

# AN APPLICATION OF VALUE STREAM MAPPING FOR TURNAROUND MAINTENANCE IN OIL AND GAS INDUSTRY: CASE STUDY AND LESSONS LEARNED

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Turnaround maintenance (TAM) in oil and gas industry concerns significant endeavours that deal with inspections, scheduled cleaning, adjustments, repairs and replacements of part of a plant to ensure operational reliability. It involves labour and material-intensive activities, thus is of the essence to minimize the financial impact. However, relevant research revealed that current process improvement strategies for TAM are random, isolated and scattered, improving individual activities in schedules without a systemic consideration of the entire process. Value Stream Mapping (VSM), a process of mapping the material and information flows in a value stream through systematic data capture and analysis, has showed its benefits in identifying and eliminating waste under various circumstances. This paper uses a case-based approach to measure efficiency improvement in TAM activities through VSM. The TAM project for a selected Liquefied Natural Gas (LNG) refinery plant is selected and analysed as a case study. This paper develops a current state map and a future state map to explore the wastes and root causes. The case study reveals that although some challenges and limitations, VSM is feasible in TAM project to improve the efficiency by identifying wastes in process and guiding value improvement.

Keywords: value stream mapping, lean thinking, turnaround maintenance, oil and gas industry.

## INTRODUCTION

Oil and Gas industry in Australia is a major component of Australia's economy and will continue to contribute to the prosperity. To be competitive in globalization, reliable production plants and high production efficiency are essential efforts to reduce cost (Lenahan 2011). It is notable that the performance of production is heavily influenced by maintenance productivity (Parida and Kumar 2009). This is because production is supported by complex capital equipment and machinery in oil and gas industry. Major maintenance activities, such as turnaround maintenance (TAM), are prime contributors towards the overall reliability and effectiveness of the plant. The challenges of international competition have placed great pressure on maintenance system.

TAM, also known as shutdown or outage maintenance, concerns significant endeavours that deal with inspections, scheduled cleaning, adjustments, repairs and replacements of a plant to ensure operational reliability, it is carried out when plants are shutdown (Duffuaa and Ben Daya 2004). The main objective of TAM is to improve the plants to ensure optimal and efficient performance and keep maintenance

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cost effective. In oil and gas industry, TAM plays an important role in sustaining long-term stability and continuous production of plant. According to Obiajunwa (2012b)'s research, it is necessary to shut down every 2 years to avoid unscheduled breakdowns which can have significant impact on the profitability. A proper TAM can lead to increased reliability and technical integrity that leads to a more predictable workload in the industry and effective maintenance work planning. However, this kind of project is usually very costly, requiring a large number of workforces, material and supporting resources to be involved in a short duration. Again, the loss of non-producing during turnaround is added to the cost of TAM. Its peculiarities of short duration, high capital, labour and material intensity, which make it become the large complex, expensive and time-sensitive project. In order to be competitive, a well-organized management process of conducting TAM is an essential part to improve maintenance productivity and drive cost down. In this context, lean thinking has gained attentions in oil and gas industry to improve the efficiency of the TAM process from planning through to completion (Smith and Hawkins 2004).

Value stream mapping (VSM) is the most efficient tool of lean thinking and has proved its value of increasing process visibility (transparency) (Klotz *et al.* 2008), and its benefits in reducing lead time and inventory (Abdulmalek and Rajgopal 2007, Seth and Gupta 2005, Singh and Singh 2012) in different areas. On an academic and practical level, VSM has been presented as a practical method by visualising the condition and interaction of actions. However, this remarkable tool has yet to be applied in any work in oil and gas industry.

The main objective of this research is to explore how VSM can be adopted in TAM uses a case-based approach. Based on a completed TAM project schedule, the map of as-is state, proposed changes for future state, and a discussion of working plan are carried out according to the guidelines of VSM.

## LITERATURE REVIEW

In TAM related research, some studies have concentrated on guideline for a structured approach for managing TAM in different phases (Duffuaa and Ben Daya 2004), some on the management skills specific towards ensuring successful TAM projects (Cui, Hayakawa and Obiajunwa 2013), others on project management in TAM activities (Pokharel and Jiao 2008). Obiajunwa (2012b) developed a framework of success measurement criteria for TAM projects. TAM success is evaluated from the perspectives of management success, perception of stakeholders and resultant benefits to the business. Project management techniques are still used to improve the efficiency of TAM, for example, risk management is used as a practical tool in TAM (Obiajunwa 2012a). It is acknowledged that project management is the main strategy used to manage and coordinate TAM in current practice, the success and efficiency of TAM project is measured by cost, time, safety, quality and scope (Ertl 2004). However, this may not be the most optimum strategy to TAM, failures are still common in practice. A new method is required for effective management of performance on TAM project.

Lean thinking is a systematic approach for identifying and eliminating waste through pull strategy in pursuit of perfection from customers' perspective. It originally came from automobile industry, developed from Taiichi Ohno's notion of 'reduce cost by eliminating waste' (Holweg 2007), which was initially well known as Toyota Production System (TPS). The early contribution of TPS is a focus on "*automotive manufacturing-based view*" (Hines, Holweg and Rich 2004) of shop-floor lean

techniques (e.g. Kanban, five-S, pull, total productive maintenance, single-minute exchange of dies (SMED), cellular manufacturing, for further reference see (Monden 1983)) to eliminate the waste. According to TPS, The seven most common types of wastes which were originated by Ōno (1988) are overproduction, waiting, transportation, inappropriate process, unnecessary inventory, unnecessary motions, and defects.

In order to set up guidelines to solve the questions been raised when non-lean production organization tries to convert to lean one, five lean principles of value, value stream, flow, pull, and perfection, as the framework for organization to understand the strategic approach of lean transformation, are summarised by Womack and Jones (2010). One of the important lean principles - value stream, is 'the set of all the specific actions required to bring a specific product' (Stone 2012), which defines the work process from the view of 'actions'. Monden (1993) divided these actions into three types: value adding, non-value adding but unavoidable and non-value adding and immediately avoidable. These actions considered information as well as physic flow within the overall supply chain. This principle focuses on the transparency of all the steps in process within the elimination of waste, providing clear value adding steps among all the participants, it awakens the awareness of drawing maps of individual value streams to holistic view the interdependence of actions.

A number of value stream tools have emerged to reduce and eliminate wastes within a value chain. Hines and Rich (1997) summarized seven mapping tools (namely, process activity mapping, supply-chain response matrix, production variety funnel, quality filter mapping, demand amplification mapping, decision point analysis and physical structure mapping). However, they are poor in revealing the links and visualizing the nature of the information and physic flows in entire value chain. VSM is an information and physical process mapping tool of lean production popularized by Rother and Shook (2003). It creates a common basis of the integral actions view in value stream. VSM is emerged as the preferred way to support and implement the lean thinking (Chen, Li and Shady 2010, Grewal 2008).

There are many studies related to VSM application in practice. VSM is used to visualise and analyse the value-adding and non-value adding activities in entire value chain from users' perspective and then redesign work system based on Lean (Jones, Womack and Shook 2003, Pavnaskar, Gershenson and Jambekar 2003, Rother and Shook 2003). The benefits of VSM are reported by Seth and Gupta (2005) for lean application and cycle time reduction. McDonald, Van Aken and Rentes (2002) enhanced VSM by simulation. Abdulmalek and Rajgopal (2007) illustrated the VSM benefits in reducing lead-time and lowing work-in-process inventory by developing a simulation model. This kind of simulation research mainly focuses on answering questions that could not be addressed only using the static view provided by VSM. Some other research concentrates on solving the limitation of VSM application. Braglia, Carmignani and Zammori (2006) proposed a new VSM approach based on seven iterative steps analysis for complex non-linear production systems. Braglia, Frosolini and Zammori (2009) proposed two alternative approaches based on statistics and fuzzy algebra respectively to include variability analysis in VSM.

Although VSM is mainly used in manufacturing environment from the literature review, Pavnaskar and Gershenson (2004) identified the differences and similarities between a productive and an engineering process that enable the adaption of VSM for use in engineering process. By a comparison to the objectives of TAM and VSM

(table 1), it is apparently to see synergic objectives of them. Therefore, it is of value to apply VSM to improve TAM efficiency in oil and gas industry. This paper uses the five steps of VSM (Tapping, Luyster and Shuker 2002) to explore the value and reduce waste in process of TAM.

1. Identify an analysis objective;
2. Current state map: graphical representation of the current state process (as-is state) of the objective;
3. Future state map: work out a future-state lean process (benchmarking) within the elimination of wastes by lean techniques;
4. Define working plan: execution strategies to narrow the gap between as-is state and benchmarking;
5. Achieve the working plan

*Table 1: comparison of objectives of TAM and VSM*

Objective of VSM	Objective of TAM
To visualize maintenance flow from material and information perspectives	To achieve higher corporate performance
To improve the process by applying lean techniques to short lead time	To improve efficiency and throughout of plant by suitable modification To make plant safe to operate till next TAM To reduce routine maintenances costs To upgrade technology by introducing modern equipment and techniques;
To achieve zero waste by identifying the source of waste	To increase reliability/availability of equipment during operation To achieve the best quality of workmanship
To translate customer's requirement into practice processes	To modify operating equipment to cope with legal requirements and or obligations such as environmental regulation (Ben-Daya <i>et al.</i> 2009)

## RESEARCH DEVELOPMENT

In this research, a case study is applied (Yin 2013) with a statistical analysis of data obtained from one oil and gas plant shutdown project. Case study can suitably be used for theory testing and refinement. Measurements in this research examine the qualitative and quantitative dimensions of wastes: (1) the qualitative dimension analyses the reasons behind the waste; (2) lean measurements are applied to measure the efficiency of each stage in quantitative dimension. Due to the considerable financial implications of any changes in TAM, the study is conducted based on historic data of one particular past TAM project. VSM has been implemented using the historic maintenance schedules provided by Company A, an oil and gas operator.

### Value stream selection and data collection

The first important thing prior to the commencement of VSM is to select a value stream. TAM in oil and gas industry concerns wide range of activities such as boilers, heat exchangers, piping and even storage tanks repair or replacement for the reasons of improvements or maintenance needs. In this case, it is about a compressor replacement, 5 types of activity are contained. The type of activity that was chosen for value stream study is spool removal. This is because on the one hand, a single map encompassing the entire process would be too large and heavy for researcher to handle. On the other hand, the actual duration (164 h) spent on spool removal is more

than twice to the scheduled duration (75 h) which caused delay of the whole process. As shown in table 2, spool removal is divided into 8 stages after considering the logical relationship between the maintenance activities, with each stage considered as an independent value stream in value chain.

Table 2: spool removal stages and attributes

Attributes	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
	Remove insulation	Releasing and measuring	Removal elbow	Removal structural work	Removal transition spool	Removal discharge	Balance line removal	Removal hot gas recycle
CT	21	88	112	51	60	65	64	73
VAT	21	33	2	2	6	2	2	2
CO	0	52	86	28	34	44	51	48
Uptime	100%	41%	34%	45%	43%	32%	20%	33%

Based on the data, five key VSM measurements are calculated in table 2: (1) cycle time (CT) is the duration that a stage needs to complete its work; (2) lead time (LT) is the time that a activity needed between one task being started to the end of a task being completed. In TAM, in order to minimize the project duration, the stages are usually carried out in parallel, therefore, the total cycle time is not the same as the lead time; (3) changeover time (COT) which is the idle time that one stage needs to wait before the completion of its preceding stage; (4) uptime is calculated by dividing actual working time by cycle time; (5) actual working time is calculated by subtracting changeover time from cycle time.

### Current state map

Current state map is a diagram that is created to capture working processes using rules created by Rother and Shook (2003). Value adding and non-value adding activities in the information and physic flows of a value chain are visualised in the diagram as interconnected processing steps. A list of process data such as cycle time, value-creating time are recorded at each processing step. In this way, it is possible to track orders throughout the value chain and to get an approximate valuation of the total lead time of the process.

The current state map developed for spool removal activity is shown in Figure 1. It illustrates the conventional approach using predefined icons of VSM. What the customer demand in TAM is to satisfy the duration-driven maintenance plan, site manager is the control centre of the whole process. Because of the characteristic of uncertainty of work scope in TAM, the demand can vary significantly from day to day. Therefore, the work schedule is not always the same.

A total of 8 stages are involved in this activity, it should be highlighted that the scheduling of the spool removal is not constant but variable because of the duration limitation and uncertainty as mentioned before. As cycle time delay in the first few stages, this led to variations of schedule and resources (workforce, material and facilities) in the whole process. For example, maintenance operation with low-value added like realising and measuring takes up excessive resources, which means a significant delay in the total lead time and a confusion of work schedule.

The information recorded in the data box is extracted from actual schedule which was collected by site managers. The problem of information system is that different professions plan and carry out their jobs separately; however, their jobs are highly related and overlapped that make the system much more complicated.

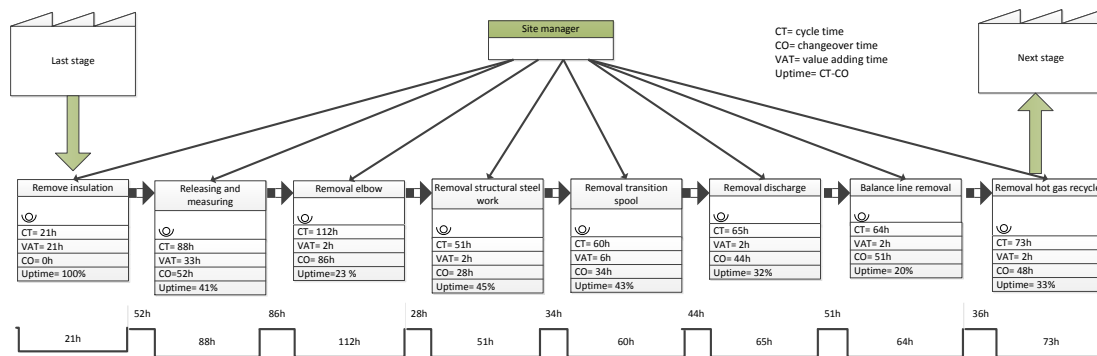


Figure 1: current state map of the spool removal process in TAM

As can be seen from the map (figure 1), the total lead time of this activity is 164 hours, which is calculated based on the start time and finish time of this activity. The total cycle time is 534 hours (total cycle time = sum of cycle time of each stage). The total value adding time is the sum of each process value adding time, and the value adding ratio is 42% (Value adding time ratio= Total value adding time/ Total lead time).

### Future state map

Future state map is a result from process improvement. Lean tools are used to streamline the value chain by identifying the wastes, analysing the root causes of wastes and eliminating non-value adding activities. This ideal pull system in future state usually represents the improvement we could achieve in practice.

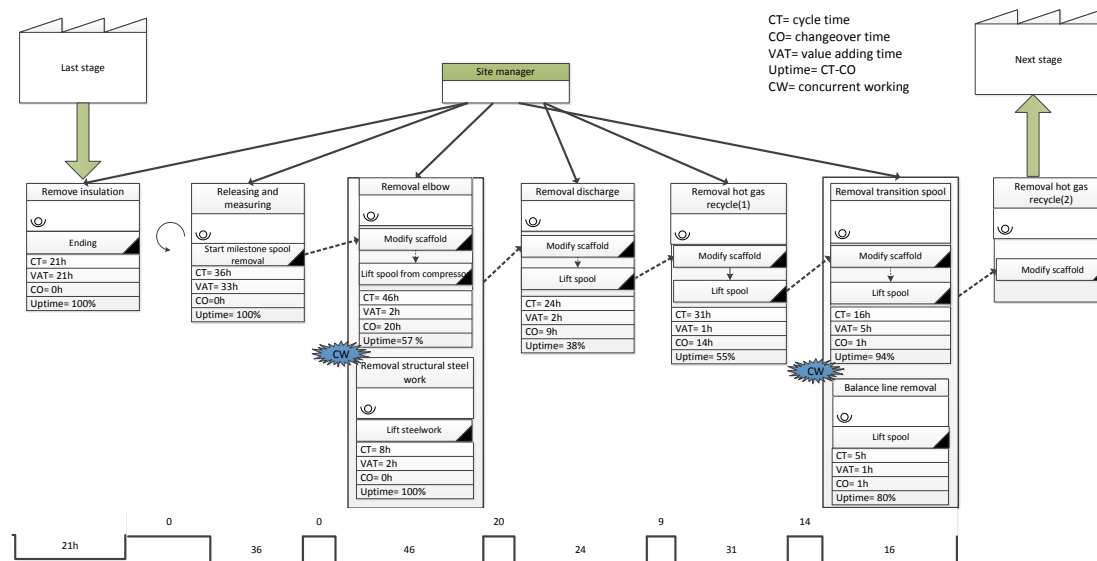


Figure 2: future state map

The maintenance process in oil and gas industry is suffering the wastes because of the uncertainty, which further causes the variability. Variability results in fluctuation of the work flow, which is the primary cause of waste. After the reasons have been recognised, lean tools are used to eliminate them in the highest possible and a future state map be drawn up. There are mainly five guidelines concluded by Rother and Shook (2003) for future improvement – TAKT time, continuous flow, supermarkets, pacemaker process and pull system. However, as discussed by (Yu *et al.* 2009) in the research paper (VSM application in house construction), continuous flow and supermarket are non-applicable in the sit-based environment as well as complex long process. This rule also could be adopted in TAM in oil and gas industry for the same

feature of project-based management. Therefore, various proposals for waste elimination have been developed in consultation with the actual work schedule. The future state depicting the various modifications of maintenance is shown in figure 2.

**Value stream re-detecting:** Value stream is re-detected by picking out the key impact jobs in each process to reduce the variation. By an analysis of this maintenance activity, it is recognised that scaffolding modifications for facility lift are the key path that decide the progress of the schedule. Therefore, current work state is adjusted with pull work flow and redeveloped from the point of scaffolding work.

**Takt time:** Takt time is a metric to measure the rhythms of production from the perspective of customer. In this case, the activity which is chosen to analyse value stream is about compressor spool removal before strip down. Here takt time is calculated according to the equation:  $\text{Takt time} = \text{available working days} / 5 \text{ spools need to be removal}$ . As 162 hours are available for this activity, the takt time is 32.4 hours. It is apparently to see that cycle time in each process is higher than takt time (figure 3). In order to meet this demand, concurrent working is introduced for process improvement. The processes of removal elbow and removal structural steel, removal transition spool and balance line removal are conducted with the same scaffolding works. Figure 3 shows the comparisons of cycle time and takt time in current state map and future state map. There is a clear indication of the improvements from this statistics.

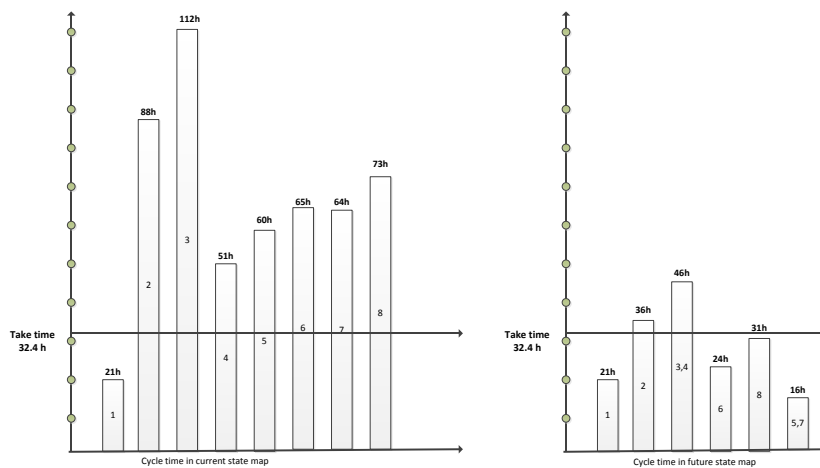


Figure 3: comparison of takt time and cycle time in current state map and future state map

### Working plan

Working plan is an execution scheme deployed to meet the improvement targets based on the analysis of the future state map. It is an important step to identify the resources that are demanded to realise the benefit of VSM in real-world application. Rother and Shook introduced value-stream plan to achieve future state (Rother and Shook 2003). However, in manufacturing, few cases have ever discussed this step as the attributes of this industry - linear continuous flow of production with limited procedures. So lean staff can focus on improvements and inefficiencies be discovered by comparing the benchmarking and the data collected on-time from work floor continuous improvement. However, on the contrary, TAM in oil and gas industry is site-based production and is finished in fixed time, so working plan, the transformation procedure from current to future state, is required to allow lean tools be effectively adopted into practice. Because this case have already finished, the data and

information used for this case study cannot enable the conduction of working plan analysis, this part will be done in next upcoming case.

## DISCUSSIONS

As mentioned above, these results came from two schedules: baseline and finished. The data is not enough to analyse all the waste and their reasons in this case. Improvements are measured by comparing the lean metrics based on the limited data (table 3). Total lead time of the value stream decreases from 164 hours to 121 hours, amounting to a reduction of 43 hours. All the unnecessary wastes are removed by reconstructing the work schedule. The total cycle time has a sharp drop from 535 hours to 174 hours. Therefore, it is concluded that VSM can be served as a guide and has a potential to improve efficiency in TAM.

*Table 3: comparison of lean metrics in current state map and future state map*

Metrics	Current state of map	Future state of map
Total lead time (h)	164	121
Total cycle time (h)	535	174
Value adding ratio (%)	42%	55%

However, some challenges to use VSM in TAM should be observed. First, the seven types of wastes are summarised based on the work in manufacturing shop floor, it would be very difficult to cover the wastes in oil and gas industry. Second, unlike manufacturing production line, the variation of process in TAM makes it difficult to draw up the sequential value stream. Third, Kanban is the tool applied for visual control to improve information management in standard VSM, while, there is a lack of information flow management in TAM for the peculiarity in the preceding part, since information flow is an important part in VSM, there should have a fundamental change to operate a lean value stream (Yu *et al.* 2009). Another important challenge is that most of the lean tools designed for future state map are hardly used in TAM environment.

Therefore, it is felt that VSM is feasible for TAM efficiency improvement because of its effective management strategy, but the full potential of VSM is hold back. The suggestions for further research are organised into two groups. First, VSM is an important tool of lean production, which is originated from manufacturing industry and has been accepted in different area, a root cause analysis of low level of usage and success in manufacturing and non-manufacturing must be done. It would be a guide to the VSM effective actual practice. Another important further development to enhance VSM would be to robust VSM with assistant tool, for example, building information modelling (BIM). BIM is a demonstration of the entire construction lifecycle that allow to redefine the work scope, and it has been widely used in engineering (Shou *et al.* 2014). The integration of BIM and VSM is of great value for improving VSM with a lifecycle perspective.

## CONCLUSIONS

This research indicates that VSM is a process redesign tool that different from other management method, it is feasible in TAM project to improve the efficiency by identifying wastes in process and guiding value improvement. Some challenges and refinement advices on working plan are provided to convert the technique into one of the important tools for TAM management.



## ACKNOWLEDGEMENT

This research was undertaken with the benefit of a grant from Australian Research Council Linkage Program (Grant No. [LP130100451](#))

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