DMAIC – BASED MEASUREMENT SYSTEM ANALYSIS (MSA) FOR OPTIMIZING HIGH PURITY PROPYLENE IN PROPYLENE RECOVERY UNIT

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MASTER OF QUALITY SYSTEM ENGINEERING

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A thesis submitted
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DECLARATION

I declare that this thesis entitled “DMAIC – Based Measurement System Analaysis (MSA) for Optimizing High Purity Propylene in Propylene Recovery Unit“ is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :..

Name :Muhammad Fuad Bin Md Hisam

Date :30 June 2025

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Quality System Engineering

Signature	:..
Supervisor Name	:Ts. Dr. Yusliza Binti Yusof
Date	:30 June 2025

DEDICATION

To my beloved wife, Aszren Binti Sahak,

You are the heart of my world. Thank you for your sacrifices, your unwavering patience, and for believing in me even when I struggled to believe in myself. This achievement reflects your love as much as it is my effort. You are, and will always be, my greatest blessing.

To my precious children, Haura Assyifa, Ayra Aleesa, and Arrian Iskandar,

You are the light that brightens every corner of my life. This dedication is a promise to walk beside you as you grow. I hope that what I have achieved today lights a path for you to follow, one filled with knowledge, resilience, and love. And may you go even further, with courage in your hearts and joy in your souls.

To my dearest parents, Mr. Md Hisam and Mdm. Intan@Anson,

Every step I take is rooted in the values you've instilled in me. Your sacrifices, and boundless love have shaped the very foundation of who I am. This achievement is not only for me, but for you. For everything you've done, to help me stand tall.

To my respected parents-in-law, Mr. Sahak and Mdm. Esah,

Thank you for your kindness, your prayers, and your heartfelt encouragement. I am grateful beyond measure for your presence in my journey, and I dedicate this milestone to you with sincere appreciation and love.

To my supportive friends, Huzairy Iqbal, Nur Irsyad, and Afifah

Your friendship has been a light through difficult times, a reminder that I was never walking alone. Thank you for every word of encouragement, and for believing in me when I needed it most. This achievement is shared with you, as your support made it possible.

To my esteemed leader, Mr. Hisamuddin,

Your guidance, expertise, and commitment to advancing knowledge have been a beacon for me in this academic pursuit. I am grateful for the opportunities to learn and grow under your mentorship. This achievement is dedicated to you as a token of my respect and gratitude

ABSTRACT

It is important to achieve and to keep the purity of propylene at ≥99.5%, in order to meet the high-quality specifications needed in downstream petrochemical uses. Nevertheless, a significant number of refineries still face the problems of repeatability and reliability of their measurement systems that affects the quality of product and the efficiency of plant operation and long-term integrity. One of such cases was witnessed at a Malaysian refinery located in Johor, where the PRU (Propylene Recovery Unit) unit performance was found to be repetitively disturbed/limited by inaccuracy in measurement because of calibration inconsistencies, operator differences, environment variations and non-standard maintenance practices.

There were significant issues with unstable process control, frequent purity excursions, excessive energy consumption, and expensive rework of product. Incorrect data from the measurement system could lead to bad decisions and nonoptimal process adjustment in the likes of pressure, temperature and flow, that adding unnecessary complexity and cost to what was meant to be a well controlled process.

To fill this void, the case study applied a DMAIC type methodology, a structured approach to process problem solving commonly used in six sigma projects, using Measurement System Analysis (MSA). The framework was applied to systematically identify, assess, and minimize the variables in PRU measurement systems. The work was centered on actual operating conditions and employed statistical Analyzes like Nested Gage R&R (ANOVA) to quantify the repeatability and reproducibility for a group of gas measurements made at the hands of various operators.

This integrated approach resulted in measurable achievements. After the enhancement, the refinery experienced improved purity readings repeatability, lower process variability and less off-spec reprocessing. The standardization of processes has significantly increased the efficiency of the workflow process and decreased material waste, very much in line with the company's environmental and workflow optimization company goals.

Finally, this work has shown that MSA and DMAIC methods can be successfully applied together based on industrial experiences of the authors. And by making data integrity a cornerstone of process control, the refinery not only increased its production of propylene, but it also inched one step closer toward attaining strategic goals for quality, cost optimization and sustainability. The approach and outputs detailed here could potentially provide a useful model for other organizations in refining or process industries who are dealing with the same issues.

THESIS TITLE IN BAHASA MELAYU

ABSTRAK

Adalah penting untuk mencapai dan mengekalkan ketulenan propilena pada ≥99.5%, bagi memenuhi spesifikasi berkualiti tinggi yang diperlukan dalam penggunaan petrokimia hiliran. Namun begitu, sejumlah besar kilang penapisan masih menghadapi masalah kebolehulangan dan kebolehpercayaan sistem pengukuran mereka yang mempengaruhi kualiti produk dan kecekapan operasi kilang serta integriti jangka panjang. Salah satu kes seperti itu telah disaksikan di sebuah kilang penapisan di Malaysia yang terletak di Johor, di mana prestasi unit PRU (Propylene Recovery Unit) didapati terganggu/terhad secara berulang-ulang disebabkan oleh ketidaktepatan dalam pengukuran akibat ketidakseragaman kalibrasi, perbezaan pengendali, variasi persekitaran dan amalan penyelenggaraan yang tidak standard.

Terdapat isu-isu ketara dengan kawalan proses yang tidak stabil, penyimpangan ketulenan yang kerap, penggunaan tenaga yang berlebihan, dan kerja semula produk yang mahal. Data yang tidak tepat dari sistem pengukuran boleh membawa kepada keputusan yang buruk dan pelarasan proses yang tidak optimum seperti tekanan, suhu dan aliran, yang menambah kerumitan dan kos yang tidak perlu kepada apa yang sepatutnya menjadi proses yang terkawal dengan baik.

Untuk mengisi kekosongan ini, kajian kes ini menggunakan metodologi jenis DMAIC, pendekatan berstruktur untuk menyelesaikan masalah proses yang biasa digunakan dalam projek enam sigma, menggunakan MSA (Measurement System Analysis). Rangka kerja ini digunakan untuk mengenal pasti, menilai, dan meminimumkan pembolehubah dalam sistem pengukuran PRU secara sistematik. Kerja tersebut tertumpu pada keadaan operasi sebenar dan menggunakan analisis statistik seperti Nested Gage R&R (ANOVA) untuk mengkuantifikasi kebolehulangan dan kebolehpulangan bagi sekumpulan pengukuran gas yang dibuat oleh pelbagai pengendali.

Pendekatan bersepadu ini menghasilkan pencapaian yang boleh diukur. Selepas penambahbaikan, kilang penapisan mengalami kebolehulangan bacaan ketulenan yang lebih baik, kebolehubahan proses yang lebih rendah dan pemprosesan semula yang kurang bagi produk yang tidak memenuhi spesifikasi. Penyelarasan proses telah meningkatkan kecekapan proses aliran kerja dengan ketara dan mengurangkan pembaziran bahan, sangat selaras dengan matlamat syarikat dalam pengoptimuman alam sekitar dan aliran kerja. Akhirnya, kerja ini telah menunjukkan bahawa kaedah MSA dan DMAIC boleh digunakan bersama dengan berjaya berdasarkan pengalaman industri penulis. Dan dengan menjadikan integriti data sebagai asas kawalan proses, kilang penapisan bukan sahaja meningkatkan pengeluaran propilena, tetapi juga melangkah satu langkah lebih dekat untuk mencapai matlamat strategik bagi kualiti, pengoptimuman kos dan kelestarian. Pendekatan dan hasil yang diterangkan di sini berpotensi menyediakan model berguna bagi organisasi lain dalam industri penapisan atau pemprosesan yang menghadapi isu yang sama.

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Lastly, I sincerely appreciate all those directly or indirectly who have contributed ideas, shared advice, offered constructive criticism, or simply stood by me during this process. Please forgive any shortcomings or mistakes along the way.

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LIST OF ABBREVIATIONS

PRU	-	Propylene Recovery Unit
DMAIC	-	Define, Measure, Analyze, Improve, Control
MSA	-	Measurement System Analysis
R&R	-	Repeatability and Reproducibility
KPI	-	key performance indicators
ANOVA	-	Analysis of Variance
FMEA	-	Failure Mode and Effect Analysis
SIPOC	-	Suppliers, Inputs, Process, Outputs and Customers

LIST OF APPENDICES

LIST OF PUBLICATIONS

The followings are the list of publications related to the work on this thesis:

Kamarul Amminudin, Thenyan S. Enezi, Mustafa A. Jubran, Zaid F. Bedoukhi (2011). "Gas Plant Improves C_3 Recovery with Lean Six Sigma Approach" (Oil & Gas Journal) Applies the DMAIC framework and statistical tools, including process performance analysis and experimentation, to improve C_3 recovery in a gas processing unit.

Norhazrina Jamil, Hamed Gholami, Muhamad Zameri Mat Saman, Dalia Streimikiene, Safian Sharif & Norhayati Zakuan, (2020). DMAIC-based approach to sustainable value stream mapping: towards a sustainable manufacturing system, Economic Research.

Jinwei Lu & Ningrui Zhao, 2021. "Application of Neural Network Algorithm in Propylene Distillation". Examines advanced statistical modelling and process reliability in propylene purification, stressing the importance of accurate input-output measurement relationships.

CHAPTER 1

INTRODUCTION

1.1 Background

The refining sector is critical for addressing the growth in global consumption of high-purity propylene, an essential feedstock in the manufacturing of plastics, synthetic fibers, elastomers and other industrial commodities. Purity of at least 99.5% is not only an important industrial specification but also important for making sure that the quality of downstream applications is met (Agarwal et al., 2018). However, even with the evolution of these technologies, it is very difficult to achieve this level of purity and stay consistent over time due to measurement system inconsistencies for the Propylene Recovery Unit (PRU). PRUs such as spatial analytics offer great potential to enhance the capability of an executive's already microscopic visibility into key operations by capturing critical process data, however, variability in the measurement system has been recognized as a significant bottleneck that depreciates the integrity of this very process data. Such inconsistencies make process optimization very difficult, resulting in higher energy consumption and operational cost, lower yield of propylene, and higher environmental impact (Agarwal et al., 2018). This defines the pressing necessity for a systematic and structured way of solving these problems.

In this study, a systematic approach to controlling variability in a measurement system is presented, along with the usage of a DMAIC (Define, Measure, Analyze, Improve, Control) framework. To determine the root cause of inconsistencies in the measurement of a process and make the right changes to the process would require a disciplined approach such as DMAIC. The framework transforms precision measurement data into decision-making data on PRU operations by minimizing variability and ensuring data consistency and reproducibility.

Simulated data was then synthesized to amalgamate Gage Repeatability and Reproducibility (Gage R&R) studies and regression analysis as advanced statistical tools to use to trace sources of variability within the measurement systems (Chaniago et al., 2019). They help in determining the most important elements responsible for causing errors in the measurement and then allow taking corrective actions based on it. This reliability of the measurement in turn affects key performance indicators (KPI), allowing for tighter control of the process, tighter control of operational parameters, and higher propylene recovery rates.

In addition to streamlining operations, the intended approach also resonates with sustainability targets in the industry. The framework also supports strategies aimed at reducing energy consumption, minimizing waste, and improving resource efficiency by decreasing variability in measurement. Such results not only lead to cost savings but also a bigger reduction in the environmental footprint of PRU activities. This research is intended to improve the reliability of key measurements, providing consistency and accuracy in data to inform strategic and operational decision making. Reduced variability allows for tighter control of operational parameters, improving process efficiency and maximizing propylene yield and purity. Moreover, the methodology proposed reduces energy consumption and waste while increasing resource usage efficiency yielding a direct contribution to sustainability and cost reduction of the manufacturing process, which are aligned with ecological and economic targets. Even more so, increased Propylene Recovery Units (PRU) performance makes the industry more competitive as it satisfies stringent market requirements without forfeiting its quest for sustainability.

1.2 Problem Statement

High-purity propylene production is fundamental step in refining industry since it is a key feedstock in the production of plastics, synthetic fibers, and other important industrial materials. Reaching a purity greater than 99.5% is critical to fulfil the high quality demands and applications for downstream (Kuah et al., 2018). Nonetheless, the seamless and reliable performance of Propylene Recovery Units (PRU) is often disrupted by problems resulting from non-uniform gauging systems. The variability leads to major challenges with operational efficiency, cost control, and environmental sustainability. Figure 1 shows propylene purity is below 99.5 by percent weight during process control test. Despite its versatility, propylene poses challenge in selective oxidation due to its hydrocarbon properties, double bond and single bond composition that led to a variety of oxidation byproducts during the refining process.

Measurement systems in PRU are vital for monitoring and controlling essential process parameters such as temperature, pressure, and flow. In such cases, accurate and reliable data from the systems are of utmost importance as this ensures process stability and desired results. However, the reliability of data is compromised with inconsistencies in measurement systems due to issues such as calibration problems, operator-induced variability, environmental factors, and poor maintenance practices. This results in sub-par process control, propylene purity upsets and low overall PRU performance.

The implications of these inconsistencies are aligned in many ways. Inaccuracies in the measurement data lead to over or under-adjustment of the various process parameters, resulting in inefficiencies in terms of increased energy consumption and lower throughput and propylene yield. As a direct result, operational costs increase, and it becomes economically less attractive to refine the oil. This also has downstream applications problems as it cannot reach stable propylene purity levels and can lead to customer complaints in cases, resulting in a cost impact. Environmental inefficiencies of the PRU have increased greenhouse gas emissions and waste leading to challenges in global sustainability progress and regulatory pressures on the refining sector.

Measurement systems are a crucial element in the PRU optimization process, yet clear, structured methods that systematically address these issues are still missing. However, utilising a statistical tool called Measurement System Analysis (MSA) which is applied to assess the measurement systems for accuracy, precision and reproducibility is not so common in such approaches. A systematic approach for the integration of the multiscale approach (MSA) into a PRU optimization framework suggests that the application of MSA is a good solution for variability mitigation and process performance improvement. Despite this, the integration is rather scarcely investigated across industrial practices, which indicates a massive gap between the deployment of quality and process improvement methodologies. Without a clear and unified structure, the PRU landscape is rife with challenges of its own which leave the refining sector unable to capitalize fully on the advantages of higher fidelity measurement and optimization strategies. Filling this gap is a prerequisite to improving the technical and economic performance of PRU, but also to responding to broader trends of sustainability and competitiveness in an ever more demanding global market.

In this line, this research aims at filling this gap through a systematic implementation of a DMAIC-oriented framework which provides the means of integration between (MSA) and sophisticated optimization methods to minimize variation of measurements systems and improve PRU performance. The approach taken aims to address the core causes of measurement inconsistencies with the objective of providing a reliable basis for process control, and in turn enables the refining industry to obtain a higher purity propylene at lower cost while delivering a greener outcome.

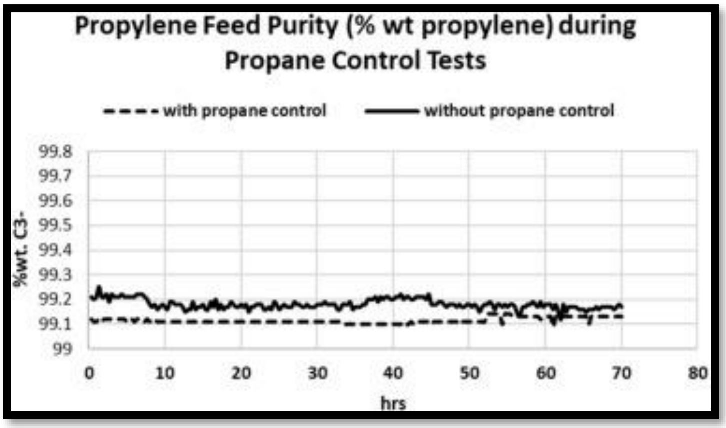

Figure 1: Propylene purity by percentage of weight
Source: Journal of Process Control Volume 99, March 2021, Pages 1-18
Website: *https://www.sciencedirect.com/science/article/abs/pii/S0959152421000020*

1.3 Research Question

The main aim of this research is to focuses on producing high purity propylene, ensuring propylene quality adhering to industry standards by detecting and reducing sources of variability increasing the precision of measurements, eliminating fluctuations, optimizing the process. Specifically, the objectives are as follows:

i) What are the primary sources of variability in PRU measurement systems? This question focuses on identifying and understanding the root causes of inconsistencies in PRU measurement systems, which directly align with the objective to address variability and the scope of investigating measurement-related challenges.

ii) How can a DMAIC-based framework be effectively implemented to reduce measurement variability in PRU?

This explores the practical application of the DMAIC methodology within PRU, aligning with the objectives and scope of developing and integrating a structured framework for measurement system reliability.

iii) How does improved measurement reliability influence PRU operational decisions and high-purity propylene outcomes?

This question investigates the broader impact of enhanced measurement accuracy on operational optimization, linking it to the objective of achieving propylene purity of ≥99.5% and the scope of assessing the relationship between reliable data and process performance.

1.4 Research Objective

Producing high-purity propylene consistently on Propylene Recovery Units (PRUs) is an important objective of the petrochemical industry. Nevertheless, this aim is constantly challenged through variations and inaccuracies in measurement systems, which jeopardise process control and, therefore, efficiency. In order to overcome these issues, this project seeks to provide a solid framework of combining MSA working practices within the DMAIC as the core of the research work. The specific research objectives are:

i) To systematically identify and define critical issues within the measurement system of the Propylene Recovery Unit (PRU) that impact data accuracy and reliability, guided by the Define phase of the DMAIC methodology.

ii) To perform a comprehensive Measurement System Analysis (MSA), including Gage Repeatability and Reproducibility (Gage R&R), in order to assess variability and uncover root causes affecting measurement consistency in the PRU.

iii) To implement targeted improvements based on MSA findings and validate the enhanced system's capability to deliver consistent, reliable, and accurate measurements that support the optimization of high-purity propylene production (≥99.5%).

1.5 Scope of Research

The scope of this research are as follows:

- Integration of DMAIC methodology in PRU measurement systems: Focus on embedding the DMAIC methodology into the measurement systems of Propylene Recovery Units (PRU) to systematically address variability and enhance the precision and reproducibility of measurement processes.
- Investigation of measurement variability and Its Impact on Propylene Purity: Examine the root causes of measurement variability and its influence on operational parameters critical to achieving high-purity propylene production, such as temperature, pressure, and composition control.
- Application of Advanced Statistical Tools for Measurement Improvement: Utilize tools like Gage R&R-ANOVA studies and regression analysis to quantify and correct measurement errors, ensuring accurate data for operational decision-making and process optimization.

1.6 Thesis Outline

Based on the objectives previously presented and on the approach proposed before, this thesis is made up of five (5) chapters, which contents are summarized as follows:

- Chapter 1. Introduction. This chapter presents the background of the study as there is a need for proper measurements in the Propylene Recovery Unit (PRU) to provide a high-purity propylene ≥99.5%wt. It describes the research problems, objectives, scopes, contributions and significance of the research.
- Chapter 2. Literature review. This chapter information research is arranged connected fields of study needed for this research. This chapter presents the review of literature and concepts measurement system analysis, Six Sigma