Optimization of a Portable Passivation Skid in Manufacturing Operations

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Abstract *— The limited internal utilization of a portable passivation skid in a biopharmaceutical manufacturing facility resulted in reliance on outsourced passivation services, increasing operating costs. This project applied a structured Define – Measure – Analyze – Improve - Control methodology to quantify the economic and operational impact of contractor executed passivation and to evaluate internal execution alternatives within a three-month project window. Baseline analysis demonstrated that contractor executed passivation events incurred significantly higher costs than internally executed activities, even when internal support labor was considered. Cost–benefit evaluation by passivation type identified recurring heat exchangers and a 500-liter tank as high impact candidates for internal execution. Results showed that internal passivation reduced per event costs by approximately 80% for the heat exchangers and by more than 70% for the tank. The primary constraint limiting internal passivation was economic dependence on external contractors rather than technical capability.*

Key Terms *— cost-benefit analysis, outsourcing reduction, preventive maintenance strategy, process standardization*

INTRODUCTION

An Active Pharmaceutical Ingredient (API) biopharmaceutical manufacturing facility relied on a portable skid to conduct specialized passivation activities on stainless-steel vessels and other critical process equipment. Passivation is a controlled chemical treatment that restores the chromium-rich passive layer protecting stainless steel from corrosion. These activities are essential after major interventions to maintain equipment integrity, reduce contamination risks, and ensure compliance with internal quality standards.

Despite having automation, integrated safety systems, and programmable recipe capability, the portable skid remained underutilized. Mobility challenges, assembly complexity, and the absence of standardized automated sequences contributed to inconsistent internal use and a reliance on contracted services for routine passivation tasks. This underutilization increased operating costs, extended equipment downtime, and limited the facility's control over surface passivation processes.

The objective of this project was to increase the routine internal utilization of the portable passivation skid used for stainless-steel passivation activities in the manufacturing facility. This was essential for cost efficiency, operational readiness, and long-term equipment health. Addressing this need required examining the technical factors that influenced stainless-steel passivation, the conditions that determined process consistency, and the operational constraints that affected deployment of portable equipment. These elements provided the necessary context to understand the limitations of the system and the opportunities for improvement.

LITERATURE REVIEW

Reliable execution of passivation activities requires maintaining the chromium-rich passive layer that provides stainless steel with its corrosion resistance. In chemical and biopharmaceutical environments, the condition and stability of this passive film are influenced by surface state, temperature, chemical exposure, and flow dynamics [1]. When these factors deviate from controlled ranges, the passive layer may degrade, increasing susceptibility to pitting, crevice corrosion, and generalized attack. Consistent passivation practices are therefore essential for restoring surface integrity and preventing corrosion-related failures [1].

Surface conditioning processes benefit from defined operating parameters, controlled chemical exposure, and repeatable flow conditions [2]. Automated skids support these requirements by providing sequenced operations with specified temperatures, flow rates, and contact times. When automation is incomplete or overly dependent on manual intervention, variability increases and the effectiveness of passivation cycles may be reduced. Standardized recipe parameters help minimize variation and improve restoration of the passive layer [1,2].

Mobility constraints also influenced how frequently portable equipment was deployed. Industrial ergonomics guidelines indicate that tasks involving pushing, pulling, and aligning heavy equipment can introduce physical strain and elevate the risk of handling-related incidents, particularly in environments with constrained corridors or tight turns [3]. These constraints mirror the operational barriers observed with the existing skid, where maneuverability and alignment requirements contributed to external passivation services rather than using the internal skid.

Effective passivation depends on more than chemical concentration. Adequate cycle sequencing, uninterrupted flow, and sufficient contact time are required to ensure complete exposure of internal surfaces to the passivating solution [1,4]. Industry guidance highlights that incomplete circulation or inconsistent flow patterns can compromise corrosion resistance even when the nominal process conditions appear acceptable [4]. Automated recipes reduce operator dependency by enforcing repeatable sequences that maintain uniform execution conditions across cycles.

Minimizing operational variation aligns with established quality-control principles, which associate predictable outcomes with standardized processes and reduced manual intervention [5]. Applying these principles to portable passivation operations supports the development of automated sequences, ergonomic improvements, and internal capability building. An optimized portable passivation skid that is easier to deploy, less physically demanding to operate, and supported by robust automated recipes contributes to improved equipment reliability and more efficient use of internal resources.

Analysis Approach

A structured approach was required to evaluate how conditions manifest within the facility/equipment and to determine which limitations most significantly affect the internal skid utilization. To accomplish this, the project followed the DMAIC (Define–Measure–Analyze–Improve–Control) framework to evaluate limitations, quantify baseline performance, identify causative factors, implement improvements, and sustain the enhanced operational performance of the portable passivation skid within the three-month project window.

Define

The Define phase documented the current state of the skid's deployment and use across the facility. Movement paths, mobility restrictions, setup and assembly steps, and passivation requirements were mapped. Input from operators, maintenance technicians, and Subject Matter Experts (SMEs) was collected to characterize ergonomic constraints and historical drivers for outsourcing. The main outputs of this phase was a clear problem statement, validated user needs, and a project scope focused on enabling safe, consistent, and routine internal utilization of the portable skid.

Measure

Quantitative and qualitative data were collected to establish baseline performance. Key measurements included the frequency, duration, and cost of outsourced passivation events; the time and labor associated with skid relocation and assembly; the number of manual steps required during a typical passivation cycle; ergonomic observations of physical effort and movement constraints; and physical measurements of corridor clearances, turning and equipment access points. Activities related to hose management and equipment staging were kept out of scope because they are covered by standard internal procedures and do not represent barriers to skid utilization.

Analyze

Collected data was evaluated to identify the factors limiting internal skid utilization. The analysis focused on operational barriers such as mobility constraints, equipment footprint, and assembly complexity; execution variability originating from incomplete automation and reliance on manual interventions; and historical or behavioral drivers, including perceptions that the skid is impractical for routine use. Root-cause tools such as cause-and-effect diagrams, workflow mapping, and process-sequence assessments were used to determine how these contributors affect efficiency, safety, and consistency and to prioritize issues with the greatest impact on achieving the project objectives.

Improve

Based on the analysis, targeted improvements were proposed to enhance internal usability and operational consistency. Enhancements included mobility or ergonomic aids, visual setup guides, and workflow simplification measures. A core improvement effort involved developing and configuring automated recipes for two pieces of equipment and their routine preventive maintenance passivation activities, enabling predictable and standardized execution. Where production scheduling permitted, engineering runs were conducted to verify improvements and quantify reductions in manual effort, setup time, and process variability; otherwise, performance estimates were derived from validated simulations of the defined sequences.

Control

To sustain the improvements, documentation updates were developed for preventive maintenance job plans, operating procedures, and recipe records. Training was provided to operators and maintenance personnel to support consistent use of the updated workflows and automated sequences. The site's Maximo system is used to monitor utilization of metrics, reductions in outsourced work, and the stability of the improved process. Final deliverables included updated procedures, training records, recipe documentation, and a long-term monitoring structure integrated into the site's quality and maintenance systems.

RESULTS

The application of the Define–Measure–Analyze–Improve–Control methodology produced quantifiable operational and economic results that demonstrate the benefits of increasing internal execution of passivation activities. The primary criterion evaluated in this study was the cost and operational dependence associated with contractor-executed passivation activities, as compared to internally executed passivation using the site's portable skid. Differences in cost impact were evaluated based on the type of passivation activity selected for internal execution.

Baseline cost analysis results are summarized in Figure 1, with the detailed cost breakdowns provided in Table 1 and Table 2 for heat exchangers and the 500-liter tank, respectively. The data show a substantial difference between contractor-executed and internally executed passivation events. Contractor-based execution resulted in an average total cost of approximately $22,500 per passivation event for heat exchangers and approximately $7,000 per passivation event for a 500 liters tank, which included contractor labor, materials, execution, documentation, and required internal support labor. In contrast, internal execution using the portable skid resulted in an average total cost of approximately $4,800 per event for heat exchangers and approximately $2,100 per event for the tank, accounting for internal labor and recurring material costs.

The detailed cost elements presented in Tables 1 and Table 2 indicate that contractor service fees represented the primary driver of the higher total cost, even though internal labor was still required during contractor-led activities. Elimination of these service costs resulted in a significantly lower total cost for internal execution.

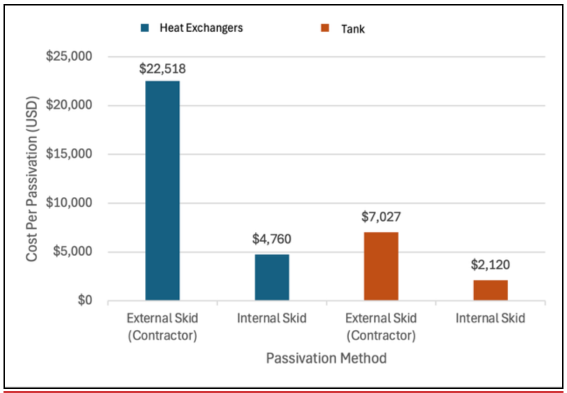

Figure 1
Baseline Cost Comparison per Passivation Event

Table 1
Heat Exchanger Cost Comparison per Passivation Event

Cost Element	External Skid (Contractor)	Internal Skid
Contractor Labor Hours	156 hrs	-
Internal Labor Hours	48 hrs	72 hrs
Internal Labor Cost ($55/hr)	$2640	$3960
Materials/chemicals	Included	~$800
Contractor Service Cost	$19,978	-
Cost per Passivation	**$22,518**	**$4,760**

Table 2
Tank Cost Comparison per Passivation Event

Cost Element	External Skid (Contractor)	Internal Skid
Contractor Labor Hours	48 hrs	-
Internal Labor Hours	16 hrs	24 hrs
Internal Labor Cost ($55/hr)	$880	$1320
Materials/chemicals	Included	~$800
Contractor Service Cost	$6,147	-
Cost per Passivation	**$7,027**	**$2,120**

To evaluate the cost–benefit impact by passivation type, single tube heat exchangers and 500 liters tank passivation activities were selected as representatives high-impact applications due to their recurring nature and historical reliance on external contractors. When annualized for five heat exchangers requiring one passivation event per year, contractor execution resulted in an estimated annual cost of approximately $112,600, whereas internal execution reduced the annual cost to approximately $23,800. This corresponds to an annual cost reduction of nearly 80% for the selected passivation activity. The tank resulted in additional annual cost reduction of approximately $5,000, corresponding to a cost reduction of 70% for this activity.

Supporting feasibility analysis confirmed that internal execution of the selected passivation activities was achievable when predefined deployment locations and transport routes were used. These findings indicate that limitations in internal execution were not necessarily from equipment size, but from historical outsourcing practices and lack of standardized internal deployment planning. Standardized automated passivation recipes developed for the selected equipment reduced reliance on manual intervention and improved execution consistency.

In addition to economic results, physical deployment and feasibility constraints were evaluated through assessment of corridor geometry, transport routes, and utility availability across multiple production floors. The analysis showed that limitations in internal deployment were not due to the inherent size or weight of the skid, but rather to the absence of predefined transport routes and designated deployment locations. When skid movement was attempted without prior route definition, corridor layout and turning constraints prevented access in certain areas. However, once specific transport routes and utility-ready deployment locations were identified and validated across Floors 1, 3, and 5, the skid could be consistently deployed. These findings demonstrate that successful internal deployment depends on advanced route planning and area qualification rather than equipment dimensional limitations. Collectively, these results demonstrate that internal execution of routine passivation activities is technically feasible, economically advantageous, and operationally sustainable when supported by targeted standardization and deployment planning.

CONCLUSIONS

This project demonstrated that the limited internal utilization of the portable passivation skid was driven primarily by economic and operational dependence on external contractors rather than by technical limitations of the equipment. Through the application of the Define–Measure–Analyze–Improve–Control methodology, this dependence was systematically evaluated, quantified, and addressed within a constrained three-month project window.

The results confirmed that internal execution of routine passivation activities provides significant economic advantages when compared to contractor-based execution. Baseline cost analysis showed that contractor service fees represented the dominant contributor to total passivation cost, even when internal support labor was required. By selecting high-impact passivation activities and executing them internally, substantial cost reductions were achieved, as demonstrated by the annualized heat exchanger and 500-liters tank case studies.

From an engineering management perspective, this project highlights the importance of data-driven decision-making and targeted optimization rather than broad process redesign. Prioritizing passivation activities based on cost–benefit impact enabled effective allocation of internal resources while reducing reliance on external services. Increasing internal passivation capability strengthens operational control, improves cost efficiency, and supports long-term sustainability of maintenance practices. The approach developed in this project can be applied to evaluate additional equipment for internal passivation based on measurable cost impact and operational relevance.

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