



# Optimizing Density-Neutron Calibration Process through PLC Based Automation System

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**Abstract.** The Logging While Drilling (LWD) calibration is one of the fundamental controls to ensure reliable formation evaluation data in an oil and gas drilling. There are many different calibration types in logging tools, one of them is density-neutron calibration. A study case conducted in one oilfield service company (Company A) showed that density-neutron calibration for nuclear logging tool takes longer time and impose more safety hazards compared to the other LWD tool calibrations. The purpose of this research is to figure out the possible improvement of calibration process to increase the efficiency and to reduce the safety hazards especially for radiation. The method of this research used DMAIC approach which the data was taken from Company A for calibration period during 2020-2022. Based on the research, a new automation system is designed and constructed in calibration area to enable remote assisted calibration. This new system consists of railway structure, pneumatic system, and PLC based automation system. The result of this study based on cost-benefit analysis showed that a new process of remote assisted density-neutron calibration will significantly reduce health and safety risks by reducing 67% of radiation dose, improving efficiency by eliminating 30% of total calibration time and reducing man-hours by 55%, also increase the calibration success rate by lowering failed calibration from 23% to only 10%. In all, this brings big impact on company operational cost by saving 19k USD annually.

**Keywords:** Density-neutron calibration, PLC, automation, DMAIC.

## 1 INTRODUCTION

Nuclear and radioactive materials show a growing application at now a day. From the beginning to the present time, the radioactive applications become wider, and the implementation are adopted in different applications. The applications that used radioactive in the systems are reported in energy conversion [1], electric generations [2], calibrations [3], defense systems [4], missile [5], oil and gas industries [6]. In term of oil and gas industries, the radioactive material applications are reported. This condition based on the operations in the form of exploration and drilling operation in the Oil & Gas industry. The process requires a reliable lithology and formation evaluation data to analyze the potential hydrocarbon reservoir in an oilfield. One of the state-of-the art technologies to get this data and one of the efficient in operation cost is the nuclear Logging While Drilling (LWD) tools [7]. This tool utilizes a radioactive

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M. A. Muflikhun et al. (eds.), *Proceedings of the 10th International Conference on Science and Technology (ICST 2024)*, Advances in Engineering Research 268,

[https://doi.org/10.2991/978-94-6463-772-4\\_57](https://doi.org/10.2991/978-94-6463-772-4_57)

logging source and is placed inside a Bottom Hole Assembly (BHA) during drilling [8], operates by oilfield services company to obtain the formation evaluation in a log data which later this data will be given to client.

Since the log data are the critical input for any reservoir evaluation, the assessment of the quality and reliability of log responses is a crucial issue for the reservoir evaluation and modelling workflow [9]. Therefore, before any formation evaluation a robust and detailed quality control of the tools and tool measurements is a mandatory step [10]. Nuclear tool calibration is fundamental as part of log quality control to establish relationship of tool measurement to the formation properties being analyzed [11].

Two of the most common formation evaluation logs obtained from nuclear logging tool are the formation density and neutron porosity. To get the most accurate measurement from the tool, a “shop” density-neutron calibration is mandatory to be done in regular intervals by service companies in their workshop. The calibration, along with wellsite verification and log quality control system for nuclear tool was reported by Olesen, 1990. The study described improved calibration techniques, new log quality control methods, and laboratory study of neutron porosity and formation density tool response stability.

The purpose of the shop calibration is to obtain the corrections to apply to detection circuits to normalize them to the reference tool. This is achieved by measuring the count rates obtained by the field tools in the field calibration standard. These will be used by the acquisition software for computing the gain factors needed to normalize these count rates to the reference values obtained with the Engineering Reference Tool [11].

The density-neutron calibration is done by inserting a chemical “dual-radioactive source” (gamma ray and neutron source) into the tool and utilize calibration blocks such as Aluminum, Magnesium, and Water as reference shop calibration standard. The tool detectors will measure the gamma ray and neutron in count rates (counts per seconds/cps) after interaction with those calibration reference blocks. To obtain a calibrated formation density-neutron porosity measurement, detectors count rates must be normalized to the Engineering Reference Tool used to establish the density and neutron response algorithm [11].

A study case conducted in one oilfield service company (Company A) showed that density-neutron calibration is a time-consuming process which normally takes an average of 9 hours. This process consists of 6 calibration steps which each requires a 30 minutes of calibration data sampling. Beside of the calibration steps itself, an average of 2 hours tool setup and dismantle from calibration area are taken before and after the calibration. Not to mention, an extra time to re-do the calibration in case of any out of specification (failed calibration) makes it a time-consuming operation.

This task is performed by 2 certified radioactive workers since it involves many equipment operations such as manual radioactive source transfers (called “loading and unloading”), manual calibration reference blocks handling, and operation of mechanical lifting. Different calibration blocks need to be changed every time one calibration phase is done. And before the blocks changed, the radioactive source inside the tool needs to be unloaded from the tool. After the blocks changed, the radioactive sources need to be inserted (loaded) again into the tools. In all, it requires 6 times radioactive loading/unloading, and 4 times mechanical lifting (using an overhead crane) and manual handling of the blocks (manually setup by manpower). Those steps are

crucial to be done correctly because the quality of the calibration really depends on the care taken in setting up the equipment. All those activities mentioned impose risks of health and safety to the workers, such as: radiation exposure, hand & finger injury, and mechanical lifting hazard. Not to mention, workers normally do the process in a long-9 hours of exhausting working environment, hence this bring a risk of fatigue which also make the risk of injury is even bigger.

Field tools are designed to replicate the Engineering Reference Tool response and to ensure uniformity and stability of their measurement response over time. Since detector sensitivity and source strength vary from tool to tool and, frequently, with time, a shop calibration is required at regular intervals to normalize the response of each tool to the standard tool response established by the primary calibration [11]. As per Company A standard, density-neutron shop calibration is done every time the electronics assembly is pulled out from the tool, the radioactive source or stabilizer of the tool is changed, also every time the tool calibration itself is expired (after 3 months). Based on the data during 2021, there were 138 LWD tool runs/operations and as part of LWD tool service, there were 60 calibrations were done in 2021. By this number, it can be concluded that the density-neutron calibration is done almost every week and this frequent calibration brings out 2 main problems: limited time to do tool service, and limited workers (field engineer) availability.

The first problem is the nuclear tool service time / tool around time (TAT) is very limited due to client's high demand. The client drilling operation is known for very fast, hence the tool needs to be ready to be serviced for only 1.5 days. This means, around 25% of the total tool service time, is allocated for calibration only. The tight time brings a no-room-for-error situation that demands a good calibration quality. However, in fact, 22% of total calibration results in 2021 are failed due to inconsistency of manual block setup. This caused calibration needs to be repeated, hence led to many overtime calibrations, and brings workers fatigue and bad calibration QC.

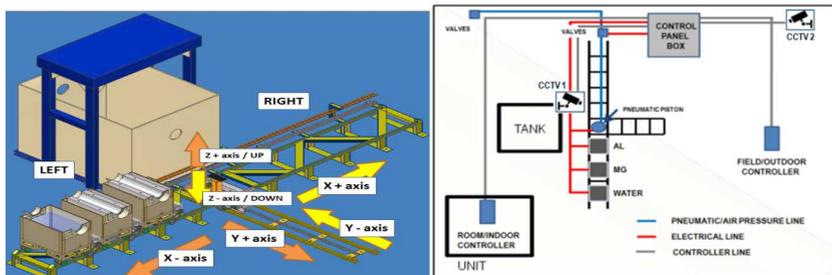
The second problem is limited workers availability because density-neutron calibration process needs 2 certified field engineers and most of the time, there is no dedicated engineer available in the workshop to do calibration. Hence, many times company need to call out engineer from days-off or from other location. As the impact, 240 days off were taken in 2021 to do calibration in workshop. Not to mention that company also spent approximately 19k USD in 2021 to pay flight ticket and accommodation for doing calibration.

Based on the mentioned problems, it is imperative to have a transformative and innovative calibration process to improve the safety aspect, improve manpower optimization, reduce cost, as well as increase the reliability of the calibration process. Hence, an integrated solution is required to tackle the problems. Having scrutinized the resources available, it is found that the resources are working independently. Combining both technology and people transformation, this research objective is to enable a remote assisted density-neutron Calibration.

To enable this new process, one set of PLC based automation system need to be installed in the calibration facility. Once it's up and running, the calibration can be performed remotely by workers: giving flexibility of doing calibration process from anywhere if it has an internet connectivity. By this new process, company will only need 1 worker standby in calibration unit, meanwhile 1 worker can perform calibration remotely.

## 2 MATERIAL AND METHODS

Materials discussed in this study is nuclear LWD tool, calibration area & facility, radioactive sources, calibration blocks, and radiation workers. The expected improvement from the existing “old/conventional” density-neutron calibration to the new “remote assisted density-neutron calibration” are that the technology and people transformation needs to be integrated to establish a new work process that is much safer and more efficient in time and cost based on Lean principles [12].



**Fig. 1.** Schematic of remote assisted density-neutron calibration system.

Technology transformation and innovation applied in calibration is a new automation system that is designed to enable remote assisted calibration. This new system as shown in Fig. 1 consists of railway structure, pneumatic system, and PLC Based automation system. The blocks movement will be done automatically by using electrical motors and pneumatic line along the railway system which controlled by PLC. To enable remote operation of the calibration, a specific designed software is installed. It contains of PLC Controller and CCTV View to operate automatic blocks movement, also PLC and system status to monitor the system condition for maintenance.

Main research method that is used to solve the problem in this research is the DMAIC which stands for Define, Measure, Analyze, Improve, and Control. DMAIC is a method that applied in practice as a generic problem solving and improvement approach [13] and it is instrumental in the implementation of Six Sigma as a process improvement methodology [14].

DMAIC is suitable for rather extensive problem-solving tasks, requiring all the components of problem definition, diagnosis, and the design of remedies [13]. Based on the calibration problems analyzed in Company A, DMAIC is suitable to be utilized as the improvement method due to extensive scope of problem solving required in existing calibration process. DMAIC method will be used in this research to establish new process and system to reduce the “waste” such as long calibration time which leads to higher cost, reduce the defect in the form of failed calibration/bad calibration QC, as well as to increase the safety factor of calibration process.

In the Define part, the problem definition and research focus has been stated as elaborated above. This problem definition is obtained from the brainstorming and data collection from the company. The improvement process was then designed specific as per the objective and deliverables/output that desired in this study. Those input of the

problems was then being processed to define the steps required to improve the calibration process. The focus also needs to be defined to maximize the impact of improvement of this process, in this case is to improve the old/conventional calibration process (related with the work process and the method of calibration).

This Measure part objective is to evaluate and to understand more about the current process which in this case is manual setup of “old/conventional” calibration. Then, every step inside the calibration process also needs to be analyzed to find the potential steps/process that seems to be inefficient/ repetitive so that it can be minimized or eliminated. Another data that needs to be measured are the calibration result. This is important to get the percentage of how much the calibration were success at first attempt, and how much the calibration need to be re-performed compared to the total calibrations performed. Then, it can be analyzed to find the potential cause of calibration failure.

On the other hand, the data about workers radiation dose also needs to be collected to give an information on worker’s dose per calibration also on worker’s annual occupational radioactive dose [15]. Those data need to be gathered and to be compared later with the study result (after) to evaluate the impact. In this case, the data that was taken is focused on density-neutron calibration during 2021.

In the Analyze part, all the gathered data as mentioned are being analyzed and breakdown. Every specific problem then needs to be found the root cause and the possible solution. The solutions proposed then being analyzed together to find an agreed solution that can tackles all problems. In this research, the analysis obtained a proposed solution to design and develop of new process: remote assisted density-neutron calibration.

Improvement part is focusing on design execution. The first part of the improvement is to apply technology transformation, i.e.: design and build the new automation system for calibration. First is the design step, started with the making of proposed calibration flow chart using automation, then from this point, a new engineering design is made as elaboration of the flow chart.

The challenge here is to find the most effective design based on the risk-based approach [16]: simple and safe to be operated, comply with the health and safety standard, and the IT standard of the company. On top of all, the proposed new system needs to be economical and respect to the company budget. The proposed system will consist of railways structure & cart movements (using electrical motors, pneumatic equipment, proximity sensors), and PLC based automation system to enable calibration performed remotely as shown in Fig. 2. Once the system up and running, a new process of remote assisted calibration will be established.

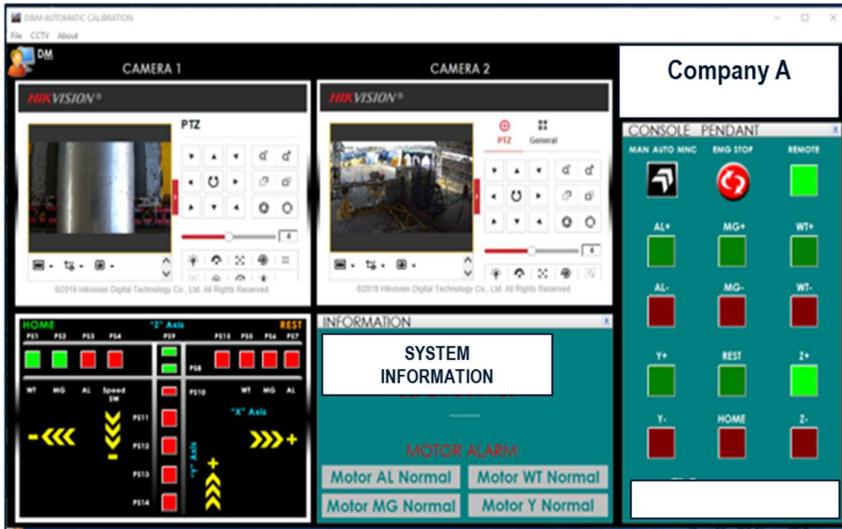


Fig. 2. Window display of automatic density-neutron calibration software.

Once the flow chart, general idea and steps design have been established, the next part is to make the detail engineering design and drawings for all required parts. In parallel, the budget and cost estimation also must be taken into accounts. The agreed engineering design and drawings then executed for fabrication and installation. The last phase of Improve is new system construction in the workshop (calibration area) based on the approved design. In this phase, construction began with PLC programming & software development, then after some simulation and algorithm review, the hardware & software were installed in calibration area.

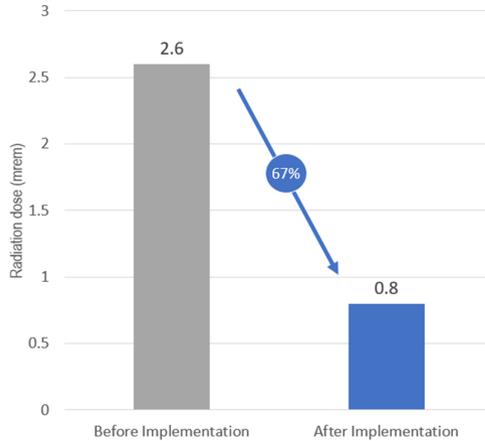
After the construction and installation of automation system are finished, the next phase (Control) is to gather the calibration result and all related data after using the new process of remote assisted calibration. Calibration data is gathered during period of May 2023–September 2023. All data will be analyzed using cost-benefit analysis to see the result after this implementation and to determine the way forward or further development.

### 3 RESULTS AND DISCUSSIONS

#### 3.1 Occupational Radiation Dose

The utmost risk and factor to be considered in designing calibration system and process is to ensure that the system and process need to be safe. The greatest hazard is radiation and the challenge to reduce the radiation dose to the minimum level using ALARA (As Low as Reasonably Achievable) principle [17]. Comparing the radiation dose coming from the other nuclear activity in Company A, the calibration process contributes to significant amount for the annual occupational dose for employee as shown in Fig. 3 below. While the maximum dose limit stated in company standard is

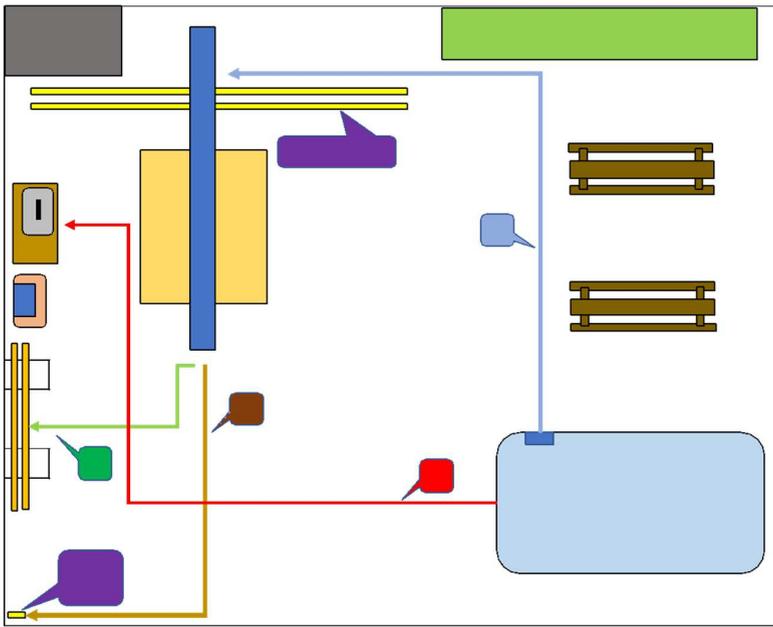
2000 mrem/year for radiation employee and 1000 mrem/year for public dose [15][17], the average radiation dose per calibration taken is around 2.6 mrem (data shown from year 2022). After the new process is implemented, the occupational dose is greatly reduced to be only 0.8 mrem per calibration (reduced by 67%). The main contributing factor is the elimination of 4 unnecessary radioactive source loading which imposed in the manual calibration blocks setup.



**Fig. 3.** Occupational radiation dose, before and after implementation

### 3.2 Workspace Layout

The design and construction process of a new PLC based automation system was done successfully with the system layout shown in Fig. 4. It promotes the most ergonomic design due to the setup can be done remotely from calibration unit of from the lab. The technician working during calibration will be less fatigue and eliminated from the others safety hazards such as mechanical lifting, manual handling, and hand & finger injury. By the help of remote-automation setup as well, time needed to setup the equipment and calibration is greatly reduced due to less waste process time.



**Fig. 4.** Workspace layout after remote assisted calibration implementation.

### 3.3 Total calibration time

Total calibration time was compared between the old (manual) calibration process and with the new remote assisted process as shown in Fig. 5 and Fig. 6. Normally for the old calibration it will take around 9 hours calibration time (including the tool setup and tool rig down), while the new calibration process will take around 6 hours for calibration time. Calibration data using new system and process were collected during May 2023-September 2023, total allocated time to do calibration reduced by 30 % as shown in Fig. 7.

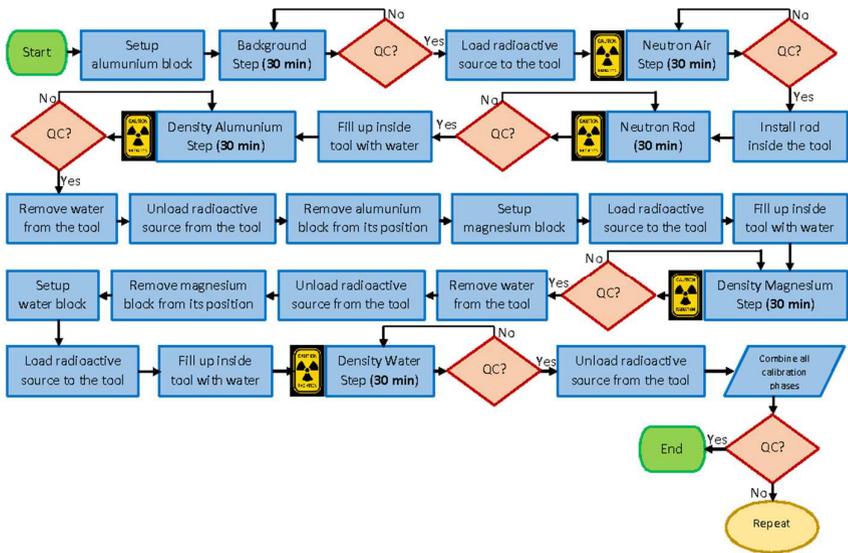


Fig. 5. Process flow of manual density-neutron calibration (before implementation).

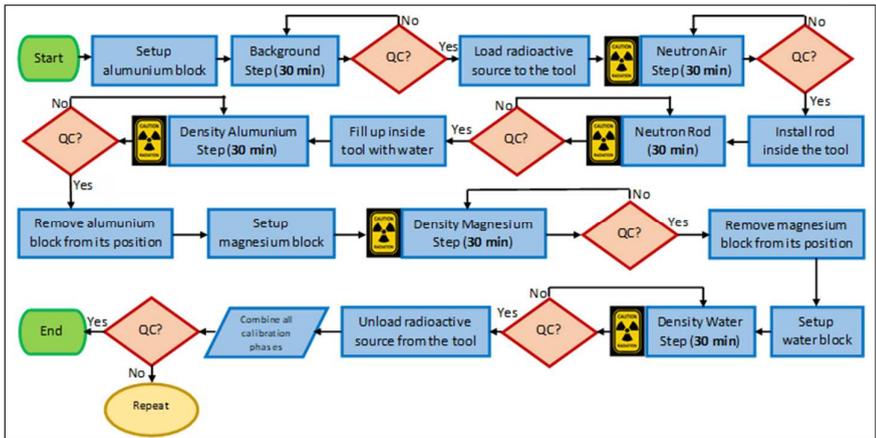
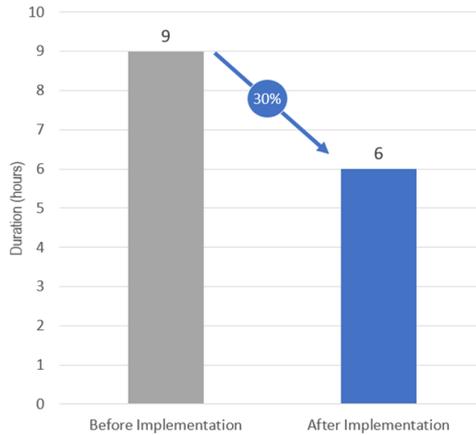


Fig. 6. Process flow of remote assisted density-neutron calibration (after implementation).



**Fig. 7.** Total calibration time before and after implementation.

The positive result using PLC based automation system also shown that the calibration process which sometimes could take more than 9 hours, it is now can be eliminated. The result after implementation showed that all calibrations can be finished under 9 hours.

### 3.4 Manpower Utilization

In terms of manpower utilization, the result after applying new calibration process brings benefit of reducing the manpower needed during calibration as illustrated in Fig. 8. Compared to the old process that requires 2 personnel to always standby in the calibration unit since the beginning until end of calibration, the new process only requires 2 personnel during loading and unloading radioactive sources, as it can't be replaced by automation as safety measure. During calibration step, 1 personnel can remotely operates the system. Not to mention, calibration average times being saved also up to 30 % hence reducing the man-hours by 55%.

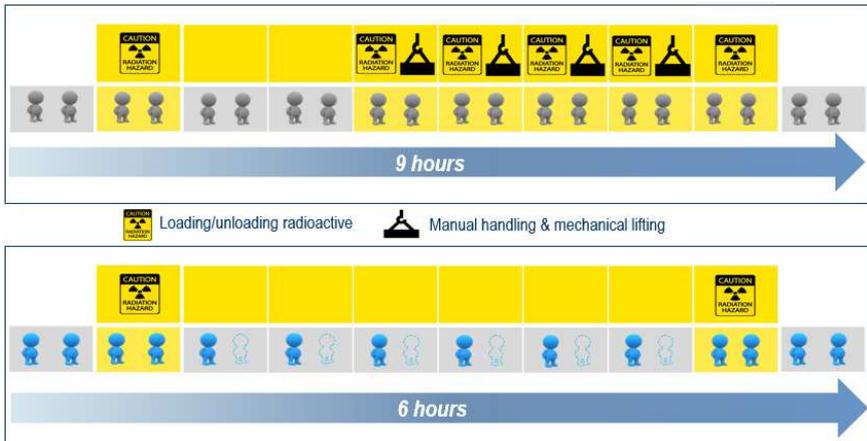


Fig. 8. Man-hour reduction (a) before and (b) after new process.

### 3.5 Calibration success rate

The old process of calibration is using manual positioning of calibration blocks, hence lead to inconsistency of accurate placement in contact with tool. Data shown from the old calibration (2020-2021), the success rate of first passed calibration was only 77%, where the 23% of calibration needs to be re-performed to get good/pass calibration. After the new system implemented, the success rate is improving, and the failure rate is reduced. Passed calibration percentage is 90% while failed calibration which needs to be re-performed was reduced to be only 10% of the total calibrations as shown in Fig. 9.



Fig. 9. Calibration success rate before and after new process

### 3.6 Cost-Benefit Analysis

The main concept of Cost Benefit Analysis (CBA) establishes the evaluation of the monetary difference between the pros (benefit) and cons (costs) of the implementation of projects or activities, and then determines the net benefits to the status quo [17]. In this study, the sum of cost spending of PLC based automation system will be compared and analyze upon the sum of benefits (both tangible and intangible). Based on the data

and results as shown previously, main factors of the calibration improved compared to the old process. A lot of benefit for company is achieved such as reduced occupational radiation dose, improved workspace layout, reduced total calibration time, improved manpower utilization, and increased calibration success rate.

From the data on Fig. 10 below, it can be concluded that by using this new calibration process, company will potentially save cost annually for around \$19,372.00 compared to the purchasing cost of \$11,100. This number of cost savings can be obtained from shorter calibration duration (30% faster compared to previous calibration), reduced man-hours to do calibration by 55%, elimination of flight and accommodation cost (no more field engineers to do calibration), and manpower optimization by using automation system, enable multi-tasking for technician and flexible working environment.

LABOR	Description	HARD SAVINGS				SOFT SAVINGS					
		Baseline process	New process	Hours Saved	Hourly Rate	Savings	Baseline process	New process	Hours Saved	Hourly Rate	Savings
Exempt time per year	Field crew days off taken, up to 300 days annually					\$ -	11627.00	0.00			\$ 11,627.00
						\$ -					\$ 11,627.00
COST AVOIDANCE / RISK REDUCTION		Baseline process	New process	Value per Unit	Number of units per year	Savings	Baseline process	New process	Value per Unit	Number of units per year	Savings
Shipping/travelling	Eliminating additional cost (flight tickets) to call out Field Crew					\$ -	120	0	\$ 126.00	\$ 15,120.00	\$ 15,120.00
Shipping/travelling	Eliminating additional cost (hotel room) to call out Field Crew					\$ -	120	0	\$ 34.30	\$ 4,116.00	\$ 4,116.00
						\$ -					\$ 19,236.00
EQUIPMENT / SOFTWARE / FOOT PRINT		Baseline process	New process	Value per Unit	Number of units per year	Costs	Baseline process	New process	Value per Unit	Number of units per year	Costs
New equipment	Purchasing Automation and remote system to 3rd Party	0	1	\$11,100.00	1	\$ (11,100.00)					\$ -
						\$ -					\$ -
						\$ -					\$ -
						\$ (11,100.00)					\$ -
						\$ -					\$ -
CONTROL PLAN		Baseline process	New process	Value per Unit	Number of units per year	Costs	Baseline process	New process	Value per Unit	Number of units per year	Costs
New equipment	Yearly maintenance cost	0	1	\$ 391.00	1	\$ (391.00)					\$ -
						\$ -					\$ -
						\$ (391.00)					\$ -
						\$ -					\$ -
						\$ -					\$ -
<b>TOTAL HARD</b>						<b>\$ (11,491.00)</b>	<b>TOTAL SOFT</b>				<b>\$ 30,863.00</b>
<b>PROJECT TOTAL SAVINGS</b>											<b>\$19,372.00</b>

Fig. 10. Potential annual cost savings by implementing new calibration process

Not to mention, the utmost benefit of remote assisted calibration is to establish the safer working environment to the radiation worker by minimizing the risk. The radiation dose is lower by 67%, also eliminate mechanical lifting involved in the block setup, minimize risk of hand & finger injury and reduced crew fatigue.

#### 4 CONCLUSION

A comprehensive study on the density-neutron calibration process had been conducted to seek the problems and potential solution that could bring benefit to company. It is observed that manual calibration system which requires manual handling of the blocks bring disadvantage of inconsistent block setup, hence lead to many failed calibrations. Besides that, calibration setup process for each calibration still has many inefficient/repetitive tasks. Those inefficient steps can be the root cause of low efficiency of density-neutron calibration in the company. Hence, a new process using PLC based automation system is needed to remove repetitive tasks and to lower setup time. With the new system, calibration repeatability and consistency are improving. The calibration quality also increases, and in return assuring better data quality to be

delivered for client during the data acquisition in the field. As per data taken during May 2023-September 2023, total allocated time to do calibration reduced by 30 % and failed calibrations reduced to be only 10% from total calibrations. Radiation dose by workers can be significantly reduced by using the new remote assisted calibration process. This new process eliminates multiple loading/unloading of radioactive sources, from 6 times in the old process to be only 2 times in new process. Hence, the radiation dose received by workers reduced by 67%. New calibration process eliminates the need of mechanical lifting and manual handling hence it lowers the physical task and fatigue of workers, also minimizing the risk of injury which are quite high in the old calibration process. PLC based automation system also enables the technician to perform calibration remotely, giving flexibility of doing the multi-task. It can also improve the manpower utilization by reducing 55% of man-hours required. Based on the Cost-Benefit Analysis, it can be concluded that this new process can potentially save up to \$19,372.00 annually.

**Acknowledgments.** The authors want to thank Company A for the support of this research also to Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada.

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