

All activities in mucking process were grasped with flow process chart to categorize each activity into three groups such as VAA, NVAA, and NVAN. After that, Value Stream Mapping was applied for further investigation on wastes from mucking process, and then a scheme to improve the current state was set. With applying the scheme to the actual site, the process was simplified and improved; 9.6% of cycle time was reduced, and equipment cost was saved as much as $162.26 in every set of operation. Moreover, the effectiveness of loader, backhoe, and dump trucks was improved as much as 3.7%, 35.1%, and 14.4% respectively.

Despite the useful findings from the case study, there exist several limitations. For example, this paper doesn't address other issues related to safety increase, optimal feet balances between equipments, and level of reliability of work flow. The future research will concentrate on more varieties of performance views based on lean principle. In addition, we will model a current as well as future work process through simulation tools to investigate more underpinning causes populated by current mucking process and further, to optimize the process (i.e., optimal equipment fleets).

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