AADE-17-NTCE-088

Leveraging Design for Manufacturing Principles in Liquid Mud Plant Design

Joel Hugghins, Ahmed Amer, Bob Pahlkotter and JW Cross, Newpark Drilling Fluids LLC

Abstract

Liquid mud plants (LMPs) are the bloodline for deepwater drilling fluids applications. The advancement of floater technology has enabled operators to drill at greater water depths. That, coupled with increased offshore rig counts, has led to larger volume requirements. The response by drilling fluids companies has included adding extra LMP capacity to handle the volume. However, adding capacity does not resolve all issues. For instance, hidden non-productive time, such as waste and flat time, continue to hinder productivity.

While planning and developing a new LMP, Design for Manufacturing (DFM) concepts address those key issues. The concepts include process automation for precise repeatability, Lean principles for eliminating waste, and Six Sigma tools for reduced variability. In addition, Lean and automation emphasize safety as well as speed of service. Finally, key performance metrics are suggested for measuring the efficiency of the LMP design.

The LMP design objectives focused on process efficiency, which included increasing capacity, improving functionality, eliminating waste and reducing process variability. The scope of the LMP project spanned the breadth from receipt of new materials to delivery of products and services including receipt of materials from the rig.

The project included a two-phase approach: (1) establish the process-control philosophy and (2) facilitate waste reduction through innovative build considerations.

Positioning plant build utilizing DFM concepts in conjunction with an appropriate process-control philosophy helped facilitate cultural change. Better understanding process activities resulted in better products and services to the customer. Moving forward, experience in these new tools will assist in improved performances for future plant builds.

Introduction

Deepwater drilling has seen a steady rise in prominence due to several factors. In recent decades, more and more activity has shifted offshore as the land-based drilling market has become increasingly saturated. The costs of offshore drilling technologies naturally continue to decline as companies gain valuable experience, refine techniques, and standardize practices. While the risks are greater in offshore plays, so are the potential rewards.

Deepwater drilling efforts require substantial amounts of support: drillpipe, casing, drilling fluids, rotation of personnel, supplies, and more which must be reliably and continuously trafficked to and from the rig in order to sustain these complex operations. A crucial component to effective drilling is the drilling fluids. Depending on the circumstances, drilling operators will shift between water-based and synthetic-based drilling fluids to capitalize on cost or performance advantages (Figure 1). These fluid programs are specifically designed around each formation taking into account customer needs and preferences. The fluids are further treated at the rig to address any particular issues the operators experience downhole. While the nature of the drilling fluids is comparable to traditional land-based drilling, deepwater work demands quantities and precision on a much larger scale. The highly-tailored nature of deepwater drilling fluids makes repeatability of formulation extremely important. Additionally, the costs, due to of loss of productivity or downtime, are unparalleled with deepwater work.

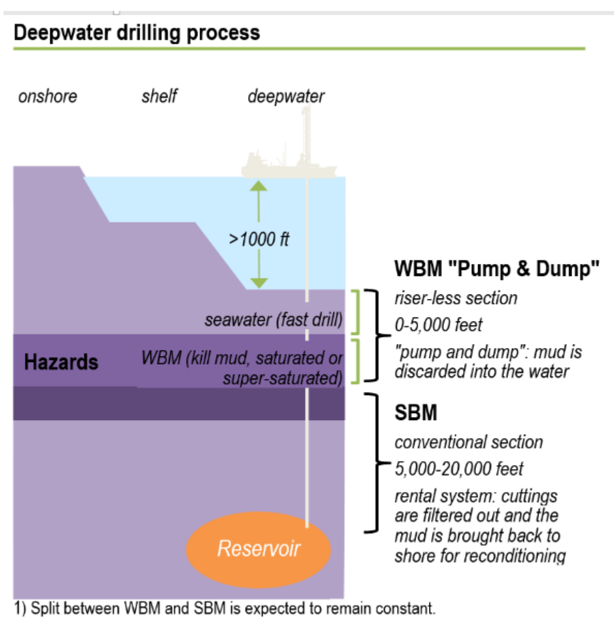

Figure 1 – Typical Deepwater Drilling

Answering the question of how one ensures reliable drilling fluid production and delivery on this grand scale is a core objective. One of the axioms with typical manufacturing processes is that scaling up inherently scales up the waste and variability associated with the process itself. Reliability, efficiency, and, most of all, consistency are all jeopardized if deliberate precautions are not undertaken.

When looking to the successes in other industries confronted with similar realities, one can identify a methodology that has developed combining the proven tools of both Lean and Six Sigma. These complimentary approaches culminate in a condition characterized by the manufacturing process flowing smoothly and predictably at any scale; known as effective DFM. However, it cannot be over emphasized that designing a smooth-running process is driven by the primary goal: understanding and satisfying the customer's needs. Only by understanding and taking appropriate action to satisfy (or even delight) our customer can we begin to craft a facility capable of competently participating in deepwater work.

VOC and the QFD tables

The needs of the customer are commonly referred to as the "Voice of the Customer" (VOC) and must be compiled and then translated into concrete services, products, activities and processes that can be incorporated into facility designs. By extensively engaging the deepwater market directly with interviews and surveys, one can develop a detailed matrix of deepwater customer needs. This matrix can easily be transformed into a master plan using a tool called Quality Function Deployment (QFD). The QFD tables derived from the matrix are an effective means of translating aspects of customer satisfaction (indicators of value in the customer's eye) into quantifiable processes. A customer expresses value in a "feature" and the design team is then empowered to focus on items of genuinely perceived value. The QFD process streamlines the prioritization of features, and the processes that provide and support those features, so that effort and moneys are not squandered on features the customer is expressly ambivalent towards. Much like a mission statement, the QFD tables provide insight on what activities are essential and which ones are likely poor investments of resources.

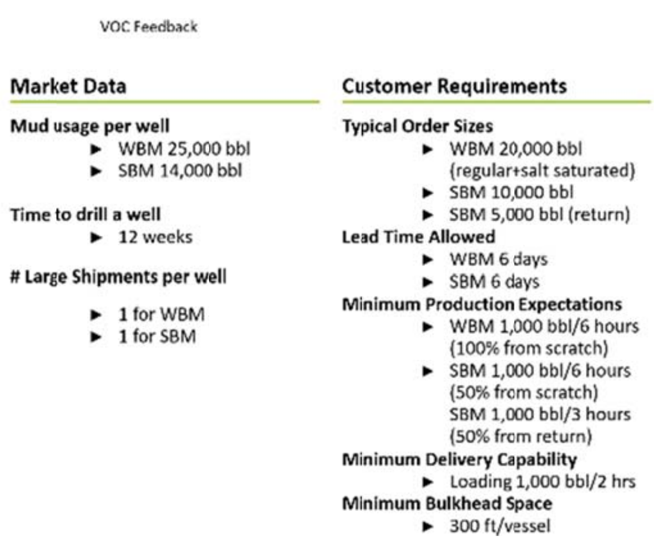

Figure 2 – VOC feedback capturing basic customer needs.

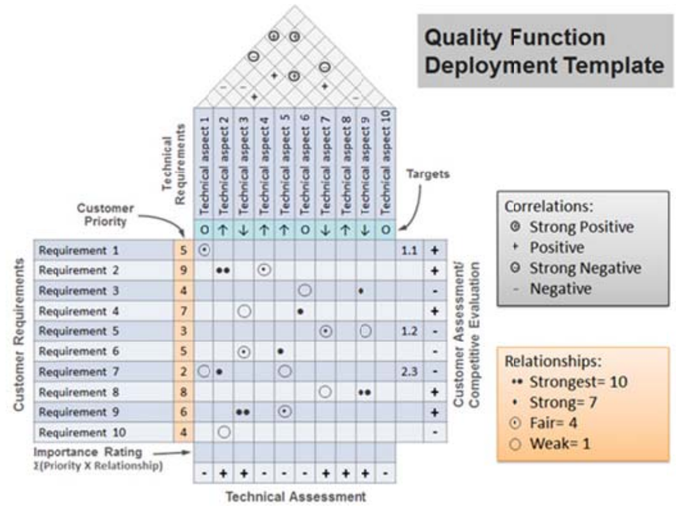

Figure 3 – QFD Matrix identifying which technical aspects correlate to value in meeting customer requirements.

Figure 2 captures the VOC customer requirements and Figure 3 relates the VOC information to specific technical processes to identify which processes offer the most value to the customer.

Once the VOC is well-understood, the next logical step is setting the overall specifications for the capacity and function of the LMP to meet these customer expectations. Knowledge surrounding the capabilities and frequency of transport vessels, generally accepted "best practices", regulations, capabilities of the competition, and a healthy dose of prognostication about the trends of the industry further inform and feed the project design objectives. For example, larger remote wells in the Gulf of Mexico are transporting and consuming WBM at a rate of up to 4,000 barrels per day. Supporting multiple rigs would necessitate taking these rates into account. Also, the newer transport vessels are designed to accept larger piping connections and the faster transfer rates those connections permit. Consideration of these types of facts greatly enhanced the design objectives of the project.

Establishing the Design

In order to bring absolute predictability into a process, standardization of a process has to be addressed. Understanding how (and when) value is actually imparted within a process is paramount. Further, one needs an accurate awareness of how the process currently functions before significant improvements can be applied. This is where the use of Value-Stream Mapping (VSM) comes in. The VSM technique helps concisely quantify the capabilities of the current condition as well as chart a course for enhancements by articulating the intended "future state". The "current state" illustration typically reveals several key design restrictions that need to be addressed by the design team. Devices, resources, procedures, and techniques to resolve these exposed weaknesses can then be readily incorporated in the "future state" design. The "future state" also includes any customeroriented enhancements that were defined in the QFD exercise.

The VSM is useful in that it illustrates the steps in the process as well as identifies which steps are contributing value to the product. Additionally, the impacts on various inventory levels are modelled explicitly. Value-Stream Mapping enables one to quantify the lead time, efficiency, and inventory needs of various scenarios so that selecting the most appropriate "future state" is easily accomplished. Careful examination also reveals the natural restrictions to work-flow, called bottlenecks, that need to be relaxed in order to smooth out the process.

Automation is a remarkable means to enhance both consistency and repeatability of almost any operation, providing both standardization and reliable operation. Automation, like any other tool mentioned here or elsewhere, is neither inherently essential nor does it guarantee success. Tools require skilled application toward some intelligent design to contribute value. The tool alone has little to no value. Automation, however, has the negative potential of serving as a means of enshrining wasteful or ineffective processes if not administered properly and thoughtfully. Additionally, Lean philosophy teaches that no resource is more valuable than an attentive, empowered, and qualified human being. For this reason, automation should be included only where it significantly contributes to process efficiencies, repeatability, or ergonomics & safety.

LMP personnel are potentially a company's most valuable resource and it is therefore advisable to use automation only to support the employees in the execution of their work activities – so that they are unencumbered to serve the customer well. One function of automation is to effectively serve by enhancing the personnel's "operational awareness" of activities within the LMP. Weigh carefully to what extent automation should be relied upon; and recognize that enhanced technology requires enhanced skillsets to maintain or modify it. Nevertheless, the VSM process may highlight several inherently wasteful steps whose elimination (via automation) could yield significant and immediate dividends.

Every design should define and accept metrics which will be used later on to evaluate the effectiveness of the project. These metrics are usually referred to as Key Performance Indicators (KPIs). KPIs usually include objective, measurable items such as: production rates, quality metrics, lead times, efficiencies, and inventory turns. KPIs are selected to be appropriate to the specific project and should reflect any value performance as identified by the VOC. Figure 4 illustrates a VSM for order fulfillment.

Design Elements and Evaluation

Each situation and application of these tools will generate unique results. The recent LMP project identified several novel production systems that would need to be developed to achieve the desired "future state". One such system was a rapid salt delivery system designed to overcome the common

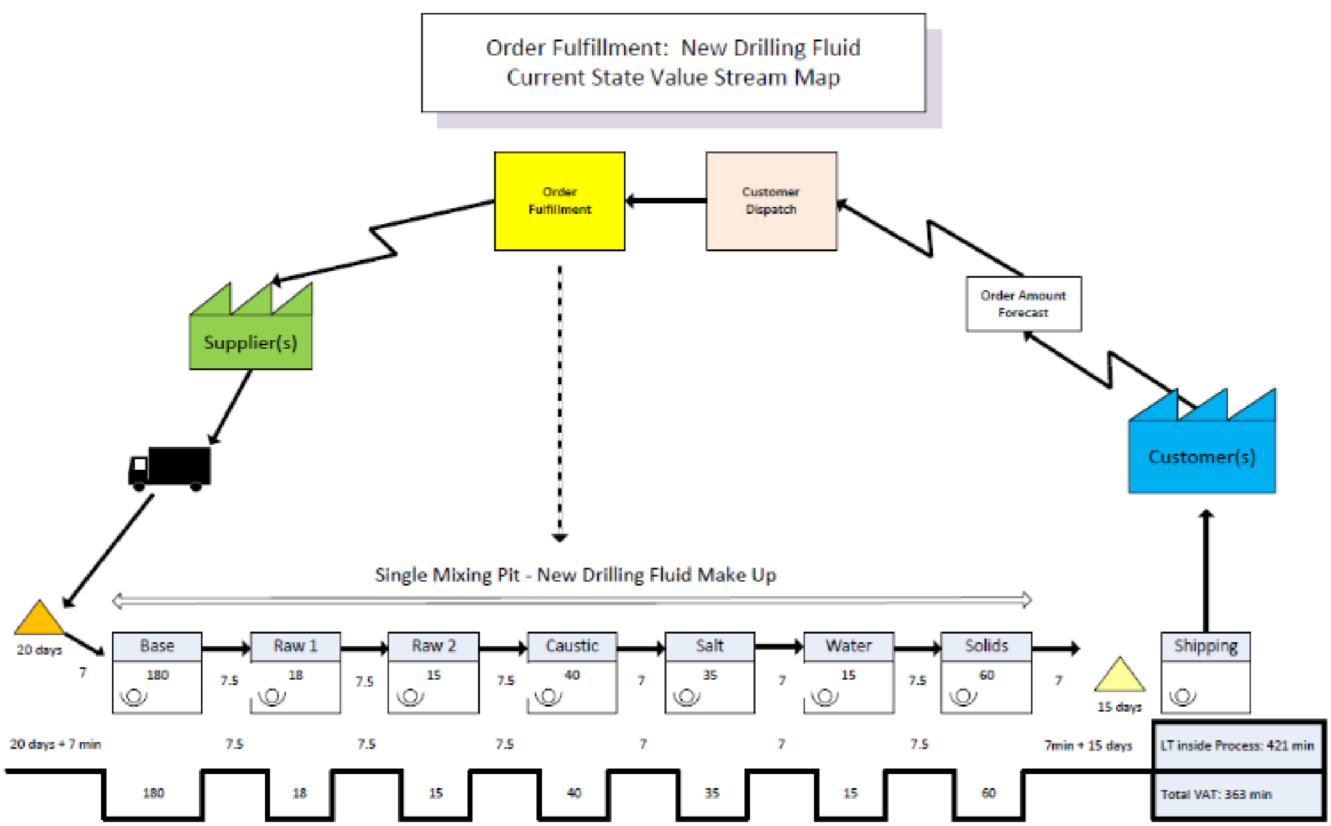

Figure 4 – Value Stream Map for Order Fulfillment

bottleneck process of salt saturation. This rail delivery system was designed to manipulate hundreds of super-sacks of salt and digest them at an incredible rate during WBM blends with minimal manpower. Furthermore, the rapid salt delivery system is able to distribute salt simultaneously to any and all of the mixing pits facilitating parallel processing of drilling fluids; providing both flexibility, and redundancy in the event of equipment failures.

Another notable area of innovation in this particular example is an extensive network of in-line measurement devices that monitor various process and product characteristics in real time. These monitoring devices keep the operators well-informed so that important process decisions are simple and timely – but explicitly not automated. Many of these devices are new to the industry and their development included extensive projects to ensure accurate, appropriate, and reliable performance. Feedback such as flowrates, live fluid properties, metering, and inventory monitoring are among the valuable real-time information utilized in this particular new LMP design.

Once a design is mature, but before a design is released for fabrication, it is advisable to engage in a comprehensive Failure Modes and Effects Analysis (FMEA) review. The FMEA process systematically evaluates each process, procedure, and device to anticipate possible failures, uncover potential design deficiencies, and to develop countermeasures to address the issues. Issues are scored by severity, likelihood, and the ability to detect. Their resolutions are then prioritized by the design team. A rigorous FMEA review will contribute radically to the robustness of a design. Many of the countermeasures and enhancements that will come from the FMEA will likely involve disaster recovery plans, process redundancies, and operator safety issues.

Overall Service Quality Planning

No discussion on DFM would be complete without a brief dialogue about product compatibility with regards to the general process. Products need to be periodically reviewed to determine if efficiencies are possible as it relates to the manufacturing process. Minor product and chemistry changes can have enormous impacts on process efficiencies if handled improperly. To this end, the notion of raw material quality has to be examined. Raw materials (such as shown in Figure 5) of superior and predictable quality will contribute to finished goods of like superior and predictable quality. Ensuring high levels of quality is known as a state of statistical control. Control over both the raw materials and the manufacturing process provides control over the quality of finished products made in the LMP. This is where Six Sigma methodologies really come to bear. Six Sigma tools and techniques enable the optimization of all the contributing factors involved in LMP operation as well as play an ongoing role in the continuous improvement activities associated with the LMP. Six Sigma offers objective statistical criteria to evaluate and refine any process to improve performance and reduce cost around intelligently chosen targets by reducing all forms of variability, giving consistency to any process. What Lean offers with respect to waste reduction, Six Sigma offers with respect to variability reduction. These complimentary toolboxes are essential in applying DFM effectively to LMP design.

Optimization using Six Sigma is frequently accomplished using a Design of Experiment (DoE) technique whereby several controlling variables are systematically and intentionally changed in order to determine causal links to process outputs. These deliberate experiments qualify the relationships among variables and also reveal set points that are used to optimize a process around whatever characteristics are most desired. DoE is a powerful tool used to ensure that the VOC is communicated throughout the process from beginning to end.

As an example, Six Sigma methodologies were applied in parallel to an LMP project to evaluate the effectiveness of several competing process equipment types. Various equipment suppliers were invited to demonstrate their technologies simultaneously and comparisons were made to determine which ones represented the best investment based on cost of ownership, cost of operation, and overall effectiveness. Statistical Six Sigma tools enabled the results to be clearly and definitively explained.

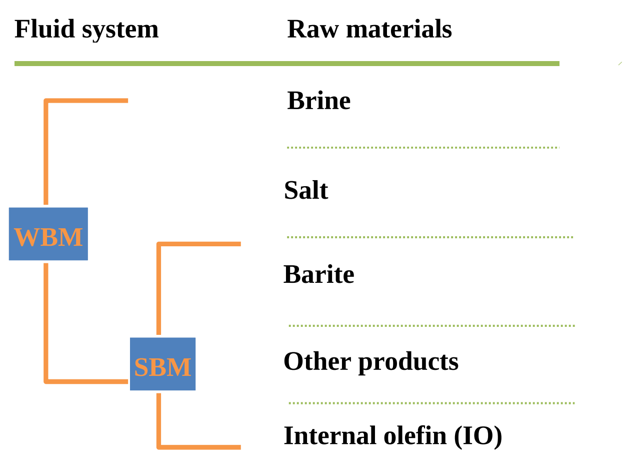

Figure 5 – Typical raw materials used in formulating drilling fluids.

Standardized Work

The next critical step is to ensure that essential processes are performed according to design time-after-time. This notion is referred to as Standardized Work and it includes work instructions, standard operating procedures, checklists, regulations, and even automation to prevent the deterioration over time of accepted best practices. Several approaches address this fundamental issue in different ways. The approach used in the examples in this paper are called Method Sheets.

Method Sheets are designed to be operating instructions reflecting the best known practices for a given process. The unique aspect of Method Sheets compared to competing standardized work formats is that Method Sheets are generated, reviewed, revised, and maintained by the very personnel carrying them out. Method Sheets can be administered in paper or digitally but they are inherently generated by the individuals who are the most intimately familiar with the process rather than a remote designer or manufacturing engineer. The Method Sheet always resides within the process – always within reach should a question arise. The format is designed to be pictorial and simple to understand, using as few words as possible. This simple, user-friendly format makes them ideal for capturing and preserving valuable process information and facilitates the rapid acclimation of new hires. Also given the sheer number of potential procedures, having front-line personnel manage them ensures timely review and response when newer, superior procedures are discovered. Each procedure is subject to expiration, forcing their periodic review and approval and most importantly, facilitating the means to get valued employees personally vested and involved in the process improvement cycle. Harvesting the valuable ideas and observations of the work force tends to be a difficult endeavor. Method Sheets naturally illicit these ideas and promote a sense of ownership in each process without the use of burdensome bureaucracy.

Project Validation

After the completion of a project, there needs to be time devoted to the validation of the project and its goals. Were the objectives achieved? Have the customer's needs been met, or even surpassed? Were the efficiencies or performance metrics met? Is the standardized work defined and in place to prevent regression? These and other questions need to be reviewed in order to determine the effectiveness of the design enhancements as well as the design and implementation teams' effectiveness. Validation of the design needs to be done with respect to the process KPIs mentioned earlier. Instances where objectives were not met or surprises interrupted any process needs to be examined carefully.

Root Cause Analysis is the appropriate tool to employ at this point to determine why performance fell short in some particular area. There are many tools associated with Root Cause Analysis, such as Five Whys, SCAT, and the Ishikawa diagram, but they all have this in common – they provide insight after-the-fact on issues.

Value is only derived from these techniques if one invests effort at the end of a project to look backward. Items discovered during this stage need to be acknowledged and socialized by some means of a "lessons learned" session. Whether the lessons learned is handled through a document, emails, a database, or simply a meeting of the project stakeholders, lessons learned tends to be the lowest-hanging fruit and unfortunately, is commonly left to rot on the vine.

Conclusions

The tools and techniques surrounding Design-for-Manufacturing are intended to promote the smooth flow of products and services from the supplier to the manufacturer and ultimately on to the customer. The success of projects utilizing DFM will vary based on levels of experience, skill, and conviction, but the rewards will almost always outweigh any upfront investment. The design implements mentioned here are only a few of the many tried and proven Lean and Six Sigma tools available for enhancing a project. Faithfully executed, they effectively address both waste and variability to reduce costs and will facilitate all ongoing continuous improvement efforts.

Nomenclature

DoE = *Design of Experiment*
DFM = *Design for Manufacturing*
FMEA = *Failure Modes and Effects Analysis*
KPI = *Key Performance Indicator*
LMP = *Liquid Mud Plant*
QFD = *Quality Function Deployment*
SBM = *Synthetic-Based Drilling Fluid*
VSM = *Value-Stream Mapping*
VOC = *Voice of the Customer*
WBM = *Water-Based Drilling Fluid*

References

1. Taguchi, G. *System of Experimental Design: Engineering Methods to Optimize Quality and Minimize Costs*, Vol. 2. Quality Resources, New York, 1987.
2. Luftig, J.T. and Jordan, V.S. *Design of Experiments in Quality Engineering*, McGraw-Hill, 1998.
3. Juran, J.M. and Godfrey, A.B. *Juran's Quality Handbook*, 5th ed., McGraw-Hill, 1999.
4. Montgomery, D.C. *Design and Analysis of Experiments*, John Wiley & Sons, 1976.
5. Imai, M. "Standards" Ch. 4, p. 51-57. In: *Gemba Kaizen*, McGraw-Hill, 1997.
6. Mascitelli, R. *The Lean Design Guidebook*. Technology Perspectives, Northridge, 2004.
7. Anderson, D.M. *Design for Manufacturability*, CRC Press, 2014.
8. Rother, M. and Shook, J. *Learning to See: Value Stream Mapping to Add Value and Eliminate Muda*, Lean Enterprise Institute, Cambridge, Massachusetts, 1999.
9. Newman, K., Lomond, P. and McCosh, K. "Advances in Mixing Technology Improve Drilling Fluid Preparation and Properties." AADE 2009-NTCE-08-02, AADE National Technical Conference, New Orleans, March 31 – April 2, 2009.