Improving efficiency of the process of oil analysis program at S·O·S^{SM} Laboratory in Indonesia

S·O·S℠

Trakindo CAT

Chula
Chulalongkorn University

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An Interactive Science and Social Project (ISSP)
Submitted to the Department of Chemistry, Faculty of Science
Chulalongkorn University, Thailand

In partial fulfillment of the requirements for
The Degree of Bachelor of Science in Applied Chemistry

In cooperation with
P.T. Trakindo Utama, Indonesia

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This report represents the work of four Chulalongkorn University Undergraduate Students submitted to the Faculty of Science as evidence of completion of degree requirement.

Abstract

Lubricant plays a very important role in machinery. It can be compared to the blood that nourishes the body of human. Therefore, regularly checking the lubricant oil is important for the machine to be able to continue working efficiently. The oil analysis program is therefore created to enable machine users to know the efficiency and condition of lubricant oil to prevent damage that may occur in the future. With new technology, oil analysis can be simpler and more efficient. P.T. Trakindo Utama desires to improve the efficiency of their oil analysis facility. We conducted a study, made observation, and interviewed laboratory personnel to access the current problems. Along with analyzing the obtained data, we proposed solutions and provided some recommendation for P.T. Trakindo Utama to incorporate into their current and future program such as updating testing equipment and improving testing methodology to achieve a new level of processing efficiency, shorter turn-around time, at reasonable break-even-point.

Acknowledgements

Foremost, our team would like to express our sincere gratitude to the individuals and organizations who were involved in this project for their support and guidance. This project could not have been completed without these people.

- Our sponsor, P.T. Trakindo Utama, for giving us the opportunity to learn and gain experience that cannot be found in the classroom.
- Mr. Bari Hamami, President Director/CEO of P.T. Trakindo Utama, for helpful suggestions and introducing us to actual working environment to prepare us for a future career.
- Mr. Hamidjojo Surjotedjo, Chief Innovation Officer, for giving feedback on our presentation in Indonesia.
- Our Advisor, Prof. Dr. Supawan Tantayanon, Prof. M.L. Siripastr Jayanta, and Prof. Dr.Numpon Insin of Chulalongkorn University and Prof. Dr. Esther Boucher-Yip, and Prof. Dr. Brigitte Servatius of Worcester Polytechnic Institute for their guidance, feedback, and kind assistance during the project.
- Dr. Satit Praipruke, Senior Technical Advisor of Chemall, for providing detailed information on machinery lubricants and helping us to set a good start in the project.
- P.T. Trakindo Utama staffs, Pak Muklisin, Ibu Wulan, Pak Tungguh, and Pak Ronny for their assistance, provided information, and for making laboratory visits and observations possible during our short stay in Indonesia.
- All S.O.S Laboratory technicians for permitting interviews and providing technical information.
- Prof. Dr. Viwat Vachirawongkwin and Prof. Dr. Nattapong Paiboonvorachat for their informative insights on the barcode system.
- Prof. Dr. Narong Praphairaksit for his insights on potential problems on the ICP instrument during routine oil analysis.
- Miss Bussaba Wongla and Mr. Uthai Saimi of Food Research and Testing Laboratory for letting us visit the laboratory and giving us information about the sample collection process.

Authorship

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Executive Summary

The Problems, Goal, and Objectives

Machinery lubricant is an important component that makes the machine run smoothly and efficiently comparable to the blood that nourishes the human body. Hence, checking the condition of the lubricant is very important. The oil condition monitoring program is therefore created to enable users to know the efficiency and problems that may cause damage to machinery due to the deterioration of the oil. Having good instruments contributes to accurate and efficient analysis. According to our observations, we found that there are still many flaws in the sampling and oil analysis processes that result in delays and causing the system to be less efficient than it should be.

Due to inadequate operation and instrumentation, various problems that should not occur has been observed during the course of this project. The goal of this project is to improve the oil analysis program for better efficiency. This will produce more accurate results, ensure completion of the analysis in laboratory within 24 hours, and ensure completion of the process within 7 days. These are the goals set by the company.

The research team has specified 3 objectives of this project as a guideline to achieve the goal of the project.

The first objective is to understand the lubricant oil analysis process. The team conducted research using various sources such as journals, online media, and conversations with a lubricant expert in Thailand. These activities were done in order to understand and access potential problems in the lubricant oil analysis process before going to explore the actual research site.

The second objective is to identify potential problems that occur during the current lubricant oil analysis process. The research team observed the laboratory and interviewed laboratory personnel in the laboratory about the problems and solutions for previous incidents. The research team gathered information from interviews and data from the laboratory to analyze and brainstorm for possible solutions to improve the efficiency of the oil analysis program.

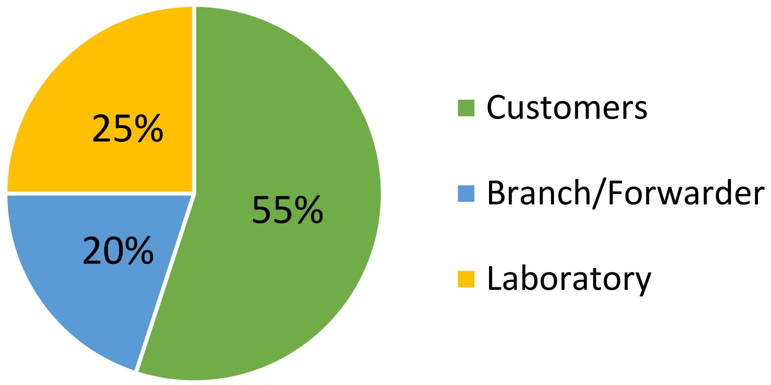
The third objective is to design and suggest methods and guidelines for efficiency improvement of the oil analysis program. The research team conducted deeper research to support recommendations that will increase the efficiency of the lubricant oil analysis program. The team has also incorporated new technologies that are environmentally friendly and reduce the cost of the process.

Research Findings

From observations and interviews, the research team has divided the sources of the problem into 3 main parts, which are:

1. Customers
2. Branch and forwarder
3. Scheduled Oil Sampling laboratory (S•O•S)

Results from the analysis in terms of the percentage of time exceeded the expectation from each of the 3 sources is shown in the diagram below.



The first section relates to problems caused by the customers. This is the section with the highest percentage of problems. We have divided the findings into 3 topics as follows:

1. Oil leakage from sampling bottles

From observations, the research team found that in some batches, the oil leaked out of the containers through the bottle caps during transportation. This resulted in oil stains on both the bottle and the label which showed the specifications of the oil sample. Sometimes the oil stain was severe enough to cause difficulties in identifying the data of the oil sample. According to the interview, the research team found that the problem was caused by some customers did not close the container cap tightly which led to leakage during transportation to the laboratory. This consumed extra time for laboratory technicians to clean the oil bottles. Also, in some cases where all of the oil had leaked out and the analysis could not be done, the laboratory had to return the sample container and notify the customer to resend the samples.

2. Customers do not follow the oil sampling instructions

According to the interview, the research team found that some customers did not comply with the oil sampling instructions by using low quality containers. In some cases, customers used a drinking water bottle to put the oil sample which could result in contaminating the sample and causing the analysis results to be incorrect. Also, another effect is it may cause damage to the machinery.

3. Customers do not send the sample immediately after sampling

According to the interview, the research team found that many customers do not send the oil samples immediately after sampling from the machine. They collect samples and keep them until they have a large quantity before sending for analysis to reduce the cost of sending multiple times. This behavior causes the oil analysis results to be inaccurate and unable to determine the quality of the used oil due to storing the oil samples for too long.

The second section is the problems from branches and forwarders. We have divided the findings into 2 topics as follows

1. Limited availability of flights or ships from distant islands

Their customers are from all over Indonesia, and as Indonesia is a country composed of many islands, transportation in some areas is therefore limited in both frequency and quantity. This problem causes delays in some areas.

2. Branches do not check the bottle before packaging

According to the interview, the research team found that there are no personnel in the branches to check the quality and condition of the packaging, which can contribute to the oil leakage problem.

For the last section, the problems from the Scheduled Oil Sampling laboratory, which divides the findings into two main topics as follows

1. Some instruments are not efficient enough

From the observation, the research team found that even though most instruments are automatic, the operation is still not optimal. Most problems come from manually operated instruments that stalling the overall process down. Also, not labeling the test tubes can cause confusion in determining samples and their position in the tray during analysis.

2. Lack of waste management

Some methods require a lot of reagents and solvents, which causes a higher amount of waste. Also, Indonesian regulations allow only companies with waste management permits to be responsible for the waste management. Therefore, the Company has to pay for the third party to take responsibility for waste disposal.

Our Recommendations

To improve the oil analysis program for maximum efficiency, the research team would like to propose a two-phase remedy programs which are short-term and long-term recommendations.

The short-term recommendations are suggestions for improvements and changes in areas that do not require investment. For example, setting rules or creating incentives for those involved to follow the Company’s policies and maximize the efficiency.

For the long-term recommendations, suggestions to change the methodology or instruments which required investment. The research team proposed to invent for instruments that are environmentally friendly and more efficient. For example, the team recommended the Company to use a barcode technology in the laboratory process.

With these recommendations, the Company would be able to reduce the cost and analysis time, resulting in increased efficiency in the long term.

Conclusion

Methodologies, procedures, instruments, and personnel are the factors responsible to affect and improve oil analysis to be more accurate and run smoothly. Thus, the research team has made comprehensive recommendations on all steps that could cause problems in the lubricant oil analysis. The research team hopes that these suggestions will improve the efficiency of analysis process of machinery lubricants and achieve the goals of the company.

บทสรุปผู้บริหาร

ปัญหา เป้าหมาย และวัตถุประสงค์

น้ำมันหล่อลื่นเครื่องจักรเป็นส่วนประกอบสำคัญที่ทำให้เครื่องจักรสามารถทำงานได้อย่างราบรื่นและมีประสิทธิภาพ เปรียบเสมือนเลือดที่หล่อเลี้ยงร่างกายมนุษย์ ดังนั้นการตรวจสอบสภาพของน้ำมันหล่อลื่นจึงมีความสำคัญเป็นอย่างมาก โปรแกรมการตรวจสอบสภาพน้ำมันหล่อลื่นจึงถูกสร้างขึ้นเพื่อให้ผู้ใช้งานสามารถทราบถึงประสิทธิภาพและปัญหาที่อาจก่อให้เกิดความเสียหายต่อเครื่องจักรจากสภาพน้ำมันที่เสื่อมคุณภาพ การมีเครื่องมือที่ดีมีส่วนทำให้การวิเคราะห์เที่ยงตรงและมีประสิทธิภาพ จากการสำรวจ พบว่ายังมีจุดบกพร่องหลายอย่างในกระบวนการเก็บตัวอย่างและตรวจสอบวิเคราะห์น้ำมันที่ส่งผลให้การวิเคราะห์เกิดความล่าช้าและไม่มีประสิทธิภาพเท่าที่ควร

ดังนั้น จากการทำงานและเครื่องมือที่ไม่มีประสิทธิภาพมากพอส่งผลให้เกิดปัญหาต่าง ๆ ที่ไม่ควรจะเกิดขึ้น จึงเกิดเป็นโครงงานนี้ขึ้นมา ซึ่งเป้าหมายของโครงงานนี้คือการพัฒนาระบบการวิเคราะห์น้ำมันเพื่อให้เกิดประสิทธิภาพสูงสุด ซึ่งจะทำให้ผลการวิเคราะห์มีความแม่นยำมากขึ้น สามารถวิเคราะห์ผลการทดลองได้แล้วเสร็จภายใน 24 ชั่วโมง เพื่อให้ทันตามกำหนด 7 วัน สำหรับทุกขั้นตอนตามที่บริษัทได้ตั้งไว้

คณะผู้วิจัยได้ทำการกำหนดวัตถุประสงค์ของโครงงานนี้ออกมา 3 วัตถุประสงค์ เพื่อใช้เป็นแนวทางในการบรรลุเป้าหมายของโครงงานนี้ โดยได้แก่

วัตถุประสงค์แรก คือ การทำความเข้าใจในกระบวนการวิเคราะห์น้ำมันหล่อลื่นเครื่องจักร โดยการศึกษาหาความรู้จากแหล่งข้อมูลต่าง ๆ ทั้งจากแบบหนังสือและสื่อออนไลน์ รวมไปถึงได้มีการพูดคุยและรับฟังข้อมูลจากผู้เชี่ยวชาญด้านน้ำมันหล่อลื่นในประเทศไทย ทั้งนี้เพื่อให้สามารถเข้าใจและเข้าถึงปัญหาที่มีโอกาสที่จะเกิดขึ้นได้ในกระบวนการตรวจวิเคราะห์น้ำมันหล่อลื่นก่อนไปสำรวจสถานที่จริง

วัตถุประสงค์ที่สอง คือ การระบุปัญหาที่เกิดขึ้นระหว่างกระบวนการวิเคราะห์น้ำมันหล่อลื่นเครื่องจักร คณะผู้วิจัยได้ทำการสำรวจห้องปฏิบัติการทดลองและสัมภาษณ์ผู้เชี่ยวชาญในห้องปฏิบัติการถึงปัญหาที่เกิดขึ้นและแนวทางแก้ไขสำหรับเหตุการณ์ที่เกิดขึ้นมาก่อนหน้า คณะผู้วิจัยได้ทำการรวบรวมข้อมูลและตารางสถิติต่าง ๆ เพื่อนำมาวิเคราะห์และประเมินถึงความเป็นไปได้ในการเสนอแนะวิธีการต่าง ๆ เพื่อเพิ่มประสิทธิภาพให้กับระบบวิเคราะห์น้ำมันหล่อลื่นเครื่องจักร

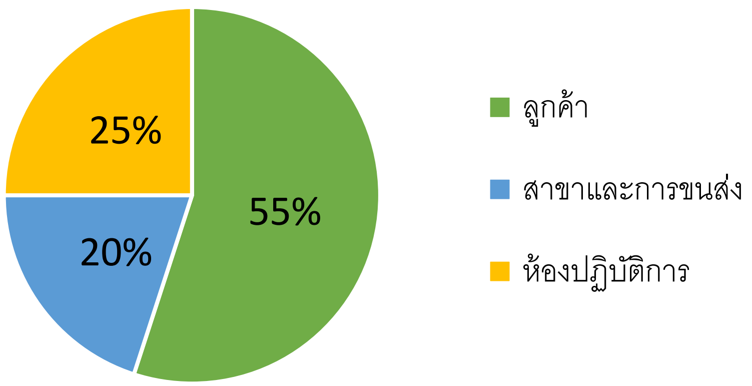
วัตถุประสงค์ที่สาม คือ การออกแบบและเสนอแนะวิธีการและแนวทางในการพัฒนาระบบวิเคราะห์น้ำมันหล่อลื่นเครื่องจักร โดยคณะผู้วิจัยได้ทำการค้นคว้าและศึกษาข้อมูลต่าง ๆ ให้มากขึ้น เพื่อสนับสนุนข้อเสนอแนะที่จะช่วยพัฒนาประสิทธิภาพให้กับระบบวิเคราะห์น้ำมันหล่อลื่นเครื่องจักร โดยมุ่งเน้นไปยังเทคโนโลยีใหม่ ๆ ที่เป็นมิตรต่อสิ่งแวดล้อม และ สามารถลดต้นทุนในการวิเคราะห์ลงได้

ผลจากการวิเคราะห์และศึกษาค้นคว้า

จากการสำรวจและทำการสัมภาษณ์ คณะผู้วิจัยได้แบ่งแหล่งที่มาของปัญหาออกเป็น 3 ส่วนหลัก ได้แก่

1. ผู้ใช้งานเครื่องจักร (ลูกค้า)
2. สาขาและการขนส่ง
3. ห้องปฏิบัติการวิเคราะห์น้ำมันหล่อลื่นเครื่องจักร

โดยข้อมูลจากการวิเคราะห์ได้ถูกแบ่งเป็นร้อยละของส่วนที่ใช้เวลาเกินกำหนดตามรูปภาพด้านล่าง



ในส่วนแรก ปัญหาที่เกิดจากผู้ใช้งานเครื่องจักรหรือลูกค้า เป็นส่วนที่มีร้อยละของปัญหามากที่สุด โดยได้แบ่งผลลัพธ์ออกเป็น 3 หัวข้อดังนี้

1. น้ำมันมีการรั่วไหลออกมาจากบรรจุภัณฑ์

จากการสำรวจ คณะผู้วิจัยพบว่า ขวดบรรจุน้ำมันบางส่วนมีการรั่วไหลของน้ำมันออกมาทางฝาขวด ซึ่งส่งผลให้ทั้งตัวขวดและแผ่นป้ายสำหรับระบุข้อมูลของน้ำมันตัวอย่างมีการเปื้อน จนบางครั้งไม่สามารถระบุได้ถึงข้อมูลของน้ำมันตัวอย่างนั้น ๆ จากการสัมภาษณ์พบว่าปัญหานี้เกิดจากฝั่งลูกค้าที่ปิดฝาไม่สนิททำให้มีการรั่วไหลระหว่างการขนส่งมายังห้องปฏิบัติการ ซึ่งเป็นการเพิ่มภาระหน้าที่ให้ผู้เชี่ยวชาญที่จะต้องมาทำความสะอาดตัวขวดบรรจุน้ำมัน และในบางกรณีที่น้ำมันรั่วไหลออกหมดจนไม่สามารถทำการตรวจวิเคราะห์ได้นั้น ทางห้องปฏิบัติการจำเป็นต้องทำการส่งคืนและแจ้งต่อไปยังลูกค้าให้ทราบทันที

2. ลูกค้าไม่ปฏิบัติตามวิธีที่ถูกต้องในการเก็บตัวอย่างน้ำมัน

จากการสัมภาษณ์ คณะผู้วิจัยพบว่าลูกค้าบางส่วนไม่ปฏิบัติตามคู่มือในการเก็บตัวอย่างน้ำมันสำหรับส่งตรวจ โดยการใช้บรรจุภัณฑ์ที่ไม่ได้คุณภาพ และในบางกรณีมีการใช้บรรจุภัณฑ์ เช่น ขวดน้ำดื่ม ซึ่งอาจส่งผลให้มีการปนเปื้อนเกิดขึ้นได้ในน้ำมันส่งตรวจ และทำให้ผลการวิเคราะห์ออกมาไม่ถูกต้อง ซึ่งมีผลกระทบที่อาจทำให้เครื่องจักรเสียหายได้ด้วยเช่นกัน

3. ลูกค้าไม่ส่งตัวอย่างน้ำมันมาทำการวิเคราะห์ทันทีหลังจากเก็บตัวอย่าง

จากการสัมภาษณ์ คณะผู้วิจัยพบว่า ลูกค้าหลายรายนั้นจะไม่ส่งตัวอย่างน้ำมันมาทันทีที่เก็บตัวอย่างจากเครื่องจักรแล้ว แต่จะทำการรวบรวมให้ได้ปริมาณมากก่อนแล้วส่งตรวจทีเดียว เพื่อลดค่าใช้จ่ายในการส่ง

หลายรอบ พฤติกรรมนี้ทำให้ผลการตรวจวิเคราะห์น้ำมันออกมาไม่แม่นยำและไม่สามารถที่จะระบุถึงสถานะของน้ำมันได้อย่างถูกต้องเนื่องจากการเก็บตัวอย่างน้ำมันไว้นานเกินไป

ในส่วนที่สอง เป็นปัญหาที่เกิดจากสาขาและการขนส่ง โดยได้แบ่งผลลัพธ์ออกเป็น 2 หัวข้อดังนี้

1. ข้อจำกัดในการขนส่งจากพื้นที่ที่ไกลจากห้องปฏิบัติการ (เกาะชวา)

เนื่องจากลูกค้าที่ส่งตรวจน้ำมันหล่อลื่นเครื่องจักรนั้นมีอยู่ทั่วประเทศอินโดนีเซีย และด้วยประเทศอินโดนีเซียเป็นประเทศที่มีหมู่เกาะมากมาย ดังนั้นการขนส่งในบางพื้นที่จึงมีข้อจำกัดทั้งด้านความถี่และปริมาณ จึงทำให้เกิดปัญหาความล่าช้าในบางพื้นที่

2. สาขาที่จัดส่งไม่ตรวจสอบความเรียบร้อยของบรรจุภัณฑ์

จากการสัมภาษณ์ คณะผู้วิจัยพบว่า ในส่วนของสาขานั้นไม่มีบุคลากรสำหรับการตรวจสอบคุณภาพและความแน่นหนาของบรรจุภัณฑ์ ซึ่งทำให้เกิดปัญหาน้ำมันรั่วไหลจากบรรจุภัณฑ์

ในส่วนสุดท้าย เป็นปัญหาที่เกิดจากห้องปฏิบัติการวิเคราะห์น้ำมันหล่อลื่นเครื่องจักร โดยได้แบ่งผลลัพธ์ออกเป็น 2 หัวข้อหลักดังนี้

1. อุปกรณ์ที่ใช้วิเคราะห์ทำงานได้ไม่มีประสิทธิภาพมากพอ

จากการสำรวจ คณะผู้วิจัยพบว่า ถึงแม้อุปกรณ์ส่วนใหญ่นั้นจะใช้แบบอัตโนมัติ แต่การปฏิบัติงานนั้นยังไม่เป็นที่น่าพอใจมากพอ ปัญหาส่วนใหญ่เกิดจากอุปกรณ์บางเครื่องที่ยังต้องทำงานด้วยมือ ซึ่งถ่วงการปฏิบัติงานโดยรวมลง อีกปัญหาหนึ่งคือ การที่ไม่มีสัญลักษณ์บอกในหลอดทดลองซึ่งทำให้เกิดความการสับสนในการวางตำแหน่งของหลอดทดลอง

2. ขาดประสิทธิภาพในการจัดการของเสีย

การวิเคราะห์บางอย่างต้องใช้สารประกอบและตัวทำละลายเป็นจำนวนมาก ซึ่งก่อให้เกิดของเสียขึ้นเป็นจำนวนมากเช่นกัน และด้วยข้อบังคับของทางการอินโดนีเซียที่อนุญาติให้เฉพาะบริษัทที่มีใบอนุญาติในการจัดการของเสียรับหน้าที่ในการจัดการของเสียเท่านั้น ทำให้บริษัทจำเป็นต้องจ่ายเงินเพื่อจ้างให้บริษัทภายนอกรับหน้าที่ในการกำจัดของเสีย

ข้อเสนอแนะ

เป้าหมายหลักที่สำคัญของโครงการนี้คือการพัฒนาระบบการวิเคราะห์น้ำมันเพื่อให้เกิดประสิทธิภาพสูงสุด หลังจากที่คณะผู้วิจัยได้ทำการสำรวจ สัมภาษณ์ และ วิเคราะห์ข้อมูลต่าง ๆ แล้ว จึงได้ทำการสรุปข้อเสนอแนะออกเป็นสองหัวข้อใหญ่ ได้แก่ ข้อเสนอแนะระยะสั้น และ ข้อเสนอแนะระยะยาว

ในส่วนของข้อเสนอแนะระยะสั้น เป็นการเสนอแนะให้มีการปรับปรุงและเปลี่ยนแปลงในส่วนที่ไม่จำเป็นต้องใช้เงินลงทุน เช่น การตั้งกฎเกณฑ์ หรือ การสร้างแรงจูงใจต่าง ๆ ให้บุคคลผู้มีส่วนร่วมในปัญหานี้ทำตามข้อกำหนดที่บริษัทตั้งไว้ และเพื่อให้เกิดประสิทธิภาพสูงสุด

ในส่วนของข้อเสนอระยะยาว เป็นการเสนอแนะให้มีการเปลี่ยนแปลงวิธีการหรือเครื่องมือซึ่งจำเป็นต้องใช้เงินลงทุน คณะผู้วิจัยได้ทำการค้นคว้าและนำมาเสนอแก่บริษัท ซึ่งเป็นเครื่องมือที่เป็นมิตรต่อสิ่งแวดล้อมและมีประสิทธิภาพมากขึ้น คณะผู้วิจัยยังแนะนำบริษัทในการนำเทคโนโลยีบาร์โค้ดเข้ามามี

ส่วนร่วมในขั้นตอนต่าง ๆ ของกระบวนการ ด้วยข้อเสนอแนะเหล่านี้ บริษัทจะสามารถลดต้นทุนและเวลาในการวิเคราะห์ รวมถึงเพิ่มประสิทธิภาพได้ในระยะยาว

บทสรุป

วิธีการ ขั้นตอน เครื่องมือ และ บุคลากรที่มีประสิทธิภาพ ล้วนแล้วแต่มีส่วนเกี่ยวข้องที่ทำให้การวิเคราะห์น้ำมันเป็นไปได้อย่างแม่นยำและราบรื่น ดังนั้นทางคณะผู้วิจัยจึงได้จัดทำข้อเสนอแนะที่ครอบคลุมในทุกขั้นตอนที่อาจก่อให้เกิดปัญหาต่อการวิเคราะห์น้ำมันหล่อลื่นเครื่องจักรได้ ทางคณะผู้วิจัยหวังเป็นอย่างยิ่งว่า ข้อเสนอแนะเหล่านี้จะทำให้ขั้นตอนในการวิเคราะห์น้ำมันหล่อลื่นเครื่องจักรดำเนินไปได้อย่างมีประสิทธิภาพและบรรลุเป้าหมายที่ทางบริษัทได้ตั้งไว้

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Chapter 1: Introduction

Anyone involving in industrial applications should be able to understand that lubricating oil is as crucial to machinery as blood is to a human being. The conditions of a human body functions can be analyzed from blood tests. The same goes for lubricant oil analysis that reflect the condition of machinery. One of the purposes of a lubricant analysis is to check whether the lubricating oil has deteriorated to the point that it can no longer carry out its functions. Oil analysis is a very important preventive routine to monitor the machines' health before costly damage occurs.[1] Lubricant analysis on oil degradation rates is useful for the prediction of types of damage that are likely to happen so that suitable preventive programs can be provided to prevent such damage.

Even though the technology on oil analysis is continually progressing, there is still a long list of problems that have been overlooked and problems that have occurred during the oil analysis. Aiming at these problems, the world-class heavy equipment solution provider of Caterpillar machines and engines, P.T. Trakindo Utama commissioned us, junior students from Chulalongkorn University, to study for improving the efficiency in the process of the oil analysis program at Scheduled Oil Sampling laboratory (S•O•S laboratory) in Indonesia. The purpose of our project was to investigate the reasons behind the problems which are causing the delays in their lubricant analyzing process, and to recommend suggestions for improvement.

S•O•S laboratory was established and developed to help customers realize the highest possible value from their equipment by minimizing repair costs and maximizing machine availability and life. With more than 25 years of laboratory experience in developing effective oil analysis programs, the accumulated information from S•O•S laboratory can be used to support the design process.[2] It is the responsibility of the laboratory's head office to ensure the program meets the company's goals and objectives. It should be noted that the materials and test methods used by the laboratory in different situations are various. Furthermore, it was necessary for the company and laboratories to analyze the common failures and delaying problems that had happened in the past.

Our first objective is to understand the overall steps in the lubricant analysis process. We realized that analyzing the oils helps to identify problems early before a component failure occurs, thus reducing repair costs and downtime.

To explore what problems are causing the delay during the analyzing process, on-the-spot investigation and interviewing were adopted as our second objective, and satisfactory results were obtained. We spent 18 days visiting the laboratory in Jakarta. Our advisors insisted that the most crucial aspect of our inquiries in the project was hands-on involvement, not just reading the previous reports in their office. The more on-the-field information we collected from S•O•S Laboratory, the more increasingly clear the direction of our project became. Furthermore, our interview questions were issued to 7 laboratory technicians and 2 head officers from S•O•S laboratory. One of the most experienced technicians and one head officer who understood the common problems which were causing the delays well expressed their in-depth views. Their answers and experiences helped us to diagnose the problem by guiding us through problem areas to the source of problem.

The final objective is to plan recommendations for improving the overall oil analysis program after gathering information acquired from the first two objectives. We evaluated the feasibility of our recommendations by discussing them with Professors at Chulalongkorn University. Furthermore, we contacted the technological suppliers and analyzed the experimental data, thus proving the feasibility and reliability of this project. Taking all this information into consideration, we refined our recommendations that we hope will be of use to our project sponsor.

Chapter 2: Literature Review

This project is sponsored by P.T. Trakindo Utama, Jakarta, Indonesia, who asked us to assist in the improving of the overall performance of their Scheduled Oil Sampling (S•O•S) laboratory. In order to provide recommendations with supportive evidences for areas of improvement, we set our first goal to learn about machinery lubricants and their analysis from various sources to gather relevant knowledge.

2.1 P.T. Trakindo Utama

2.1.1 Background[3]

Figure 1 P.T. Trakindo Utama Facility in Jakarta[4]

P.T. Trakindo Utama, established by AHK Hamami at December 23rd,1970. P.T. Trakindo Utama located at JI. Raya Cilandak KKO No.1, RT.13/RW.5, Ragunan, Ps. Minggu, Kota Jakarta Selatan, Daerah Khusus Ibukota Jakarta 12550. P.T. Trakindo Utama is an authorized dealer of Caterpillar in Indonesia. The Company operates as a construction equipment dealer such as construction, mining, agricultural, marine, forestry, energy, etc.

P.T. Trakindo Utama has supported many of the major construction projects in Indonesia such as Jagorawi Toll road (the first toll road in Indonesia), Soekarno-Hatta International Airport, Saguling Dam, etc. P.T. Trakindo Utama is the first dealer to operate the online system support by caterpillar dealer information system (CDIS). Nowadays P.T. Trakindo Utama has more than 50 branches throughout Indonesia from Sumatra To Papua and provides a world-class service to its customers.

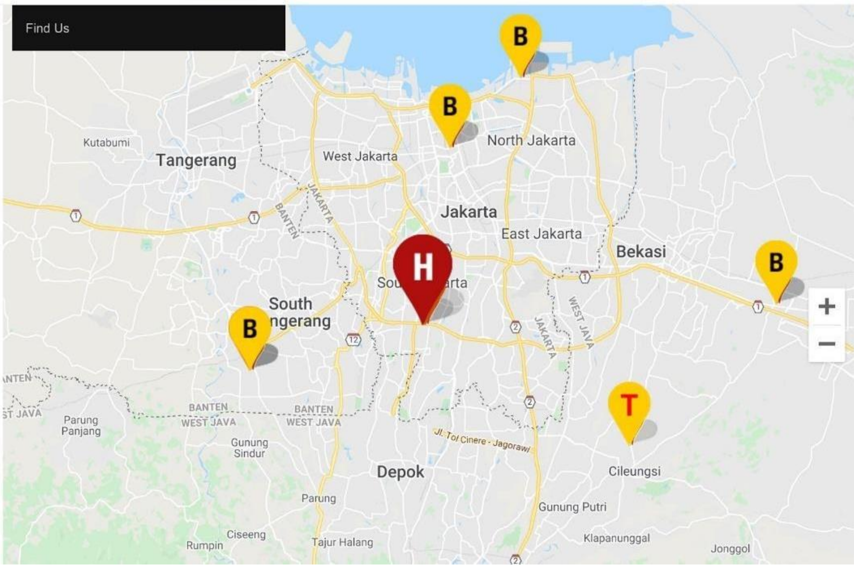

Figure 2 Facility locations of P.T. Trakindo Utama in Jakarta, H is headquarter, B is branch, and T is training center[5]

2.1.2 Scheduled Oil Sampling Laboratory[2]

Scheduled Oil Sampling laboratory (S•O•S laboratory) is a laboratory for testing lubricants as part of the Caterpillar services program. The purpose is to monitor the lubricating oil condition in machinery and equipment of customers to minimize the cost of machinery repairs due to machinery breakdown. The laboratory can detect many parameters required for oils such as wear analysis, contamination, water content, viscosity, etc.

P.T. Trakindo Utama has 4 laboratories in Indonesia to handle the vast area and customers from many islands. They are located in Jakarta, Balikpapan, Batu Hijau, and Papua.

Figure 3 A map showing the locations of S•O•S laboratories in Indonesia[6]

2.2 Environmental Permit

Some activities could harm the environment or human health and require controls to minimize the impact. Therefore, the permit, approval, license, or other authorization required is necessary under the environmental law.

With an environmental permit, any activity that may cause pollution is allowed to be carried out under certain conditions.[7] Since the permit gives a clear direction about how to protect the environment from this activity, the risk of health problems and polluting the environment will be under control.

There is a wide range of activities needed for the environmental permit in S•O•S laboratory, which covers water, air pollution, radioactive contamination, and other environmental hazards.[7] For S•O•S laboratory, tons of used solvents can be used as reclaimed valuable raw materials, and thus some hazardous materials have to be treated specially. In addition, some polluted air may affect the health of the employees which is of major concern to P.T. Trakindo Utama. Thus, they check their laboratory's environmental situation every half year.

2.2.1 Environmental Issue

Nowadays, every country in the world is facing environmental problems at different levels of severity. Due to rapid industrialization, economic development, and high population density, Indonesia is exposed to the grim hardships of nature. The problems include deforestation, over-exploitation of marine resources, air pollution, traffic congestion, and many other problems.[8]

Although the environmental degradation is an inevitable side effect of the economic development, Indonesia does not seek to develop at the expense of environment. In fact, it seeks to find a way of sustainable development in the peaceful coexistence of humans and nature. Indonesia has attempted to reduce the emissions and impacts from fossil fuels even though it reduced the economic growth rate.[8] However, in the process of achievement of the economy, Indonesia needs to find a new balance between urban society, economic development, and the environment.

2.2.2 Environmental Permit Regulation in Indonesia[7]

Although the Indonesian government has set the high goals in order to manage the environment for their country, it has been ineffective in putting their policies into practice. However, the government has recently increased the efforts on Environmental Impact Assessment (EIA) laws and regulations. At first, the proposed project can receive an environmental permit during the EIA process. Then, the next step is to implement the permit. At the same time, there is environmental monitoring due to law enforcement.

Environmental permit holders have the responsibility to comply with the requirements and obligations contained in the environmental permit and environmental protection and management permit. After that, the holders must prepare and submit a report on the implementation of the requirements and obligations in the permit to the Minister of Environment, the Governor, or regent/mayor. Also, they are responsible to provide a guarantee fund for the restoration of environmental functions following the regulations.

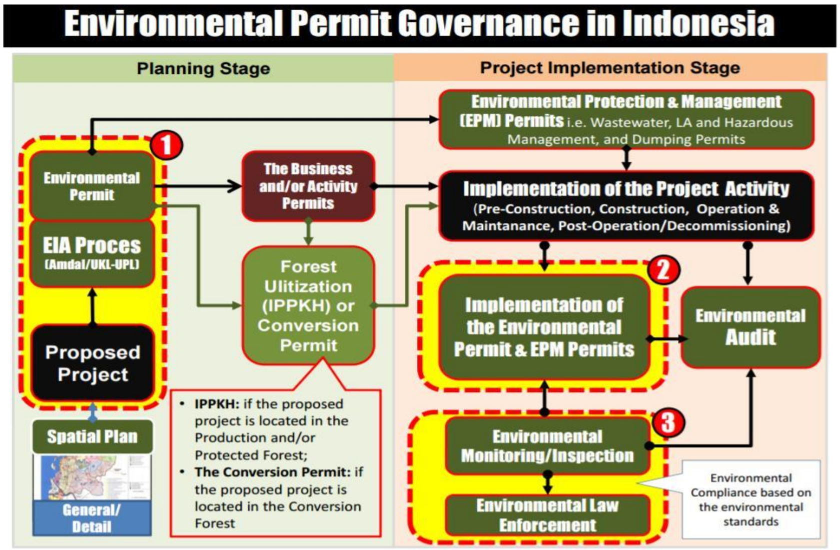

Figure 4 environmental permit process in Indonesia[7]

2.2.3 Pollution prevention and waste minimization

Pollution prevention (P2) and waste minimization can reduce or eliminate the amount and toxicity of pollutants at the source.[9] According to the pollution prevention act, P2 will achieve the goal through cost-effective changes in production, operation, and use of raw material. It contributes to increased efficiency in the use of energy, water, and protects these resources through conservation. P2 approaches can apply in almost every field such as agriculture, the industry and even homes and schools.

Here are some examples of P2 practices:[9]

- Modifying the production process to produce less waste
- Using non-toxic or less toxic chemicals such as cleaning agents, degreasers, and other maintenance chemicals
- Implementing water and energy conservation practices
- Reusing materials rather than disposing of them as waste

Waste minimization is similar to pollution prevention, but instead of eliminating the pollutant, it considers a wider range from the product design to the industrial process until the end of consumption.[9] In other words, compared with pollution prevention, waste minimization is about the reduction and elimination of waste prior to its generation.

For a global company such as P.T. Trakindo Utama, pollution prevention and waste minimization could cut down the waste management and cleanup fee and reduce the environmental damage. Furthermore, good health of the employees working in P.T. Trakindo Utama are guaranteed. Pollution prevention protects the environment by conserving and protecting natural resources, while waste minimization strengthens economic growth through more efficient production in industry and less pollutant release.

2.3 Lubricants

Lubricants play an important role in making machines functional and expanding their life cycle.[1] This section explains the main functions of lubricants and types of lubricants based on the production method.

2.3.1 Main functions[10]

Lubrication is the action of reducing friction in the system using a suitable liquid. Thus, to understand the functions of lubricants, it is firstly needed to understand the concept of friction. Friction is the force created by two surfaces contacting each other whereby this force resists the motion between that contact.[11] From the motion of that contact, the friction generates heat. If the machine comes into operation, the heat will be accumulated which will increase the temperature of the entire system of the machine. This process will eventually cause the machine to break down and fail to operate. Lubricants are added into the machines to reduce friction which reduces the heat generated in the process and extends the life cycle of the machines.

The next function of the lubricant is to reduce the wearing down effect. When two surfaces move across each other, small parts of them wear off. Those small parts then move across the joining surface speeding up the wearing down process. If lubricants are applied, the wearing down of those parts can be reduced.

Machines must be free from contaminants which means there should not be any outside particles not related to the system in the machine in order for it to fully function. However, it is impossible to avoid those particles completely and eventually those contaminants will wear the machine down. Thus, machines are lubricated to wash away those contaminants and remove them from the machine.

In addition, as machines are made of metals, rust and corrosion caused by air and moisture is unavoidable. Lubricants can be applied to protect the metal surface from corrosion.

2.4 Lubricant Analysis

To protect the machines and to extend the lifecycle of the lubricant, oil analysis or lubricant condition monitoring is an important process. It serves to ensure that the oil in the machine is in usable condition and the additives in the oil are not exhausted.[1][11] This section describes some important criteria used in the processes for oil analysis and their importance.

2.4.1 Viscosity

Viscosity is the resistance of fluids to flow.[12] High viscosity means the fluid has difficulties flowing from one place to another. It is one of the most fundamental characteristics of a good lubricant. Change in viscosity indicates change in quality and usefulness of a lubricant and may also imply that the lubricant is either deteriorated or impure. The standardized temperature for viscosity analysis of industrial oil is 40 degrees Celsius.[11] Viscosity can be affected by pollution, oxidation, and thermal cracking.

2.4.2 Acid/Base Number

Total Acid Number (TAN) and Total Base Number (TBN) are indicators of how far the lubricant has degraded.[13] The breaking down process of the lubricant produces acidic components in the oil in a stress environment. Those acidic components can be measured by calculating the TAN to identify how acidic the lubricant has become, or by calculating the TBN to quantitate the alkaline components that remain in the oil.

2.4.3 Water Content

The presence of water in the lubricant can be dangerous for the machines in many ways. One of the most common damages caused by water is rust and corrosion as machines are made from metals. Water can also degrade the oil and additives by hydrolysis reactions.[11] Thus, the water content is an important criterion in oil analysis to ensure that there are very few traces of water or no water at all in the lubricant.[14]

2.4.4 Oxidation

Oxidation is one of the major reactions occurring in lubricating oils which can lead to oil deterioration.[15] The byproducts of this reaction are usually acids and sludge,[12] which can corrode the metal surface and change the viscosity of the oil.[11] Therefore, it is important to monitor the oil oxidation stage closely.

2.4.5 Wear Elements

During the operation of machines, their parts can come into contact with each other, creating tiny metal debris which remains in the lubricant.[10] If there are too many, those pieces can scrape the machine and speed up the breakdown of the metallic surface which reduces the lifetime of the machine. To avoid this problem, the lubricant should be changed or analyzed regularly to monitor the amount of wear elements.

2.5 Instruments and Analytical Methodologies

This project involves many methods of analysis processes which also uses many instruments. To identify and understand problems and recommend suitable solutions to improve the laboratory efficiency, it is necessary for us to gain some background knowledge of the analytical instruments especially how they work and basic principles behind the method.

2.5.1 American Society for Testing and Materials

American Society for Testing and Materials (ASTM), commonly known as ASTM International is an organization that develops and publishes technical standards of testing methods commonly used in international laboratories for analysis. Nowadays, more than 12,000 ASTM standards are recognized around the world to ensure product quality.[16] ASTM standards are updated and contained in the annual book.

To arrange their large number of standards, they have designated a code to classify the types of standards.[17] Generally, the code starts with a preceding letter followed by a sequential number. Each alphabet classifies types of standards as follow:

- A – Ferrous metals and products
- B – Nonferrous metals and products
- C – Cementitious, ceramic, concrete, and masonry, materials
- D – Miscellaneous materials and products
- E – Miscellaneous subjects
- F – End-use materials and products
- G – Corrosion, deterioration, weathering, durability, and degradation of materials and products

The standards used in S•O•S laboratory are mostly in the D category, while a few are from E. We have included a list of standards used in the laboratory in appendix A

2.5.2 Potentiometric Titration (TAN & TBN Analysis)

The potentiometric titration is the method of measuring potential from the differences between a working electrode in reference to a reference electrode as function of a titrant volume. Potentiometric titration is based on the principal of potentiometry which is a technique of measuring an electrochemical cell consisting of a reference electrode, indicator electrode, analyte, and a salt bridge. A reference electrode is a half-cell having known constant potential and independent to the composition of the analyte. An indicator electrode is a half-cell whose potential varies depending on the concentration of the analyte. A salt bridge is a component that prevents the analyte from mixing with electrodes. Finally, an analyte refers to the component which is being tested, in this case the lubricant oil.[18] Those two electrodes are used to measure the difference in the electric potential of the reference electrode and the indicator electrode. The obtained data is then used to calculate the pH value which is also used to convert into TAN and TBN value.

Figure 5 Reference and standard electrodes used in potentiometric titration

The ASTM standard methods for potentiometric titration of TAN and TBN are ASTM D664 and ASTM D4739, respectively. ASTM D664 employs isopropyl alcohol (IPA), toluene, potassium hydroxide (KOH), and distilled water as reagents.[19] Meanwhile, ASTM D4739 employs IPA, toluene, chloroform, hydrochloric acid (HCl), and distilled water as reagents.[20]

2.5.3 Inductively Coupled Plasma Spectroscopy (Wear Element Analysis)

Inductively Coupled Plasma spectroscopy (ICP) is the method of detecting and measuring elements in the sample. This technique uses the principle of ionization of atoms. When atoms are heated to a certain temperature, they reach an unstable state called the excited state. Atoms then emit light to release energy and revert back to a ground state.[21][22] The detector, an optical emission spectrometer (OES), detects the wavelengths of emitted light from atoms which is specific to each element. The instrument that combines these two techniques is called Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES).

Figure 6 shows the key components and process of an ICP-OES.[22] The sample is introduced to the system by vacuum pump while the nebulizer sprays the sample into droplets in the spray chamber. Argon gas acts as a carrier gas that carries sample droplets to the ICP torch. Argon also flows through the torch and creates a channel to secure the heat in the torch which is created by a radio frequency generator. The sample droplets are heated inside the torch and the electrons collide with argon and become excited. Finally, the OES detects the emitted radiation from atoms of the sample, converts the result into an electrical signal, and the result is shown in the computer.

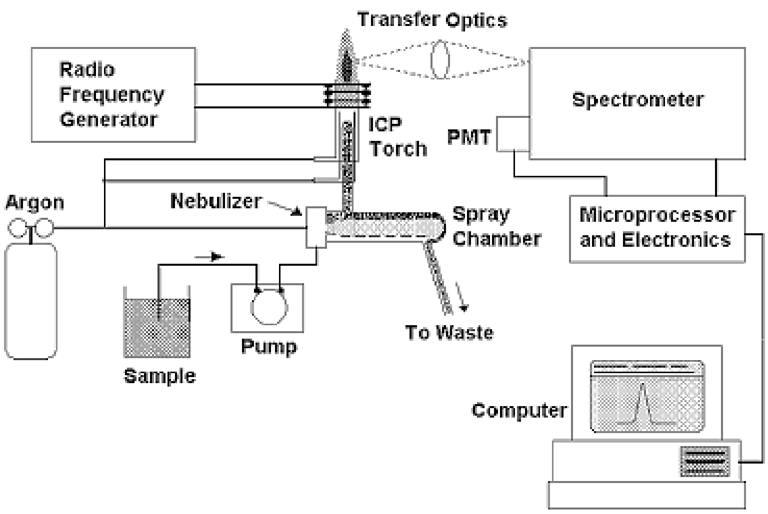

Figure 6 Diagram of process in ICP-OES[22]

ICP-OES technique and instruments are accepted by ASTM D5185 for analyzing the wearing down properties of metals and additives in lubricating oil. The standard lists 22 elements that can be determined in the lubricating oil.[23] The list of these elements is provided in Appendix B.

Figure 7 ICP-OES instrument[24]

2.5.4 Fourier Transform Infrared Spectroscopy (Functional Groups Analysis)

Fourier Transform Infrared Spectroscopy (FTIR) is a mathematical process combined with a high-resolution infrared spectroscopy. FTIR is widely used for detecting functional groups of organic compounds.[25] This technique sends electromagnetic spectrum in infrared region (IR) to molecules and observes the response. When molecules are exposed to IR, they vibrate, stretch, twist, etc.[26] Also, different types of bonds absorb and respond to IR in different wavelengths. Thus, results can be observed from the response and absorption of molecules and can be interpreted to functional groups of the molecules qualitatively.[27] Some common functional groups and their absorption range are provided in figure 8.

IR Absorptions of Common Functional Groups

Functional Group	*Absorption Location (cm⁻¹)*	*Absorption Intensity*
Alkane (C–H)	2,850–2,975	Medium to strong
Alcohol (O–H)	3,400–3,700	Strong, broad
Alkene (C=C) (C=C–H)	1,640–1,680 3,020–3,100	Weak to medium Medium
Alkyne (C≡C) (C≡C–H)	 2,100–2,250 3,300	 Medium Strong
Nitrile (C≡N)	2,200–2,250	Medium
Aromatics	1,650–2,000	Weak
Amines (N–H)	3,300–3,350	Medium
Carbonyls (C=O) Aldehyde (CHO) Ketone (RCOR) Ester (RCOOR) Acid (RCOOH)	 1,720–1,740 1,715 1,735–1,750 1,700–1,725	Strong

Figure 8 Infrared absorptions in common functional groups[27]

With its ability to detect functional groups of molecules, FTIR can detect multiple components in the oil such as water, fuel, glycol, soot, oil oxidation, and certain additives.[25] This technique is then used to monitor the overall oil condition. FTIR usage in analyzing the oil condition is accepted by ASTM E2412 which allows FTIR in the monitoring of change in the oil sample.[28] From Figure 9, the difference in amount of components in the oil is clearly observed in FTIR spectra.

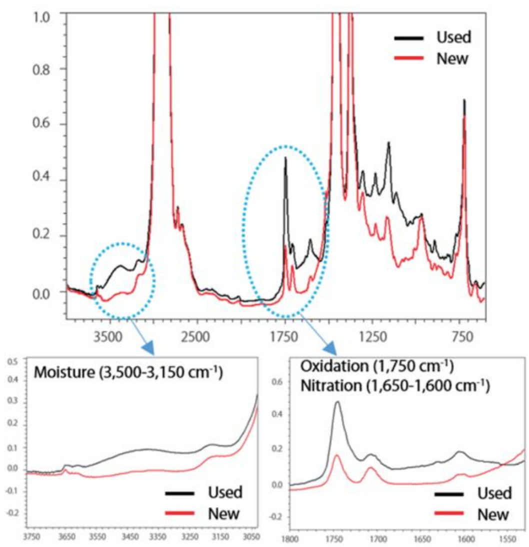

Figure 9 Example of FTIR result showing change in amount of component in oil[29]

In addition, some studies showed that FTIR can be used for measuring TAN and TBN with an accuracy equivalent to ASTM D664 and ASTM D4739 methods that use potentiometric titrations. FTIR then gains the advantage of not requiring reagents. However, measuring TAN and TBN with FTIR has not been yet approved by ASTM.[30]

Figure 10 FTIR[31]

2.5.5 Viscometer (Viscosity Analysis)

A viscometer is the instrument used to measure kinematic viscosity in lubricating oils. The instrument uses the definition of viscosity for analysis. As the viscosity means the resistance of fluids to flow, a viscometer measures the flow rate of the samples.[12][32] One common method for measuring the flow rate is the capillary viscometer test method. The sample is sent through a small capillary tube and the time taken to flow is measured; the slower the flow, the more viscous the sample.[32]

The viscometer test method is accepted by ASTM D445 for determining the viscosity of liquids. It certifies the method of sending the sample through the capillary using gravity and allows the applications of using this method for determining the viscosity in lubricants.[33]

Figure 11Capillary Tube Viscometer[32]

2.5.6 Karl Fischer Titration (Moisture Analysis)

The Karl Fischer titration is the method of measuring the water content in the sample.[34] Karl Fischer titration uses two titration techniques during analysis based on a suitable amount of water to be determined.

1. Volumetric Titration is used for samples with a higher water content (more than 1% water content).[35] The titrant is added directly to the sample.[36] The endpoint of this technique is determined potentiometrically,[35] similarly to potentiometric titration.
2. Coulometric Titration is used for samples with a lower water content (less than 1% water content).[35] This method uses a titration cell which contains reagent ions and generates the titrant to react with the samples. The amount of water is measured by the electric current used to convert iodide ions into iodine.[36] In this titration, 1 milligram of water takes 10.71 Coulombs to oxidize iodide ions.[34]

The reagents used in the titration are iodine and sulfur dioxide as titrants, pyridine or other basic solutions, and alcohols as solvents.[34] This method was accepted by ASTM D4377 for water content oil analysis, but it was withdrawn because of no update for more than eight years since its approval.[37] Another standard available is ASTM D6304 which accepts specifically for coulometric titration.[38]

Figure 12 Karl Fischer titration apparatus[39]

Chapter 3: Methodology

P.T. Trakindo Utama offers lubricant analyses as part of their heavy machinery services to their customers. The Company strives to provide the highest and most efficient quality of services. The goal of our project was to improve the efficiency of the oil analysis program at the S•O•S laboratory in Indonesia. To achieve the goal, we investigated the causes of the problems at the S•O•S laboratory and attempted to provide suitable solutions to improve the overall process and turnaround time of the lubricant analysis service. This in return allows our sponsor to gain more profit and make their business more secure. We have proposed a methodology and subdivided into 3 objectives as follow:

1. Understand the whole lubricant analysis process
2. Identify potential areas in the process in which problems can occur
3. Design recommendations to improve the oil analysis program

3.1 Objective No.1: Understand the whole lubricant analysis process

The first objective was to understand the overall steps in the lubricant analysis process, the types of lubricants involved, and the purposes of each step in the analysis and the methodology. We conducted an in-depth literature review and consulted various experts to deepen our understanding of the lubricants and their analyses.

3.1.1 Investigate the lubricant analysis process

Before beginning our tasks, we needed to first understand the role of lubricants in heavy machinery. To meet this objective, we conducted an in-depth literature review on the chemistry of lubricants, the functions of lubricants in machinery, the importance of routine lubricant analysis, purposes and types of analysis. We later focused our literature review on analysis methodology and the theory behind it and the instrumentation involved. Once we completed this step, we prepared discussion topics that needed clarification from a lubricant expert to understand machinery lubricant more deeply.

3.2 Objective No.2: Identify potential areas in which problems can occur during the process

This objective was divided into two parts. Part I focused on understanding the overall lubricant analysis process at our sponsor’s facility. In part II, we collected data with on-site observations, interviews, and discussion with laboratory employees and supervisors. The purpose was to understand P.T. Trakindo Utama’s laboratory environment and their routine. Data was analyzed to identify areas that could be improved.

3.2.1 Meet the sponsor

To gain access to the laboratory of P.T. Trakindo Utama and understand their overall lubricant analysis process, we presented our background research and proposed our research plan. The sponsor in return told us their requirements and we further discussed about the tasks and how to work together during our stay in Indonesia. Appointments for observations and interviewing were decided.

3.2.2 Visit the Scheduled Oil Sampling Laboratory

We requested to conduct an observation of the oil testing laboratory to learn what they were doing and what happened on a daily basis. We tried to identify the flaws in their process after understanding how they prepare, arrange in order, and analyze the sample.

3.2.3 Interview laboratory supervisors and technicians about problems during the process

After the observation, we analyzed the overview of the laboratory and mapped out where we should focus. We then analyzed the information received from the observation and made a list of issues that needed more clarification. We also interviewed laboratory supervisors and laboratory technicians to gain more insight.

The content of the questions for supervisors was about their vision, objectives, data interpretation, and issues with technician. Meanwhile, the questions we asked technicians were about what problems they see, their opinion of what to improve, time consumed in the process, and the waste produced from the instruments. Details of the interview questions are provided in Appendix C.

3.2.4 Analyze all information gathered and consider the results

From site observation combined with the interview of laboratory supervisors and laboratory technicians, we brainstormed on finding the strengths and weaknesses of their current analysis process. Finally, we used those findings to list areas of improvement on which we would recommend the sponsor to work.

3.3 Objective No. 3: Design recommendations to improve the oil analysis program

This objective has the purpose of gathering information acquired from the first two objectives to plan recommendations for improving the overall oil analysis program. We accessed different sources to carry out research to obtain additional information which we could use in designing recommendations in various aspects and solve problems.

3.3.1 Categorize problems

Different problems need different solutions. We divided the problem sources which are from customers, P.T. Trakindo Utama branches, transportation, and laboratory. From these categories, we knew that customers, employees at P.T. Trakindo Utama branches, forwarders, and methods in the laboratory were responsible for the problems. We identified key personnel to whom we needed to focus lead to positive changes. As different audiences have different knowledge and points of view, we looked for a variety of options to make communication effective. Appropriate communication was chosen for different group to carry on with the most suitable recommendations.

3.3.2 Research for potential new instruments for the laboratory

Following the findings from the interview (see Appendix C), some laboratory technicians wished to move toward automation to speed up the testing process while minimizing cost and labor. Also, some instruments required a lot of reagents and would generate a large amount of chemical waste. The technicians advised that they would like to migrate toward new test methods that are green (less chemicals), automated, and cost effective. In order to do so, we researched and compared different test methods to recommend an improved replacement.

For seeking in-depth information of the new instruments, we contacted sales managers and local suppliers in Indonesia via e-mail. We asked about the selling price, availability of products, accuracy, compliance with related standards, and any requirements of reagents so that we could consider whether they would be worthwhile for replacing the existing instruments used by P.T. Trakindo Utama.

3.3.3 Consult professors from Chulalongkorn University for additional information

We consulted with many professors at Chulalongkorn University who work on testing instrumentation. We asked questions on some specific aspects of the instrument which we did not understand. We obtained information on instruments and the working principles. We gained insight on new perspective to improve the analysis that would be useful to our sponsor.

3.3.4 Brainstorm for recommendations of solving human errors

Some problems P.T. Trakindo Utama is facing arise from carelessness of customers and employees at the branches. Thus, we discussed ways to understand both customers and employees and attempted to find methods to recommend to them. As each party has a different background, we would present our recommendations in a different manner and adjust the language used in communication to better suit each audience.

Chapter 4: Results and Analysis

In this chapter, we discussed the information we obtained from laboratory observations and interviews with laboratory personnel of P.T. Trakindo Utama. We segmented our findings into 4 main sections based on findings and problems found in each section of the overall oil sampling process including the goals P.T. Trakindo Utama wants S•O•S laboratory to achieve.

4.1 P.T. Trakindo Utama's current goals

From our interview with the laboratory supervisors, Pak Tanguh and Pak Mukhlisin, we learned about the goals of S•O•S laboratory for the year 2020. We understood the future direction of our sponsor from findings in this section.

Finding 1: P.T. Trakindo Utama's expected turnaround time from customers to laboratory, including sending the result, is within 7 days

To maximize the process efficiency of their S•O•S process, P.T. Trakindo Utama has set an expected time to complete each step of the process. From customers sampling the oil and transporting to P.T. Trakindo Utama branches is expected to be within 48 hours, 24 hours for collection by branches and packing of samples, 48 hours for transportation, 24 hours for laboratory analysis, and 12 hours to interpret and send the results back to customers. P.T. Trakindo Utama also sets the maximum turnaround time for all steps combined to be within 7 days.

Figure 13 Simplified flow chart of S•O•S process

Finding 2: P.T. Trakindo Utama focuses on ensuring the sample analysis time is within 24 hours

To be able to have the analysis results in time before problems occur with the machine and for the highest satisfaction of customers, the time factor of the analysis is therefore important. This section is one of the most important steps that P.T. Trakindo Utama wants to focus on. Based on the interview, the goal of P.T. Trakindo Utama is aimed at completing the analysis process from sample arrival to result interpretation within 24 hours.

Finding 3: P.T. Trakindo Utama wants to increase the number of customers using the oil analysis services from S•O•S laboratory

As the number of P.T. Trakindo Utama's customers is growing and it is important to regularly check the oil condition, they expect to receive more samples for S•O•S laboratory. According to the interview, P.T. Trakindo Utama has set the goal which is to increase the number of oil samples sent to S•O•S laboratory in 2020 by 5-10%.

4.2 Problems from customers segment

Since there were difficulties in collecting the information directly from the customers, we decided to interview the laboratory supervisors and obtain the data of the customers' lead time. Also, from laboratory observation, there were some problems from customers that could be observed in the laboratory.

Finding 4: Oil leakage from sampling bottles

Based on laboratory observation, the first process before analysis is to collect the oil sample, which customers usually do by themselves or their technicians. We found that many bottles arrived at the laboratory with oil stains all over the label and the bag. This indicated that the oil had leaked out of the bottle during transportation which makes extra work for the technicians because they have to clean the bottles before arranging them on trays. They also have difficulties with the stained labels on the bottles. From the interview, the laboratory supervisor explained that the reason is customers sometimes did not check the sampling bottle before sending them to P.T. Trakindo Utama branch.

Figure 14 Oil leakage from the package during transportation

Finding 5: Customers do not follow instruction on oil sampling

Based on interviews, some of the customers did not follow the instructions and performed the oil sampling carelessly. We found that some sample bottles were unsuitable containers such as drinking bottles or used-oil bottles, which may cause contamination of the oil sample and the reason for this was they did not want to spend any money on buying the certified bottles. This behavior can result in inaccurate and ineffective results which may adversely affect machinery maintenance.

Figure 15 Customers use their own choice of sampling bottles

Finding 6: Customers do not send the sample immediately after sampling

According to the interview and lead time data we received from laboratory supervisors, most customers take much longer than 48 hours to deliver samples to the branch. One of the reasons is most customers wait until there is a large quantity of oil samples to send to the branch in one batch instead of sending a smaller number of samples immediately. This behavior produces inaccurate results which do not reflect the actual condition of the oil.

4.3 Transportation difficulties and a problem from the branches

As the branches and transportation steps have only one finding from each part, we decided to merge two steps into one section. From our interview with the laboratory supervisors, we found the problem from the branches and the reason why the transportation time exceeds the expected time.

Finding 7: Limited availability of flights or ships from faraway islands

Since their customers are from all over Indonesia, the transportation routes varied depending on the location. Some isolated areas have lower transportation frequencies than some other main islands. Also, the capability of samples received is limited in some branches of S•O•S laboratories, causing them to decide to send samples to a laboratory that is located further away. Thus, the transportation lead time in those areas is much higher than other islands.

Figure 16 Faraway islands where they need to come to S•O•S laboratory in Java island

Finding 8: Branches do not check the bottles before packaging

Based on the interview, we found that customers sent oil samples to the branch without properly checking the cap of the sampling bottles resulting in leakage being noticed during transportation. The problem could have been solved easily by re-checking the bottle at the branch. However, the branch did not check the cap and caused the oil leakage problem persisted, resulting in more work for the technicians in cleaning up.

4.4 Problems found in the S•O•S laboratory

We made observations and interviewed the laboratory technicians to gather information in the actual laboratory. With the information received, we were able to determine problems that occur in the laboratory. As we were able to directly observe these problems and receive information directly from the staff, the findings in this section will be more abundant than other stages in the process albeit coinciding with P.T. Trakindo Utama's requirement that we focus on the laboratory.

Finding 9: Most instruments are automatic but the process is inefficient

During observation, we found that mostly automated instruments are employed. However, the process efficiencies can be much improved. Some instruments such as TAN & TBN titration apparatus and Karl Fischer titration apparatus are operated manually and take much longer time compared to automated analyses.

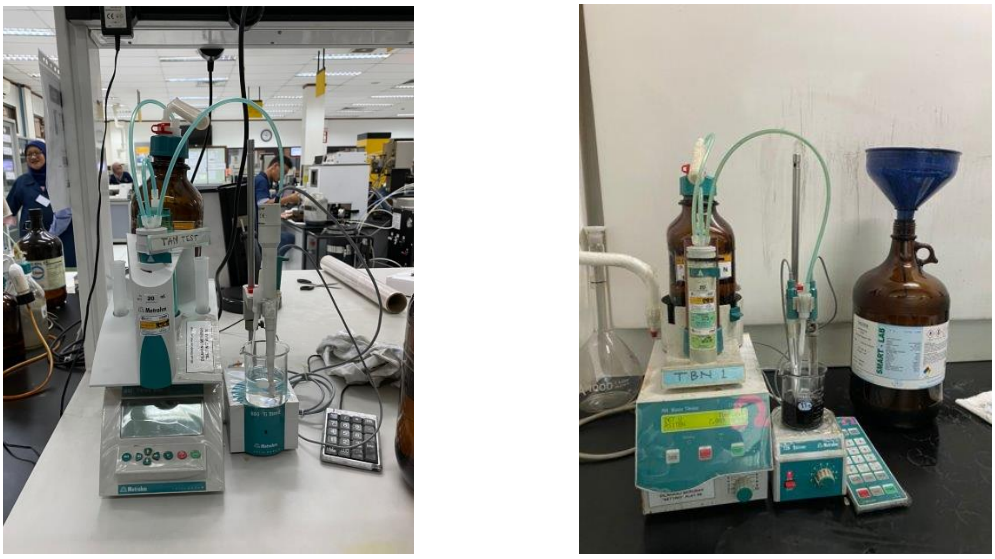

Figure 17 TAN&TBN titration apparatus are manually operated

Figure 18 Karl Fischer titration apparatus

Finding 10: Lack of waste management

Some analysis methods being used require a lot of reagents which produce a lot of chemical wastes as the result. Also, since the sampling bottle only be used once, the used sample bottles must be disposed of after analysis. Since they are unable to handle the waste by themselves due to the lack of a permit, they have to pay a lot of money to the third party to eliminate waste from the laboratory.

Figure 19 Wastes from used reagents and used bottles

Finding 11: Laboratory lead time exceeded target time resulting from workforce error, and an unpredictable amount of samples

Based on the interview, the laboratory supervisors told us that due to unavoidable reasons, some technicians sometimes asked for leave without advance notice which placed a burden on other staff. In addition, the number of samples received each day varied and on some days the number of samples greatly exceeded the average amount that arrived on other days, resulting in more time being needed to analyze them all. To achieve their goal, the technicians had to work overtime.

Finding 12: Non-labeled test tubes

During the laboratory observation, we found that all sample test tubes were not labeled when they are spread out during each part of the analysis. From our interview with the laboratory technicians, they told us that there was a lot of confusion about the order in the trays especially when they first arrived at work and they needed to check the tubes carefully. They also would like the tubes to be labeled to avoid confusion in the future.

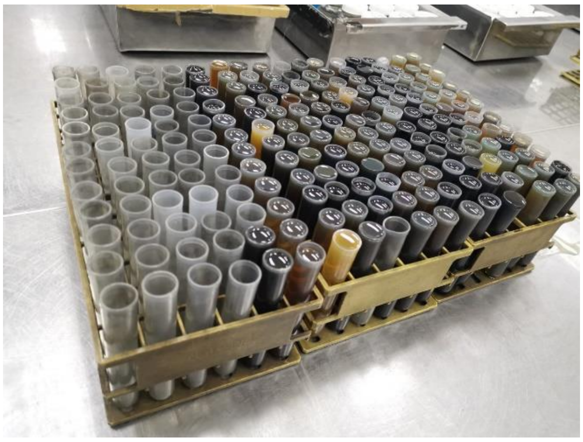

Figure 20 Many samples in the test tube are without labeling

Finding 13: Difficulties of introducing samples into ICP

Based on the interview with laboratory technicians, ICP instruments may have some problems with the vacuum pump and sample tubing. Bubbles were observed during sample introduction which caused poor accuracy of the results. We consulted an ICP expert who suspected poor sample preparation of oil samples which could cause the pump to malfunction. Sample tubing should be thoroughly rinsed between analysis to prevent cross-contamination and the tubing should be changed at regular intervals to make sure that it is in good condition. At the end of each day, the instruments should be washed with strong solvent to remove lubricant residues with may cause the clogging of the injection port. The instrument should be tested each day for level of sensitivity and a maintenance plan should be set up for trouble-free analysis.

Figure 21 Bubbles formed inside the tube, observed by the discontinuity of sample (black liquid)

4.5 Detailed steps of the program and conclusion

To conclude the source of the problems, we provided detailed steps of oil sampling by creating a table below to organize which party is responsible in which step.

	Responsibility			
	Head office	Customers	Branch	Laboratory
1st step: sampling samples				
Choose the appropriate sampling location		✓	✓	
Follow correct sampling procedures		✓	✓	
Use appropriate sampling tools and containers		✓		
Ensure the cleanliness of sampling bottles		✓	✓	
Provide appropriate sample information for data logging		✓		
2nd step: transport samples				
Transport samples to the branch		✓		
Ensure samples are sent to laboratory on time			✓	
Check sealing problems			✓	

3rd step: analysis of samples in the S•O•S laboratory				
Log sample information into computer database			✓	✓
Categorize oil sample types				✓
Ensure laboratory is using correct procedures	✓			✓
Ensure that testing procedures are accurate, documented and follow the standards				✓
Control analysis time to be within 24 hours	✓			✓
4th step: data diagnosis				
Evaluate wear debris data and fluid cleanness				✓
Review all sample data and make initial interpretative assessment				✓
Give customers feedback	✓			✓
5th step: performance tracking				
Ensure targets are being met	✓		✓	✓
Use oil analysis data in conjunction with asset management information to evaluate cost benefits of oil analysis	✓			✓
Continually review and improve the oil analysis program to optimize the oil analyzing system	✓			

Table 1 Detailed steps of the process and parties responsible in each step

Figure 22 summarizes the percentage of time which exceeded the expectation of P.T. Trakindo Utama in the process which was recorded in December 2019. 55% of the exceeded time was due to customers' behavior of not sending their samples immediately. The exceeded time of the branches was very little and therefore negligible, while forwarders had difficulties in transportation, taking 20% of the exceeded time. Laboratories had the problem of unexpectedly high number of samples and absence of technicians, taking 25% of the exceeded time. Meanwhile, the interpretation step never exceeded the expected time at all. Thus, this step was not indicated in the chart. Detailed information of the average time taken in each step from the regions to arrival at the laboratory in Java is shown in Appendix D.

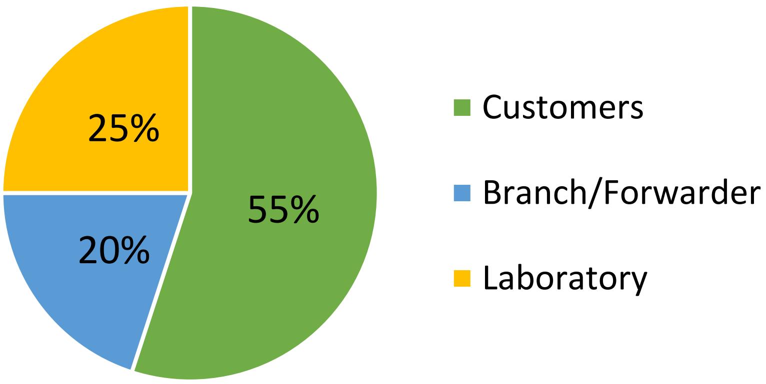

Figure 22 Pie chart illustrating percentage of exceeded time in each step

Chapter 5: Conclusions and Recommendations

In this chapter, we concluded the analyzed data from our background research, interviews, observation, and lead time data. We were able to identify that some customers violated the instructions, branch and transportation problems, and the inefficiency of the instruments in the laboratory. Our team brainstormed, researched, and selected the available suitable ways to recommend to our sponsor and improve the efficiency of the oil sampling process in S•O•S laboratory in Indonesia. We have made two main categories of recommendations which are short-term and long-term recommendations to present to P.T. Trakindo Utama regarding those that can be done immediately, and those which will take time due to the cost involved.

5.1 Short-Term Recommendations

The purpose of short-term recommendations was to solve problems that often occur in the daily work of the laboratory. These recommendations do not cost a large amount of money and can be done right after we recommend them. Most recommendations are enforcing or motivating responsible parties to follow the regulations to reduce problems on a daily basis. By following these recommendations, P.T. Trakindo Utama and S•O•S laboratory will be able to work more conveniently and efficiently.

Recommendation 1: We recommend S•O•S laboratory to warn customers to follow instructions provided by the laboratory

The behavior of customers who do not follow the instructions provided by the laboratory can cause inaccurate results. They tend to use their own choice of bottles instead of using certified sampling bottles. This causes their samples to be contaminated and producing inaccurate results. Also, they wait until they have many samples so they can send a large amount instead of immediately sending samples as soon as they finish sampling from their machines. These results will not be able to accurately describe the actual condition of the lubricating oil in the machine.

To address these problems, we recommend S•O•S laboratory to remind customers to be aware of the importance of following the instructions. S•O•S laboratory should give warnings to customers who violate the instructions and remind them to review the instructions carefully. If they repeatedly violate the instructions, the laboratory can decide to reject and send samples back and remind customers again. Meanwhile, to promote good behavior of the customers, the laboratory can make promotions or a discount plan to customers who follow the instructions accordingly. We also would like to recommend S•O•S laboratory to simplify the instructions so that they are easier for the customers to follow. We believe that this will make customers become aware of the importance of following the instructions and consider changing to the correct container and send samples immediately after sampling from the machine.

Recommendation 2: We recommend P.T. Trakindo Utama to enforce branch employees to double check the sample bottle cap and prevent the oil leakage problem

Good inspection is one of the factors for preventing and avoiding oil leakage which can cause contamination. Thus, branch employees also have responsibility to check sampling bottles carefully before sending the samples to the laboratory. However, the leakage problems were often observed at the laboratory which indicated that there was a lack of good inspection by branch employees.

In order to address this problem, we recommended that P.T. Trakindo Utama set up policies or procedures for checking the quality of the samples and ensuring that employees comply with the policies. P.T. Trakindo Utama can reward branch employees who understand the importance of reducing the leakage problem and try to reduce the problem by checking the sample bottle caps. They can be rewarded with a prize or a bonus. P.T. Trakindo Utama also has to enforce penalties on branches that repeatedly have oil leakage as it shows carelessness at those branches. We believe that this method would be able to reduce the number of oil leakage from bottles and reduce the time spent in cleaning up the oil stains in the laboratory.

Recommendation 3: We recommend S•O•S laboratory to label numbers and direction on test tube racks to prevent confusing the laboratory technicians

As the test tubes and test tube racks used in their laboratory do not contain any labels, laboratory technicians are sometimes confused with the order of samples during analysis. We recommend labeling test tube racks instead of the test tubes. We understand that labeling test tubes does not help laboratory technicians that much because after labeling the tubes, they have to arrange numbers on the test tube racks and they have to spend more time doing so. Labeling test racks indicating which side contains the first row of test tubes and which side contains sample number 1 of the row will be simpler for technicians.

Recommendation 4: We recommend S•O•S laboratory technicians to change the ICP tube regularly

ICP used in their laboratory often has bubbles inside the vacuum tube when they introduce the sample into the instrument which causes inaccurate results. The cause of the problem is the tube was already expired due to constant usage. We recommend S•O•S laboratory technicians to check the ICP tube more often and always prepare new ICP tubes so that they can change the tube immediately after observing the bubbles inside the tube. To extend the usage of ICP tubes, we recommend using strong solvent to wash the instrument and remove sample residues so that they will not block the tube.

Also, we would like to recommend S•O•S laboratory to consult the manufacturer of the ICP they are using so that they can receive further recommendations from the expert. We believe that increasing the frequency of checking the condition of the tube can improve the accuracy of the result from ICP-OES technique and consulting experts can provide insights for prolonging the usage life of instruments.

5.2 Long-Term Recommendations

The purpose of long-term recommendations was aimed to increase the efficiency of the laboratory process and reduce the costs in the long term. These recommendations are categorized as long-term recommendations because P.T. Trakindo Utama needs to invest in changing laboratory instruments which have a high cost. However, in the long term, they will spend less money since the new instruments can reduce the overall processing time and consume less chemicals in each sample. With less processing time, they can analyze more samples each day and be able to handle more work, resulting in more profit.

Recommendation 5: We recommend P.T. Trakindo Utama to replace the inefficient instruments in S•O•S laboratory to more efficient instruments which need less analysis time and produce less waste

Inefficient instruments take more analysis time and create more hazardous wastes which need to be eliminated. Those issues cannot support P.T. Trakindo Utama to achieve the goal of ensuring the analysis time to be within 24 hours. We recommend P.T. Trakindo Utama to consider investing in newer instruments which can reduce the analysis time and reduce the overall turnover time. Those instruments we recommend use different analysis methods which produce less waste compared to current instruments. Also, by reducing waste, P.T. Trakindo Utama can spend less money on waste disposal. The detailed comparisons of recommended instruments and current instruments are available in Appendix E. We believe that our recommended instruments will increase the efficiency of S•O•S laboratory analysis process and achieve the goals set by P.T. Trakindo Utama.

Recommendation 6: We recommend S•O•S laboratory to employ a barcode system in the process

When S•O•S laboratory received oil samples from all over the Indonesia, employees had to spend time in sample data registration. According to the observation and interview of an employee who is responsible for sample registration, laboratory technicians had to manually record each test result into their database system, Oil Commander. The more samples the laboratory received, the more time the employees needed to spend in registering samples information into the database. We recommended S•O•S laboratory use a barcode to register samples instead of registering manually. However, according to recent contact with P.T. Trakindo Utama after we came back to Thailand, they had started to update the database to contain barcodes for sample registration and is planning to implement the barcode system in the laboratory in near future. We support their idea because barcodes can increase accuracy of sample registration.

5.3 Limitations

During the stay in Indonesia, we were given opportunities to observe the laboratory in Banten, interview technicians and laboratory supervisors, and have a discussion with the Chief Executive Officer about the project. However, we were not given opportunities to observe their local branches where they receive samples from customers. We could not go to observe how customers sample the oil either because of language barrier together with difficulties of transportation outside of Jakarta in our limited time. Thus, we could not interview or discuss with people outside the laboratory. The only information we received was from P.T. Trakindo Utama's side and therefore they may cause some bias in our findings outside the laboratory.

After coming back to Thailand, during additional research, we searched about ASTM which is the main standard P.T. Trakindo Utama uses for laboratory instruments. However, to access the full data of ASTM, we had to pay a lot of money as each standard has its own license which is costly. If we paid to fully access all standards of all instruments, the cost would be too much for us to handle. Thus, we could use only the introduction of the ASTM as the reference even though we would have preferred to include more information.

We also had difficulties in researching for the cost of recommended instruments as some websites did not provide the price unless we complete the request form. Furthermore, the price we received did not include the shipping cost to Indonesia. After that, we had difficulties in contacting instrument suppliers in Indonesia. Some companies did not even answer our e-mails addressing inquiries of the instrument price. Thus, the prices of our recommended instruments were not the exact amount and when P.T. Trakindo Utama decides to buy the instruments, the actual price will be different from our recommendations.

5.4 Conclusion

This project aims to improve the process efficiency of the oil analysis program at Scheduled Oil Sampling (S•O•S) laboratory in P.T. Trakindo Utama (Indonesia). By implementing our proposed short-term and long-term recommendations for consideration, we believe that S•O•S laboratory will accelerate its development and build a new growth engine in total laboratory automation and an efficient oil analysis program. Also, to support the head office core business goals i.e. increase 5-10% amount of sample and provide analyzing results in 24 hours as well as explore a new field in saving cost.

Before we implemented our methodology on site, we made preparations to reinforce our background information of lubricant analysis and analytical methodologies related to the lubricant. When we arrived in Jakarta, we observed S•O•S laboratory and interviewed laboratory supervisors and technicians. They kindly assisted us in our project by guiding us through the facility in S•O•S laboratory of Jakarta on Java island. They also let us observe their laboratory and were happy to answer our interview questions.

Following our methodologies, we received information and were able to identify problems from customers, branches, forwarders, and within the laboratory. We took our obtained findings into consideration and made the final recommendations to solve their problems. Considering time and cost efficiency, we divided our recommendation into short-term and long-term with expected commercial value. The most impactful way to quantify improvement, especially for an advanced laboratory such as S.O.S laboratory, is to lower the overall laboratory expenses without lowering the laboratory analysis reliability over the short and long term.

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[1] Brown, K. (2005, September). *Making Good Environmental Choices for Lubricants*. Retrieved October 20, 2019, from https://www.machinerylubrication.com/Read/795/environmental-choices-lubricants

It is not necessary to study the environmental choices for lubricant as our main task is to improve the lubricant analysis process, not the lubricant choice. So, we did not use most of the information provided in this article. However, this article reminds the importance of oil condition monitoring, which is to remind users to regularly check the condition of the oil and extend the lubricant lifecycle. Thus, we cited this article for that particular information as that part is important to our project (analyze the oil).

[2] P.T. Trakindo Utama. (n.d.). *S•O•S℠ Services*. Retrieved December 20, 2019, from https://www.trakindo.co.id/en/services/sos-services

This website includes basic information about the Scheduled Oil Sampling (S•O•S) services. S•O•S is a fluid analysis laboratory that analyzes the lubricating oils used in the machinery component. This website also provides the location of laboratories of Indonesia and a video showing the correct way to sample the oil from the machine. It is related to our project since our project revolves around the S•O•S laboratory. We should understand their work briefly before going there and learn more details from laboratory personnel.

[3] P.T. Trakindo Utama. (n.d.). *History*. Retrieved October 13, 2019, from https://www.trakindo.co.id/en/about-us/history

This website explains chronologically about the history of P.T. Trakindo Utama, our sponsor. P.T. Trakindo Utama is a company that actively contributes to Indonesia's national development. It is related to our project because we could understand what has P.T. Trakindo Utama has done and we could perceive how our sponsor acted according to their vision.

[4] P.T. Trakindo Utama. (n.d.). *Company Profile*. Retrieved October 31, 2019, from http://en.trakindoutama.web.indotrading.com/contact

We used this site for the basic information of P.T. Trakindo Utama and an image of their headquarter in Jakarta.

[5] P.T. Trakindo Utama. (n.d.). *Location*. Retrieved November 1, 2019, from https://www.trakindo.co.id/en/about-us/location

This website contains a map of facility locations of P.T. Trakindo Utama in Jakarta. We used the map to locate the location of the headquarter.

[6] ASEAN Up. (2018, May 7). *6 free maps of Indonesia*. Retrieved February 28, 2020, from https://aseanup.com/free-maps-indonesia/

This website provides a map of Indonesia without paying for copyrights. We used a map from this site to show locations of S•O•S laboratories in Indonesia. We also edited by adding arrows to illustrate the transportation routes of oil samples in some islands to the laboratories, and why they came to the laboratory in Java instead of other laboratories.

[7] Sudijanto, I. A. (2018, November 1). *EIA and Environmental Permit: Tools for Sustainable Tropical Peatland Management* [Presentation Slides]. SlideShare. Retrieved January 26, 2020, from https://www.slideshare.net/CIFOR/eia-and-environmental-permit-tools-for-sustainable-tropical-peatland-management

The slideshow illustrates the Environmental Impact Assessment (EIA), environmental permit, and how Indonesian companies have to follow them to reduce environmental impact according to Indonesian Law. The slide also describes the detailed procedures about applying for the permit from the Indonesian government.

[8] Juliansyah, R., Zulham, T., & Gunawan, E. (2019). The Influence of Economic Growth, Population, and Industrial Sectors on Environmental Degradation in Indonesia. *Sriwijaya International Journal of Dynamic Economics and Business, 3*, 93-106. doi:10.29259/sijdeb.v3i1.93-106

The paper analyzes the relationship of environmental issues and economic growth in Indonesia from both theoretical and practical points of views. The authors consider a variety of environmental issues caused by Indonesian economic development. This paper helps us to identify the environmental issues in Indonesia. Besides, it indicates the limitation of that developing countries hardly address the environmental problem with steady economic growth.

[9] Fielden, R. (2015). *Pollution Prevention and Waste Minimization (P2/WMin) in Environmental Management* [Presentation Slides]. SlidePlayer. Retrieved January 24, 2020, from http://slideplayer.com/slide/3291352/

The information from the slides provides us the general concept of pollution prevention and waste minimization. Since these two are similar topic, sometimes it is hard to distinguish. However, the diagram in slides explains its difference. Besides, the content of slides not only about what are the pollution prevention and waste minimization, but also explains how these two are related to the real business chain.

[10] Noria Corporation. (2010, May). *Lubrication Basics*. Retrieved October 20, 2019, from https://www.machinerylubrication.com/Read/24100/lubrication-basics

This article describes what lubricant oil is. It provides the meaning of lubrication, roles of the lubricant in machinery, and how it helps maintaining the machinery lifecycle. This web article is very useful because it contains the most basic information we need to review in our project before learning how to analyze the lubricant oil.

[11] Praipruke, S. (n.d.). *Training Used Oil Analysis* [Presentation Slides]. Total ANAC.

This is a slideshow we received from Dr. Satit Praipruke, the lubricant expert we held a discussion. This slideshow defines some technical terms regarding the lubricant and analytical techniques such as friction, wear, lubrication, etc. This slideshow also describes some analysis criteria such as viscosity, water content, acid number, and wear elements. This slideshow can be used to review technical terms and cross-reference with some other sources.

[12] Praipruke, S. (n.d.). *General Knowledge on Lubes* [Presentation Slides].

This is also a slideshow from Dr. Satit Praipruke. It is about main functions of lubricant, characteristics, and criteria to be analyzed of lubricants. The information in this slideshow guided us to understand lubricant more and help understanding the other sources. This slideshow also contains the production of lubricants and types of synthetic lubricants which we first included in literature review. However, we later found them unnecessary as they were not in our focus, so we did not include that information.

[13] Spectro Scientific. (2017, October 24). *Guide to Measuring TAN and TBN in Oil*. Chelmsford. Retrieved from https://www.spectrosci.com/resource-center/lubrication-analysis/literature/e-guides/guide-to-measuring-tantbn/

This document describes the definition of total acid number and total base number (TAN&TBN). It lets us understand the basic terms used in lubricant. It also recommends some analytical methods and some instruments for analyzing oil samples and determining TAN&TBN.

[14] Fluid Life. (2017). *The Impact of Water Contamination on Lubricants.* Retrieved from https://www.fluidlife.com/the-impact-of-water-contamination-on-lubricants/

A booklet in this website explains what water contamination means and impacts of water contamination in lubricant. As it is one of the criteria to be analyzed, it is necessary to understand its importance and reason why it is analyzed. This file also provides the possible analytical methods to analyze water content in oil.

[15] Bureau Veritas. (2017, May 11). *What Effects does Oxidation Have on Lubricant Oil?* Retrieved February 13, 2020, from http://lubrication-management.com/en/2017/05/11/what-effects-does-oxidation-have-on-lubricant-oil/

This website contains an information of what oxidation is and effects of oxidation to lubricant oil. As oxidation is one of the criteria to analyze, it is related to our project and necessary to learn the importance of checking this criterion.

[16] ASTM International. (n.d.). *Detailed Overview*. Retrieved January 22, 2020, from https://www.astm.org/ABOUT/full_overview.html

This website contains the meaning, purpose, and detailed overview of the American Society for Testing and Materials (ASTM). The standard is important to certify the testing methodologies S•O•S laboratory is using. We could understand the brief history from this source.

[17] ASTM International. (2010). *Form and Style for ASTM Standards.* West Conshohocken. Retrieved from https://www.astm.org/bluebook

This is a book that guides how to understand more about ASTM standards. We cited this book mainly to understand how they categorized the standards and how to understand the code they are using. It is related to our project as P.T. Trakindo Utama and S•O•S laboratory always refer to ASTM in their testing methods. Thus, we should understand the standard and how to understand the ASTM category.

[18] METU. (n.d.). *Potentiometric Titrations*. Retrieved January 20, 2020, from http://users.metu.edu.tr/chem223/potentiometry.pdf

This is a laboratory manual from Middle East Technical University. This manual describes the general principle, reagent, apparatus, and procedure of the potentiometric titration method. In our project, potentiometric titration is a method for determining the total base/acid number in lubricant oil. This information helps us to understand more about the basic principles behind potentiometric titration method, one of the techniques S•O•S laboratory is using.

[19] ASTM International. (2018). *Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration*. Retrieved January 25, 2020, from https://www.astm.org/Standards/D664

ASTM D664 is a standard method of analyzing the total acid number in the lubricant. It is about the analysis method that this standard covers, which is to determine acid number of petroleum products like lubricants with potentiometric titration. It is related to our project because this method is one of the methods that the S•O•S laboratory is using.

[20] ASTM International. (2017). *Standard Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration*. Retrieved January 24, 2020, from https://www.astm.org/Standards/D4739

ASTM D4739 is a standard method of analyzing the total base number in the lubricant. It is about the analysis method that this standard covers, which is to determine base number with potentiometric titration. This standard also covers the application on lubricants. It is related to our project because this method is one of the methods that the S•O•S laboratory is using.

[21] ศรีนาวาวงศ์, ธ. (2008). *การพัฒนาวิธีวิเคราะห์ธาตุองค์ประกอบหลักในตัวอย่างดินโดยเทคนิค Inductively Coupled Plasma Optical Emission Spectroscopy*. Bangkok: Department of Mineral Resources Thailand. Retrieved from http://library.dmr.go.th/Document/DMR_Technical_Reports/2551/20254.pdf

This is a textbook from Department of Mineral Resources of Thailand. It describes how to analyze the elements in soil by inductively coupled plasma – optical emission spectroscopy (ICP-OES). We did not do the project about the soil, but we could relate on the principles of ICP-OES to detect elements which is what S•O•S laboratory does to the lubricant oil. We could understand its main components, principles, and the process of ICP-OES from this textbook.

[22] Boss, C. B., & Fredeen, K. J. (2004). *Concepts, Instrumentation, and Techniques in Inductively Coupled Plasma Optical Emission Spectrometry Third Edition*. Shelton: PerkinElmer.

This textbook is a detailed information of ICP-OES instrument. We looked through the textbook for deeper understanding of ICP-OES. As the textbook from Department of Mineral Resources of Thailand also refers information from this textbook, the content of these two textbooks are somewhat similar. This textbook also contains the diagram of components in ICP-OES.

[23] ASTM International. (2018). *Standard Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)*. Retrieved January 24, 2020, from https://www.astm.org/Standards/D5185

ASTM D5185 is a standard method of analyzing wear metals and other contaminants in the lubricant. It is about the analysis method that this standard covers, which is to detect element in the lubricant with ICP-OES. This standard also states that it can cover 22 elements to be determined. It is related to our project because this method one of the methods that the S•O•S laboratory is using.

[24] Scientist Instrument. (n.d.). *Agilent ICP-OES Spare parts*. Retrieved February 28, 2020, from https://www.scientist-instrument.com/agilent-icp-oes/

There is no information in this site. We just used an image from this site to show readers what typical ICP-OES instrument looks like. The ICP-OES used in the S•O•S laboratory has different design.

[25] Noria Corporation. (2002, March). *Fourier Transform Infrared Spectroscopy*. Retrieved January 25, 2020, from https://www.machinerylubrication.com/Read/305/fourier-transform-infrared-spectroscopy

This article explains the process of FTIR and its use in oil analysis. It tells about what components FTIR can detect from the oil, and some basic principles of spectroscopy. It helps us understanding their process and cross-reference with other sources we used to confirm the liability of information of this source and other sources about FTIR.

[26] Wade, L. G., Jr. (2013). Infrared Spectroscopy and Mass Spectroscopy. In Wade, L. G., Jr., *Organic Chemistry Eighth Edition* (pp. 514-520). Washington: Pearson.

We used Organic Chemistry textbook to review concepts of basic Infrared Spectroscopy and how it is developed to Fourier transform Infrared Spectroscopy (FTIR). We reviewed about how molecules move when expose to IR, the measurement, and basic principles of the instruments.

[27] Winter, A. (2019, September 27). *How to Find Functional Groups in the IR Spectrum*. Retrieved January 26, 2020, from www.dummies.com/education/science/chemistry/how-to-find-functional-groups-in-the-ir-spectrum/

This website explains about how to find functional groups in IR spectrum. It also provides the basic functional groups and their absorption ranges. We cited this site for that table because we found it is quite easy to use their tables to let readers know about the absorptions of most common functional groups.

[28] ASTM International. (2018). *Standard Practice for Condition Monitoring of In-Service Lubricants by Trend Analysis Using Fourier Transform Infrared (FT-IR) Spectrometry*. Retrieved January 25, 2020, from https://www.astm.org/Standards/E2412

ASTM E2412 is a standard method of using FTIR for condition monitoring of lubricant. It is about the analysis method that this standard covers, which is to monitor the change in oil components with FTIR. It is related to our project because this method is one of the methods that the S•O•S laboratory is using.

[29] Shimadzu Corporation. (2019, November). Degradation Analysis of Lubricants Based on ASTM E2412 by Fourier Transform Infrared Spectrophotometer FTIR. Retrieved February 13, 2020, from https://solutions.shimadzu.co.jp/an/n/en/ftir/jpa219022.pdf?_ga=2.162223615.2117812581.1583423700-1533457870.1583423700

This document summarizes ASTM E2412 with a bit easier language for their company (Shimadzu Corporation), but they shared to the public so we could use. We used a figure from this document for an example of FTIR analysis results. This figure shows the difference of components in the lubricant clearly as seen in the spectra.

[30] Winterfield, C., & van de Voort, F. R. (2014). Automated Acid and Base Number Determination of Mineral-Based Lubricants by Fourier Transform Infrared Spectroscopy: Commercial Laboratory Evaluation. *Journal of Laboratory Automation*, 577-586. doi:10.1177/2211068214551825

This scientific journal is about the comparison of the results obtained from using FTIR and potentiometric titrations for determination of TAN and TBN. The study shows that the results were not different in accuracy, but FTIR uses less reagents. However, this method is not accepted by ASTM.

[31] PerkinElmer. (n.d.). *Spectrum Two FT-IR Spectrometer*. Retrieved February 28, 2020, from https://www.perkinelmer.com/product/spectrum-two-ft-ir-sp10-software-l160000a

We cited this site just for an image of typical FTIR instrument in laboratories. We did not use any information from this site in our report except the image.

[32] Noria Corporation. (2002, November). *Oil Viscosity - How It's Measured and Reported*. Retrieved January 26, 2020, from https://www.machinerylubrication.com/Read/411/oil-viscosity

This article provides the general information about methods to determine the kinematic viscosity in laboratories which are using capillary tube viscometer and rotary viscometer. However, S•O•S laboratory focuses on using capillary tube viscometer, so we used only the information from that part. This article also explains about the basic principle of viscosity. We could understand viscosity and instruments to measure from this article.

[33] ASTM International. (2019). *Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)*. Retrieved January 26, 2020, from https://www.astm.org/Standards/D445

ASTM D445 is a standard method of analyzing the kinematic viscosity in lubricant oil. It is about the analysis method that this standard covers, which is to determine the kinematic viscosity by using gravity to send the sample through the capillary. It is related to our project because this method is one of the methods that the S•O•S laboratory is using.

[34] Mitsubishi Chemical. (n.d.). *What is the Karl Fischer Method?* Retrieved January 24, 2020, from Aquamicron: https://mcckf.com/english/kf-basic/what.html

This website provides information about the Karl Fischer method. It describes 2 titration techniques of Karl Fischer which are coulometric and volumetric titration. Then, it explains what those two techniques and principles behind them. Karl Fischer titration is one of the methods used in the S•O•S laboratory to detect the water content in lubricant oil.

[35] Bozic, D. (2018, May 31). *What Is Karl Fischer Titration and What Are Its Applications?* Retrieved February 20, 2020, from www.azom.com/article.aspx?ArticleID=16017

This website provides the information of development of Karl Fischer titration method. It also explains the two techniques of Karl Fischer, the condition suitable for each technique, and the method to determine the endpoint of each technique.

[36] Noria Corporation. (2004, March). *Karl Fischer Coulometric Titration Explained and Illustrated*. Retrieved February 8, 2020, from www.machinerylubrication.com/Read/594/karl-fischer-coulometric-titration

This article compares the difference between coulometric and volumetric techniques of Karl Fischer titration such as how the titrant is added. After that, it continues explaining mainly about the coulometric titration, its titration cell, reagents, and features.

[37] ASTM International. (2020). *Standard Test Method for Water in Crude Oils by Potentiometric Karl Fischer Titration (Withdrawn 2020)*. Retrieved January 26, 2020, from https://www.astm.org/Standards/D4377

ASTM D4377 is a standard method of analyzing water in crude oil by Karl Fischer titration. It is about the analysis method that this standard covers, which is to determine the water content in lubricant by Karl Fischer titration. It is related to our project because this method is one of the methods that the S•O•S laboratory was using. Since this standard has not been updated for more than eight years since the approval of the standard, this method was withdrawn in January 2020.

[38] ASTM International. (2016). *Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration*. Retrieved February 15, 2020, from https://www.astm.org/Standards/D6304

ASTM D6304 is a standard method of analyzing water in lubricant oils by coulometric Karl Fischer titration. This standard is the one that the S•O•S laboratory is using to replace the outdated standard of ASTM D4377. It is related to our project because this method is one of the methods that the S•O•S laboratory is using.

[39] Metrohm. (n.d.). *KF Titrando*. Retrieved February 28, 2020, from https://www.metrohm.com/en-th/products-overview/karl-fischer-titration/kf-titrando/

We cited this site just for an image of typical Karl Fischer titration instrument in laboratories. We did not use any information from this site in our report except the image

[40] ASTM International. (2014). *Standard Test Method for Diesel Fuel Diluent in Used Diesel Engine Oils by Gas Chromatography*. Retrieved January 28, 2020, from https://www.astm.org/Standards/D3524

ASTM D3524 is a standard method of using gas chromatography to analyze diluent diesel fuel. We did not focus on gas chromatography in this project, but we researched to understand the method that the S•O•S laboratory is using.

[41] ASTM International. (2016). *Standard Test Methods for Flash Point by Small Scale Closed Cup Tester*. Retrieved January 27, 2020, from https://www.astm.org/Standards/D3828

ASTM D3828 is a standard method about analyzing the flash point of petroleum products using a small scale closed cup tester. This method can determine flash point of samples within the range of -30 °C to 300 °C. We did not focus on determining flash point in this project, but we researched to understand the method that the S•O•S laboratory is using.

[42] ASTM International. (2014). *Standard Test Method for Automatic Particle Counting and Particle Shape Classification of Oils Using a Direct Imaging Integrated Tester*. Retrieved January 26, 2020, from https://www.astm.org/Standards/D7596

ASTM D7596 is a standard method of using direct imaging integrated tester method for particle counting and particle shape classification of oils. We did not focus on particle counting in this project, but we researched to understand the method that the S•O•S laboratory is using.

[43] ASTM International. (2018). *Standard Test Method for Ferrous Wear Debris Monitoring in In-Service Fluids Using a Particle Quantifier Instrument*. Retrieved January 26, 2020, from https://www.astm.org/Standards/D8184

ASTM D8184 is a standard method of ferrous wear debris monitoring by particle quantifier instrument. We did not focus on particle quantifying in this project, but we researched to understand the method that the S•O•S laboratory is using.

[44] Raszkiewicz, E. (2014, July 17). *Lab Technology Face Off: ICP-AES vs. ICP-OES vs. ICP-MS*. Retrieved March 5, 2020, from https://www.labcompare.com/10-Featured-Articles/165450-Lab-Tech-Face-Off-ICP-AES-vs-ICP-OES-vs-ICP-MS/

This website tells the difference between ICP-AES, ICP-OES, and ICP-MS. ICP-MS was not what we intended to research for this project so it was not mentioned. We cited this source just to ensure the fact that ICP-AES and ICP-OES are the same thing with different name, and these two names can be used interchangeably.

[45] ASTM International. (2015). *Standard Test Method for Determination of Moisture in New and In-Service Lubricating Oils and Additives by Relative Humidity Sensor*. Retrieved February 1, 2020, from https://www.astm.org/Standards/D7546

ASTM D7546 is a standard method of analyzing the moisture content in the lubricant oils. It is related to our project because this method is used in one of the instruments from our recommendations. We can understand the scope and applications in this method before we suggest to the S•O•S laboratory.

[46] ASTM International. (2013). *Standard Test Method for Field Determination of In-Service Fluid Properties Using IR Spectroscopy*. Retrieved January 28, 2020, from https://www.astm.org/Standards/D7889

ASTM D7889 is a standard method of field determination of fluid properties using IR spectroscopy. It is related to our project because this method is used in one of the instruments from our recommendations. We can understand the scope and applications in this method before we suggest to the S•O•S laboratory.

[47] ASTM International. (2017). *Standard Test Method for Field Determination of Kinematic Viscosity Using a Microchannel Viscometer*. Retrieved January 29, 2020, from https://www.astm.org/Standards/D8092

ASTM D8092 is a standard method of field determination of kinematic viscosity using a microchannel viscometer. It is related to our project because this method is used in one of the instruments from our recommendations. We can understand the scope and applications in this method before we suggest to the S•O•S laboratory.

[48] Bartsch, N. (2017). *Lubricating Oil Analysis According to ASTM D5185 Using the Thermo Scientific iCAP 7400 ICP-OES*. Retrieved January 26, 2020, from https://assets.thermofisher.com/TFS-Assets/CMD/Application-Notes/AN-43158-ICP-OES-Lubricating-Oil-ASTM-D5185-AN43158-EN.pdf

This document is a summary of ASTM D5185 provided by Thermo Scientific, the ICP-OES supplier. It uses easier language to explain the standards so that customers who want to buy can understand. This document also provides the list of 22 elements that this standard covers.

[49] AMETEK Brookfield. (n.d.). *Computrac® Vapor Pro® XL*. Retrieved February 1, 2020, from https://www.azic.com/computrac/computrac-vapor-pro-xl/

This website is about moisture content analysis instruments called Computrac Vapor Pro XL which is one of our suggestion instruments. This instrument does not use toxic nor hazardous reagent, so it is safe for the environment and users. It is related to our project to gain a deeper understanding and information to suggest to the sponsor.

[50] Eralytics. (n.d.). *ERASPEC OIL*. Retrieved January 27, 2020, from https://eralytics.com/instruments/eraspec-oil-used-oil-analysis/

This website is about the portable FTIR device that can analyze lubricant oil at high speed and deliver the result as high as an instrument from the laboratory. The data from this website is related to our project as this device can make the process of analysis lubricant faster. The device can give various data for oil condition such as TBN, TAN, measure contaminants, degradation product, etc.

[51] Spectro Scientific. (n.d.). *FluidScan® 1100 - Handheld Infrared Oil Analyzer*. Retrieved January 28, 2020, from https://www.spectrosci.com/product/q1100/

This website is about Fluid Scan 1000/1100 which is the portable IR spectrometer for checking the lubricant condition such as TAN&TBN, oxidation, nitration, etc. This is one of the interesting instruments that we will suggest to the S•O•S laboratory to use it for on-site analysis. This website also provides a short video clip introducing the instrument.

[52] Spectro Scientific. (n.d.). *MiniVisc 3000 - Portable Kinematic Viscometer*. Retrieved January 29, 2020, from www.spectrosci.com/product/pvisc-q3000/

This website is about MiniVisc 3000/3050 which is the portable viscometer for determine kinematic viscosity at 40°C. This is one of the interesting instruments that we will suggest to the S•O•S laboratory to use it for on-site analysis. This website also provides features, benefit, and short video clip introducing the instrument.

[53] Zhao, Y. (2014). *Oil Analysis Handbook Third Edition.* Spectro Scientific.

This is a textbook of how to analyze lubricants in the format of PDF file. This textbook explains mostly about different instrumentations and components they analyze in the Technologies section. It also explains about some technical terms for more understanding and cross-reference with other sources. It is related to our project because we would like to know how those machines work so that we can gain understandings of lubricant analysis process. We also looked through this textbook to find if there is any instrument from it that is interesting enough to recommend to our sponsor.

Appendices

Appendix A: List of ASTM Standards

A.1 Standards Used in S·O·S Laboratory

Standards Number (ASTM)	Description
ASTM D445[33]	Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
ASTM D664[19]	Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration
ASTM D3524[40]	Standard Test Method for Diesel Fuel Diluent in Used Diesel Engine Oils by Gas Chromatography
ASTM D3828[41]	Standard Test Methods for Flash Point by Small Scale Closed Cup Tester
ASTM D4377 [*][37]	Standard Test Method for Water in Crude Oils by Potentiometric Karl Fischer Titration (Withdrawn 2020)
ASTM D4739[20]	Standard Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration
ASTM D5185[23]	Standard Test Method for Multi-element Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry [**]
ASTM D6304 [*][38]	Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
ASTM D7596[42]	Standard Test Method for Automatic Particle Counting and Particle Shape Classification of Oils Using a Direct Imaging Integrated Tester
ASTM D8184[43]	Standard Test Method for Ferrous Wear Debris Monitoring in In-Service Fluids Using a Particle Quantifier Instrument
ASTM E2412[28]	Standard Practice for Condition Monitoring of In-Service Lubricants by Trend Analysis Using Fourier Transform Infrared (FT-IR) Spectrometry

[*] ASTM D4377 was withdrawn in 2020 and is no longer be used. Another standard related to using Karl Fischer titration to lubricant is ASTM D6304.
[**] Atomic emission spectrometry (AES) and optical emission spectroscopy (OES) represents the same meaning and can be used interchangeably.[44]

A.2 Standards of Instruments from Our Recommendations

Standards Number (ASTM)	Description
ASTM D7546[45]	Standard Test Method for Determination of Moisture in New and In-Service Lubricating Oils and Additives by Relative Humidity Sensor
ASTM D7889[46]	Standard Test Method for Field Determination of In-Service Fluid Properties Using IR Spectroscopy
ASTM D8092[47]	Standard Test Method for Field Determination of Kinematic Viscosity Using a Microchannel Viscometer

Appendix B: List of Elements ICP can Detect which are Accepted by ASTM D5185[48]

Symbol	Name
Ag	Silver
Al	Aluminum
B	Boron
Ba	Barium
Ca	Calcium
Cd	Cadmium
Cr	Chromium
Cu	Copper
Fe	Iron
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
Ni	Nickel
P	Phosphorus
Pb	Lead
S	Sulfur
Si	Silicon
Sn	Tin
Ti	Titanium
V	Vanadium
Zn	Zinc

Appendix C: Interview Questions

C.1 S·O·S Laboratory Supervisors

1. How long have you been working in this Company?
2. What is your vision for your lab and the Company?
3. What are your objectives for the lab in this quarter?
4. Originally, were there problems in the past? How did you or your lab solve those problems?
5. Most instruments you are using now are very advanced such as ICP and FTIR. When did you decide to apply the new instruments?
6. Have there been any improvements in your lab record history?
7. Have you recently seen any problems occurring? In which part do you think it is most likely to have problems? Is there anything you think which could be better?
8. Could you please give me more details about the problem? Are they technical matters, methodological issues, or operation mistakes?
9. Who are P.T. Trakindo Utama's competitors? In other companies, do they have any labs such as yours? Do you know their lab process?
10. You have mentioned environmental concern even though you already have a third party which deals with the waste. Why are you concerned about that? Which part most concerns you?
11. From the data in Excel you sent to us before we came [*], there were some parts that exceeded the estimated time. However, from our observation, we didn't think it should take that long. In your opinion, what was the cause?
12. Why don't you send samples from areas that are far away (East Indonesia) to nearer labs?
13. We have seen that customers take such a long time to send samples to the branch. Do you know the reason? Have you thought of any solutions?
14. What is the package the customers use when they send the samples to the branch office? Are the specified bottles filled with the oil samples at the site? If not, how do you transfer the oil samples to the specified bottle?

[*] We were referring to the lead time of each step in the process. We did not provide the raw data, but we provided the interpreted data in Appendix D.

C.2 Laboratory Sample Receiver

1. How long have you worked here?
2. Are you the first person to accept the sample from the customer?
3. How many samples do you receive each day?
4. Do you see any problems at present?
5. Do you think anything could be better?

C.3 S·O·S Laboratory Technicians

1. How long have you worked here?
2. In which part of the lab is your work carried out?
3. Do you also analyze other equipment?
4. How many samples do you analyze/can you take each day?
5. What is the average time taken for your part? How many minutes do you take for each sample?
6. Which part do you think takes more time than the average?
7. Do you see any problems at present? Which part do you think could be better?
8. Are there any cases that your sample cannot be analyzed?
9. How must waste is produced from your part in each day? What type of waste?
10. Have you ever been confused about the sample in the test tube that is not labeled? Is there any way you make sure that you pick up the correct tube?
11. How many samples do you analyze each day?

Appendix D: Average Time Taken in Each Step from Regions that Arrive at S·O·S Laboratory in Java Island [*]

D.1 List of Acronyms and Symbols used in Appendix D

List of Acronyms and Symbols	
Symbol	**Description**
X	The sample
X <	Samples that take less time than
X >	Samples that take more time than
avg	Average
hrs	Hours
Red number (e.g. 5.76)	This part exceeds the target time

D.2 Amount of Samples Arrived to Java in December 2019

Amount of Sample	
Area	**Total Sample (X)**
Northern Sumatra	2224
Southern Sumatra	1569
East Indonesia	1792
West Java	1094
East Java	1364

D.3 Average Time Taken by Customers

Customer Lead Time (Target: 2 days)			
Area	**X < 2 days**	**X > 2 days**	**Avg Time (days)**
Northern Sumatra	155	2069	5.76
Southern Sumatra	595	974	8.25
East Indonesia	150	1642	10.78
West Java	280	814	9.64
East Java	121	1243	8.69

[*] This data was recorded in December 2019.

D.4 Average Time Taken by Branches

Branch Lead Time (Target: 24 hrs)			
Area	**X < 24 hrs**	**X > 24 hrs**	**Avg Time (hrs)**
Northern Sumatra	2212	12	1.53
Southern Sumatra	1342	227	11.58
East Indonesia	1748	44	9.01
West Java	1081	13	1.55
East Java	1219	145	21.07

D.5 Average Time Taken by Forwarder Transportation

Forwarder Lead Time (Target: 48 hrs)			
Area	**X < 48 hrs**	**X > 48 hrs**	**Avg Time (hrs)**
Northern Sumatra	2070	154	36.88
Southern Sumatra	778	791	34.91
East Indonesia	1590	202	114.31
West Java	1059	35	29.17
East Java	1301	63	19.36

D.6 Average Time Taken by Laboratory Process

Laboratory Lead Time (Target: 24 hrs)			
Area	**X < 24 hrs**	**X > 24 hrs**	**Avg Time (hrs)**
Northern Sumatra	1965	259	18.44
Southern Sumatra	1083	486	26.14
East Indonesia	1084	708	21.98
West Java	613	481	24.37
East Java	623	741	27.89

D.7 Average Time Taken by Interpretation Process

Interpretation Lead Time (Target: 12 hrs)			
Area	**X < 12 hrs**	**X > 12 hrs**	**Avg Time (hrs)**
Northern Sumatra	1793	431	4.59
Southern Sumatra	1324	245	3.65
East Indonesia	1470	322	4.63
West Java	992	102	2.4
East Java	1210	154	3.34

D.8 Average Turnaround Time

Turnaround Time (Target: 7 days)			
Area	**X < 7 days**	**X > 7 days**	**Avg Time (days)**
Northern Sumatra	1059	1165	8.59
Southern Sumatra	612	957	11.67
East Indonesia	613	1179	17.32
West Java	480	614	12.11
East Java	353	1011	12.01

Appendix E: List of Recommended Instruments

E.1 Water Content Analysis[49]

Computrac® Vapor Pro XL

Technical Information	
Moisture Range	10 ppm (10µg/0.001%) to 100%
Moisture Resolution	1 ppm (0.1µg/0.0001%)
Temperature Range	25ºC to 300ºC
Sample Size	0.01g to 8g
Results	% moisture, ppm moisture, µg water
Calibration	Manual calibration with NIST traceable capillary tubes
Weight	8 kg
Warranty	One year international
Carrier Gas	Dry nitrogen or dry air at 17-22 psi

	CURRENT INSTRUMENT	**RECOMMENDATION**
10,000 samples/month	**787 KF Tritino**	**Vapor Pro XL**
Price	$25,000	~$27,000
Reagent Use	Yes	No
Reagent Cost	$6,400	0
Sample Throughput	~20 samples/hr	~60 samples/hr
Waste Produced	410 liters/month	0 liters/month
Disposal Fee	$65 / month	$0 / month

Work principle	**787 KF Tritino**	**Vapor Pro XL**
ASTM	ASTM D 4377	ASTM D 7546
Method	Karl Fischer Titration	Relative Humidity Sensor

E.2 Total Acid/Base Number Analysis[50]

Eraspec Oil: Oil Condition Monitoring

Technical Information

Spectrometer Type	Patented mid-FTIR spectrometer Laser and temperature-controlled design
Measurement Cell	100µm path length
Calibration	Factory calibrated with a matrix of international lubricants
Sample Viscosity	0 – 2 00 cSt at 20ºC
Sample Volume	10 mL
Operation Condition	Temperature range 5ºC to 45ºC Humidity up to 90% RH, non-condensing
Weight	9.7 kg

	CURRENT INSTRUMENT	**RECOMMENDATION**
10,000 samples/month	**848 Tritino Plus**	**Eraspec Oil**
Price	$20,000	~$29,000
Reagent Use	Yes	No
Reagent Cost	$11,600	0
Sample Throughput	~10-12 samples/hr	~60 samples/hr
Waste Produced	520 liters/month	0 liters/month
Disposal Fee	$82 / month	$0 / month

Work principle	**848 Tritino Plus**	**Eraspec Oil**
ASTM	ASTM D 664, ASTM D 4739	Not accepted by ASTM [*]
Method	Potentiometric Titration	Fourier-transform infrared spectroscopy

[*] There is no reference to accept ASTM standard for using FTIR to detect TAN and TBN. However, there are few studies which show that FTIR can give result with high accuracy equivalent to titration methods from ASTM D664 and ASTM D4739.[30] The references to ASTM in their site are related,[50] but rather indirectly related to our recommendation purpose. We thus stated that it is not accepted.

E.3 Infrared Oil Analyzer (On Site)[51]

FluidScan® 1100

Technical Information	
Price	~$20,000
Reagent Use	No
Function	Infrared spectroscopy to TAN and TBN
Sample throughput	~60 samples/hr
ASTM	ASTM D7889
Measures	AW additive, Biodiesel Dilution, Glycol, Fluid integrity, Nitration, Oxidation, Soot, Sulfation, TBN, TAN, Water, Total Water

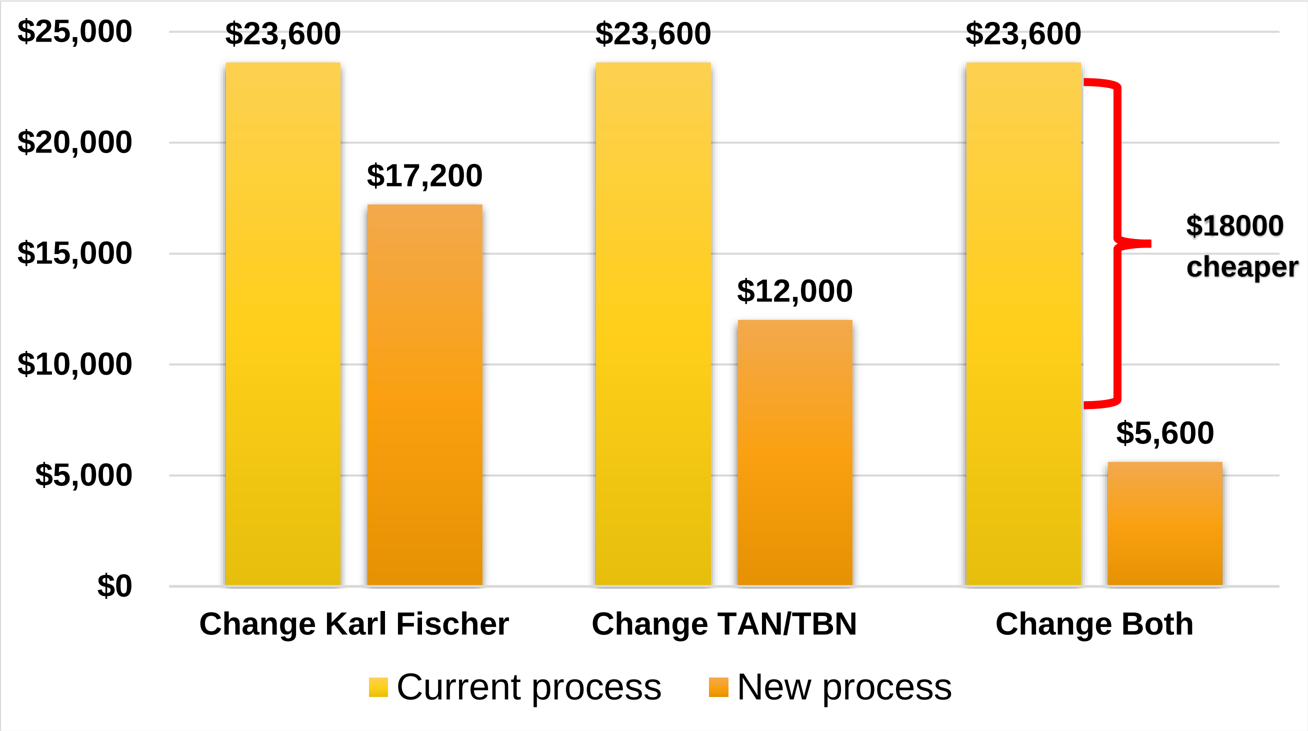
E.4 Kinematic Viscosity Analysis (On Site)[52]

MiniVisc 3050

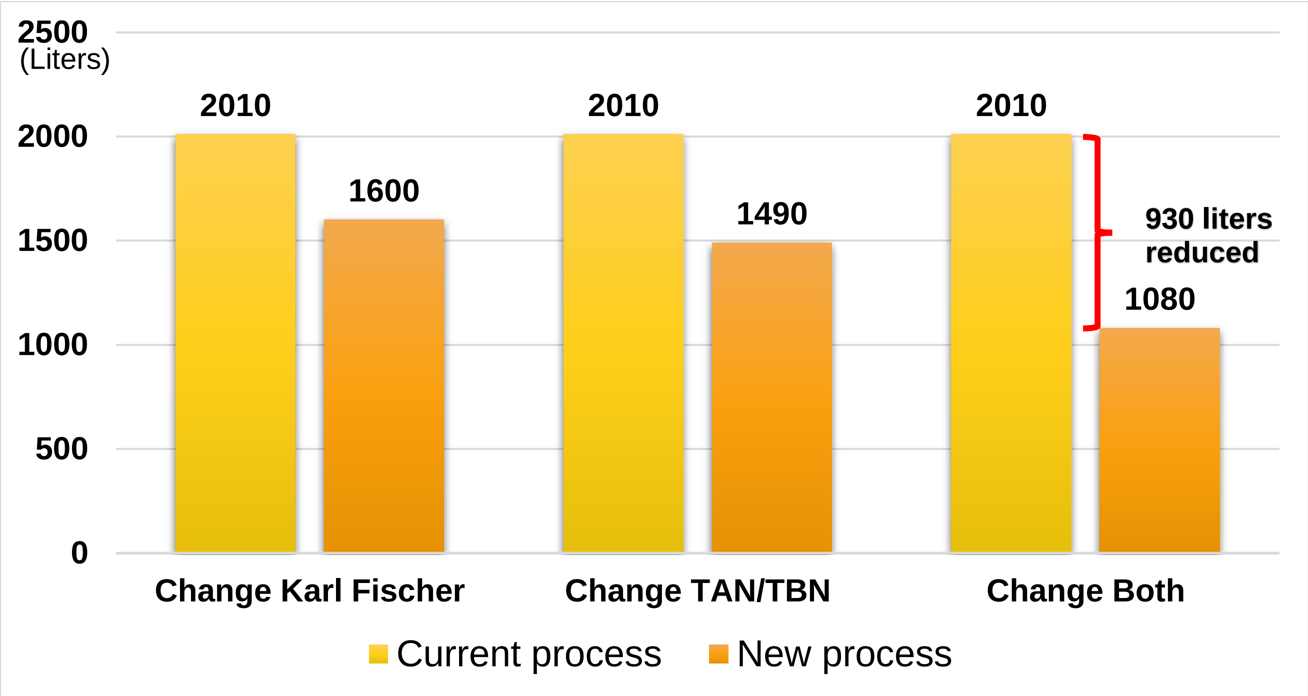
Technical Information	
Price	~$25,000
Reagent Use	No
Function	Determine kinematic viscosity test at 40 C°
Sample throughput	~60 samples/hr.
ASTM	ASTM D8092

Appendix F: Calculations

F.1 Reagent Cost



F.2 Wastes Produced



F.3 Disposal Fee