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PROPOSITION OF A METHODOLOGY FOR LABORATORY VALIDATION OF HYDRAULIC REAR REMOTE IN MEDIUM POWER AGRICULTURAL TRACTORS

by

JOÃO HENRIQUE HECK DETERS

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Prof. Dr. Ignacio Iturrioz
Mechanical Engineering Course Coordinator

Area of Concentration: Energy and Transport Phenomena

Tutor: Prof. Dr. Guilherme Henrique Fiorot

Evaluation Committee:

Prof. Dr. Guilherme Henrique Fiorot (President)

Profª. Dra. Adriane Prisco Petry

Prof. Dr. Darci Barnech Campani

Prof. Dr. Alexandre Vagtinski de Paula

Porto Alegre, August 2024

DEDICATION

Sometimes, the cliché is inevitable: I dedicate this work to my family: my mother, Alice, my father, Jair, and my sisters, Joice and Júlia. I would also like to thank other family members, too many to name, but especially Jean's, Juliane's, and Vanessa's families. Finally, for my most dear friends, those who have never let me down, thank you so much.

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EPIGRAPH

Quality is not an act; it is a habit
Aristotle

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RESUMO

A engenharia de validação é responsável por testar e verificar se novos produtos estão aptos para serem adotados no catálogo de produtos da empresa, neste caso, a fabricação de tratores agrícolas. Um dos sistemas mais importantes de um trator agrícola é o hidráulico, pois permite que a máquina opere os implementos. Este trabalho baseia-se em um projeto de validação executado em uma empresa de máquinas agrícolas e se concentrará na validação em laboratório do conjunto traseiro hidráulico, fornecendo um caminho claro de testes e resultados esperados para validar o desempenho deste sistema, com foco na capacidade hidráulica sob muitas configurações e situações diferentes. O foco deste projeto é ajudar a solucionar a atual falta de documentação e planejamento para validação do Pacote Traseiro Hidráulico de tratores agrícolas de média potência. Obteve-se uma metodologia que alia a validação criteriosa, juntamente com a praticidade e uma facilidade de planejamento, entregue pela metodologia de gestão de projeto. Por fim, com a análise de custos evidencia-se o elevado investimento, mas também elevado retorno do projeto no longo prazo.

PALAVRAS-CHAVE: Engenharia de Validação, Pacote Traseiro Hidráulico, Validação de Máquinas Agrícolas, Hidráulica de Tratores, Metodologia de Validação.

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ABSTRACT

This project's focus is to help solve the current lack of documentation and planning for validating Medium Power Agricultural Tractor's Hydraulics Rear Pack. Validation engineering is responsible for testing and verifying if new products, such as agricultural tractor manufacturing, are suitable for adoption in the company's product pipeline. One of the more critical systems of a farming tractor is the hydraulics, as they allow the machine to operate implements. This project will focus on the laboratory validation of the hydraulic rear pack, providing a clear path of test and expected results to validate the performance of this system, with a focus on the hydraulics capability under many different configurations and situations. The methodology of this work is based on improving the validation process to reduce the time to validate the system, reduce the need for rework, anticipate possible problems, and overall give the validation engineering the efficiency-oriented look that it needs. A methodology was obtained that combines rigorous validation with practicality and ease of planning, delivered by the project management methodology. Finally, the cost analysis highlights the high investment, but also the high return of the project in the long term.

KEYWORDS: Validation Engineering, Hydraulic Rear Remote, Agricultural Machinery Validation, Tractors Hydraulics, Validation Methodology.

NOMENCLATURE

Symbols

Q	Volumetric Flow Rate	[m³/s]
r	The radius of the pipe	[m]
ΔP	The pressure difference between the two ends of the pipe	[Pa]
L	Length of the pipe	[m]
e	Euler Numer	
t	Equipment age	[years]
A	Constant	
B	Constant	
C	Constant	
D	Depreciation	
I	Cost of Instruments	[R$]
l	Labor Costs	[R$]
O	Cost of Opportunity	[R$]
d	Cost of Devices	[R$]
DAQ	Cost of Data Acquisition Equipment	[R$]
T	Cost of Tractor Hours	[R$]
T_C	Total Cost	[R$]

Greek Symbols

μ	Dynamic viscosity of the fluid	[Pa·s]
π	Pi number	
$\phi_{(\tau,\mu)}$	Function of the work regime and maintenance practices	
η	Life Cycle	[years]
τ	Work Regime	
M	Maintenance Practice	

Abbreviations and acronyms

FAO	Food and Agriculture Organization of the United Nations
IBGE	Brazilian Institute of Geography and Statistics
DUT	Device Under Test
GDP	Gross Domestic Product
FEA	Finite Element Analysis
SAE	Society of Automotive Engineers
ISO	International Organization for Standardization
OECD	Organization for Economic Cooperation and Development
PTO	Power Take-off
PMI	Project Management Institute
DAQ	Data Acquisition
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
LPI	Liquid Penetrant Inspection
IEC	International Electrotechnical Commission
CAN	Controller Area Network

SUMMARY

1. INTRODUCTION

According to the United Nations Population Division (ONU, 2022), by the year 2050, the world population will reach 9.7 billion people, compared to the current 8.07 billion of December 2023, a 20% increase in 26 years. So, the globe has the challenge of feeding this new generation, and not only that, but also constantly reducing poverty and malnutrition, which are still a big concern for the nations. Figure 1 shows how the Food and Agriculture Organization of the United Nations (FAO, 2023) projects the growth of calorie consumption per person during the past decades and in the future.

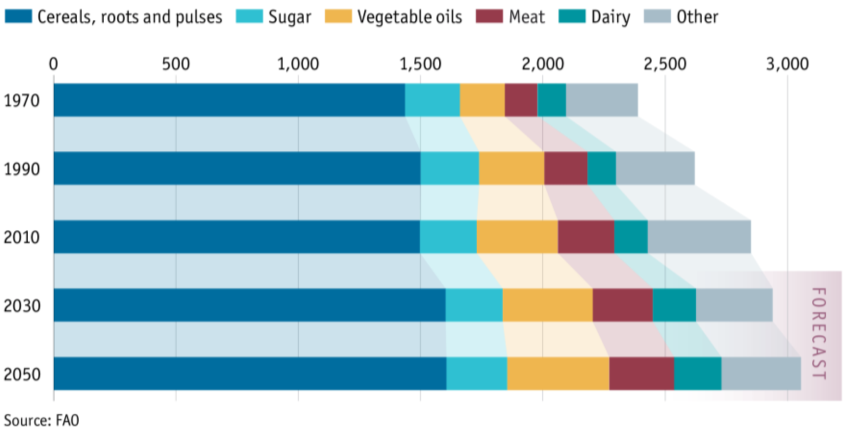

Figure 1 – Daily calorie consumption per person by type of food in the past and forecasted for the next decades (The Economist, sourced from FAO)

Figure 1 shows that calorie consumption per person should increase yearly, most of which is directly linked to agricultural output. So, the farmers will have to produce more people and more for each person. This scenario will still have global hunger, so the growth margin should be much more significant.

Increasing productivity has become a much more difficult task, considering that the nations also aim to reduce deforestation. This means that the agricultural land should not increase considerably. However, this can be both a challenge for some countries and an opportunity for others. Brazil, for instance, has a large amount of arable and fertile land and has already made progress in developing technologies and techniques that improve agricultural productivity.

According to the Brazilian Institute of Geography and Statistics (IBGE), agriculture and livestock represents around 6.8% of the country's gross domestic product (GDP), which has been increasing in the last few years. This represents a significant opportunity for countries like Brazil to develop financially by exporting agricultural output to countries that cannot feed their entire population. Not only that, but this also represents an opportunity to gain geopolitical importance, as it would get increasingly more challenging for nations to provide food for their population, and a commercial partnership with Brazil could prove to be a defining factor for food supply.

With this scenario in sight, investments in the agricultural sector have increased considerably in the past decades, and the ability to produce more with the same farmland has been the main focus; involving developing better farming techniques and new technologies, improving the management of the farms, getting cheap lines of credit, etc. However, the goal is to produce more with less; there is a way to get it done: by increasing efficiency. This efficiency increase will be possible if all the technologies have that focus, and the agricultural machinery is a big part of this equation.

Agriculture is directly linked with the prosperity of humans. In fact, the beginning of agriculture also caused the beginning of societies. With every significant industrial and technological revolution, agriculture also suffered a comparable change. Then, mankind learned to cultivate variable crops, learned to use animal traction, and learned a range of techniques. With the advent of self-propelling vehicles, the farms gained the first tractors, harvesters, planters, and sprayers. More recently, the farms gained telemetry with the satellites, allowing them to interconnect all the machines' systems.

It wasn't always common to study the tractor's capabilities and efficiency. It was a sector of mechanical engineering that focused on being as robust as possible with high power and durability. Nowadays, tractors are no longer designed to endure decades of working on the same farm and being passed from father to son across generations but to occasionally operate in big farms with heavy and essential tasks.

To fabricate a new tractor model, the design must be fully validated. This knowledge area is called Validation Engineering, and it is responsible for testing every part, system, and model. This job requires instrumentation, the definition of a test methodology, the definition of acceptance criteria, data acquisition, data analysis, and documentation for the functioning, durability, reliability, safety, and comfort of the Device Under Test (DUT). It is important to notice that, according to FAO (2003), Validation and Certification are different processes, the last being a procedure done by a third party that gives assurance that the product is in conformity with national or international standards, while the validation is usually run by the own company.

Validation engineering must ensure the company that the new product is fitting for being produced, is in line or better than the current product, can endure the specified duty cycle, is equipped to operate for the specified tractor datasheet, and is safe for the operator. Not to be misjudged with quality, which analyzes current products and how they compare to the approved prototype.

The design process is shown summarized in Figure 2. The marketing and business intelligence teams acquire customer information and the overall market data. The design team projects the new product, calculates the dimensions based on the expected performance of the machine, and delivers the drawings to the computation analysis team to do Finite Element Analysis (FEA) and the manufacturing engineering team that builds the prototypes. The validation engineering team tests the prototypes using the company standards, the FEA data, and expected product specifications. The validation process will return feedback to the design team, which will provide modifications if needed. When the product is approved, it is added to the company's catalog, and the manufacturing team takes over the project to produce it on a large scale.

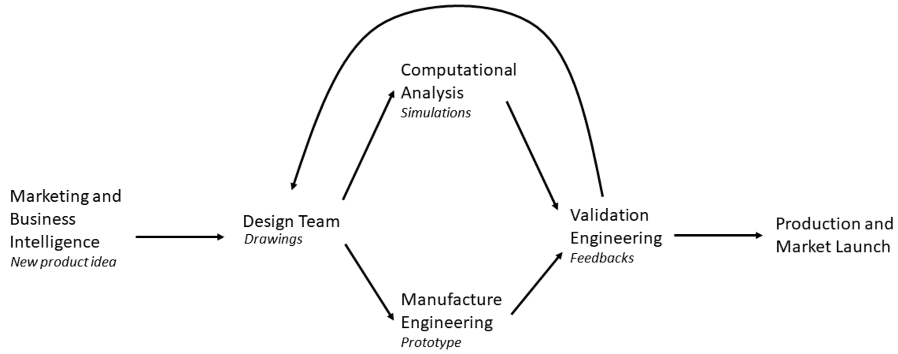

Figure 2 – Summarized diagram of how a new product is developed in an agricultural machinery company (Font: the author)

The validation process does not add value to the product; it only serves as a guarantee that the product functions well. Thus, it must be done fast so as not to delay the new model's release. At the same time, it needs to be reliable because, in the worst-case scenario, the product can be launched with defects, causing safety problems, lack of performance, low durability, and even callbacks for updates. One model released with some of these problems could cause significant losses to the farmer, harm the company's reputation with the customers, and even cause injuries to the operators.

It is unlikely that small businesses could be capable of running a full-scale validation process on their new products since it is costly. This is also one of the reasons why the agricultural machinery market is heavily dominated by big multinational companies, known to buy competitors to gain market share and technology. This gives even more urgency to a design and validation process roadmap, democratizing the knowledge held by the big brands.

2. LITERATURE REVIEW

The Society of Automotive Engineers (SAE), with SAE J283, and the International Organization for Standardization (ISO), with ISO 730:2009, provide most of the standards used in the industry regarding testing agricultural tractors. Almost every test performed on this project does have a direct standard counterpart. They bring a clear path to perform tests and what should be the acceptance criteria. There are many issues with this approach: 1) these organizations have paid content, so the information on how to run this test is not easy to access; 2) many of the specific tests for verifying issues do not have a fitting standard; 3) many of the acceptance criteria are too bland for the industry, especially for high performing tractors. Because of this, it is common for manufacturers to design their roadmap of tests with acceptance criteria that function for their specific products.

Regarding an actual roadmap of tests, containing mandatory and optional tests, depending on the targeted performance and configurations of the prototype, the best documentation available is the one created by the Organization for Economic Cooperation and Development (OECD), 2019 released the Code 2 guidelines for tractors performance. OECD is a forum where many nations (including Brazil) cooperate to create standardization and technological development agreements, frequently meeting with specialists to review the current code and add new testing procedures.

A significant percentage of tests for agricultural tractors' hydraulic rear packages are already fully standardized; the hitch and the PTO (Power Take-off), for instance, are frequently studied and have similar designs even in different models and brands. The hitch is a part that not only allows the tractor to operate implements but also to do other of its most essential tasks, such as transporting equipment and loads (Liu Changqing et al., 2023). However, the flow valves that regulate the outlet flow to the cylinders and implements still lack research papers.

The validation engineering process is not only testing according to standard procedures and defining if the model “Passed” or “Failed” the test, but it should work as a part of the design process, following the projects from the beginning and being able to create feedback loops to generate inputs for new tests. The simplicity of only asserting a test result caused testing centers to close (Lanças et al., 2020).

The process of designing engineering products has become increasingly sophisticated. Today, it is necessary for all areas to contribute to the process with multifunctional teams (Basso et al., 2010), providing feedback on results, contributing to discussions, and finding creative, practical, efficient, and assertive solutions to the problems encountered with globalized teams (Shibata, 2010). This type of vision is not provided by standardizing agencies, which is why many companies have been developing their acceptance criteria for new products, as there is a demand in the market for products of excellent quality. For the same reason, competition has become fierce, with several giants in the sector competing for market share, especially with Asian companies, such as Kubota and Mahindra, starting to threaten the hegemony of the previously dominant John Deere, CNH Industrial, AGCO Corporation and Claas.

Romano (2003) considers validation a final step of the process, executed mainly for safety and regulatory reasons. Still, it does not detail how to proceed with the validation, disregarding the damages that an unfinished product could represent for the brand. On the other hand, Shibata (2010), citing Sobek (1999) and McCord (1993), states that in a more modern approach to product development engineering, to increase efficiency and reduce the duration of the project, steps must co-occur, with the error being treated as feedback. Each feedback triggers a new loop of discussion, which changes the product even during the development. Although this causes constant reworks and demands good communication between all the design sectors, it prevents significant setbacks in the project since a failing test at the end of the project could result in the process restarting from the beginning.

According to Vieira (2007), failures in recently launched products are highly damaging to companies because they represent a significant financial cost of having to replace parts, even more so when it comes to a need for a call-back. The latter also profoundly damages the reputation of the brands, since the customers of this niche (automobile and agricultural machinery) pay high prices for having equipment that they expect to not fail. Because of this, a validation process should cover the maximum possible errors and failures on the prototypes, thus avoiding problems not predicted by the current standards.

When it comes to developing a project methodology, according to Spowage (2010), a methodology becomes increasingly efficient as it becomes customized. Spowage affirms that standards, such as ISO and SAE, represent the lowest efficiency on project methodologies than the company-designed methodologies figured at the center and a specific methodology, as one that only consists of just one type of project (in this case, a validation of a system) should figure at the best efficiencies projects possible.

3. METHODOLOGY

Given all the weaknesses of the existing methodologies and knowing it could not be possible to test the proposed methodology in real projects due to the time limitations and the difficulty of executing academic activities on prototype areas in big companies, the proposed methodology will focus on 1) proposing a standardized project management methodology; 2) identifying a larger amount of procedures than the existing ones, and 3) analyzing the costs of the project.

Project management skills are an increasing necessity for engineers because it does not matter if the professional can run the tests if he cannot control the project. Not only that, but with a competitive market, time to market is a highly regarded indicator, and this depends on the project management capabilities of the engineers. Thus, to get a viable project management methodology, the guidelines from the Project Management Institute (PMI) and Project Management Body of Knowledge (PMBOK) will be the primary source of research.

According to PMBOK, the project will be separated into five stages: Initiation, Planning, Execution, Monitoring and Controlling, and Closing. Every activity on the project, beginning from the demand for a new validation and concluding with the complete approval of the product, will be appropriately separated at each stage. Every stage will have its inputs and deliverables, all focusing on the quality and agility of the project. This should help the engineers to keep the project under control as well as their targets.

With a project management methodology completed, the focus will turn to the technical part, which is planning a roadmap of tests. This roadmap will be based on 1) the current standards, which already cover the most critical performance evaluating tests; 2) the experience running a similar project on an agriculture machinery company, where it was possible to observe firsthand the most significant challenges the validation team faces and what were the tests that were more underdeveloped; 3) the research on the market expectations to the product and how the product works. These three sources should be enough to prepare a detailed roadmap.

At the end of the work, a methodology that helps engineers manage and execute validation projects on agricultural tractors' rear hydraulic packages is delivered. In summary, engineers have a project management methodology that guides them on what to do at every stage, like preparing for the project, managing the team, determining the time, determining the deliverables, etc. The roadmap contains the knowledge on how to prepare for the test, how to do the instrumentation, how to run the test, how to evaluate the results, and how to report it, with insights on what could go wrong and how to avoid it.

In addition to the methodology, the costs of each test are also evaluated, considering 1) the cost of labor, 2) the cost of instruments, 3) the cost of Data Acquisition Equipment, 4) the cost of machinery, 5) the cost of diesel and lubricant, and 6) the cost of devices. This analysis can also guide the engineers in planning the tests and determining which tests the company can execute based on the budget.

4. SYSTEM OPERATION

Tractors can have different components between each other, but the most important ones are common within all models and branches. Figure 3 shows in a simple sketch what those components are and how the system works.

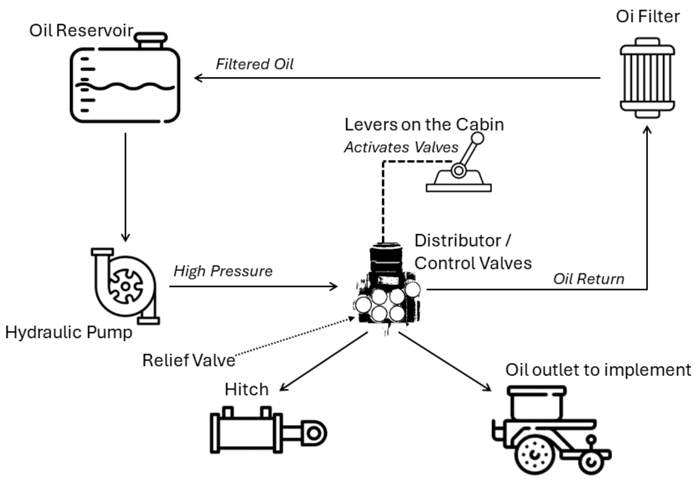

Figure 3 – Schematic showing the rear hydraulics' main parts and oil flow (Font: the author)

According to the schematic, oil flows from the Oil Reservoir or Oil Tank, where the Hydraulic Pump extracts it. The Hydraulic Pump is powered by the tractor's engine, which means that the hydraulics partly consumes the tractor's power output. This can influence the tractor's performance when it runs different tasks simultaneously, so it is essential to test every part considering multiple engine speeds.

The oil flows through a path of hoses from the reservoir to the hydraulic pump, which is pressurized and then sent to the distributor. The distributor will activate the Hydraulic Pump and Control Valves when the operator (usually directly from the cabin) pushes or pulls the controlling levers, linked from the cabin to the solenoids in each control valve, which means that the slice is activated by only one lever, with another controller (either a lever or a button) to control the hitch.

When the hitch is activated, the oil goes through a hose or pipe on one of the sides of the hydraulic manifold and gets separated into two hoses, one for each cylinder. The hose is connected to the lowest side of the hitch cylinder, where the oils get injected with high pressure, pulling the piston and making the hitch go up proportionally to the exposed side of the cylinder rod.

When the operator deactivates or lowers the hitch, no pump is used to reverse the oil flow and get the cylinder to a neuter stage, this is done by the force of gravity, pulling the piston downward and, thus, sending the oil back to the valve.

The same method is followed to provide hydraulic power to the implements: The implements' hoses are connected to the valves' inlets and outlets, and when activated, the valves deliver high-pressure oil through the hoses. The return happens by a mix of gravity’s force and the pressure differential when the return valve is opened.

Before the oil returns to the Reservoir, it must be filtered to reduce the oil impurities and thus not compromise its physical attributes.

5. TESTING ROADMAP

It is important to emphasize that to execute all the following tests, the hydraulic package must be fully and correctly equipped in a tractor model that fits the requirements of software, power, and root. Before performing each test, the engineer should ensure that the tractor is in working condition and has the proper oil and temperature. Also, all the mechanics must be familiar with the tractor’s mechanics and functions. The engineer should follow each test closely, ensuring the system works and has no flaws regarding safety, comfort, leakage, or any other problem that could harm the operation. Not only that but all the tractors should be taken to field tests, where they should be instrumented and monitored while performing the tasks it was designed to execute; this work will not go into depth, focusing mainly on laboratory tests.

Most instruments can be reused throughout the project, using the same ranges and overall specifications, which helps cut costs and facilitate the project without the risk of mistakenly using wrong-range sensors. Data acquisition frequency is not a defining factor, as the system is primarily steady, and movements are in the range of seconds. Any sensor and data acquisition module with around 60 Hz frequency can be used.

Some of the tests will be discussed in this paper, but the full roadmap involves 14 tests. With three being necessary (A Tier) – without those it is impossible to launch the product (Hitch Capacity, Flow Capacity, and Levers Endurance), five very important (B Tier) – without those, almost certainly there will be high warranty costs (Noise test, Climatic Chamber tests, Impact of the flow distributor on the flow and lowering time, Levers Force Characterization and Electro Dynamic Shaker Life Cycle), and six complementary tests (C Tier) – to be sure of the product quality (Downward Movement Time, Reaction Time, Relief Valve Impact, Effort to activate the Flow Divider, Current Impact on the Flow, and Breakaway Test).

5.1 Downward Movement Time and Reaction Time

Many conditions had to be tested to validate the hitch's lowering time, but the primary objective is to achieve the same or less lowering time than the baseline. So, the first configuration shall be tested with the tractor within ambient conditions with no load on the hitch or implement connected. The time comparison could be made using a clock or an inclinometer for higher precision.

A simple procedure is available: a tractor should be equipped with an inclinometer in the hitch links, and then the hitch should go up and down at least five times; the average time to complete each movement should be similar to the baseline or factsheet. Another essential measure is the reaction time, which can be easily calculated by fixing a string pot sensor to the cab and fixing the string to the cursor that activates the hitch (Appendix A a) and b)). The time the string pot starts to move minus the time the hitch begins to move (acquired with the inclinometer or with the CAN (Controller Area Network) if it provides the hitch position) is the reaction time and should be less than 0.5 seconds. A reaction time of more than 1 second can harm the tractor usage, possibly caused by either software issues or a slow-paced oil flow to the cylinders.

5.2 Downward Movement Time at Low Temperature

This test is created to verify the hitch's functioning and lowering time when subjected to small temperatures. The recommended lowest temperature for Europe and the United States is usually around -20°C, depending on the model's intended market.

As it is known, the rate of chemical reactions, including those that involve the viscosity of oils, depends on the temperature. This relationship is described by the Arrhenius equation (1), which shows the reaction rates decreasing at low temperatures (T), leading to a less likely to overcome activation energy (E_A) required for molecular interactions. Svante Arrhenius first proposed this relationship in 1889 (Arrhenius, 1889), where k is the rate constant, A is the pre-exponential factor, and R is the gas constant.

$$k = Ae^{-\frac{E_A}{RT}} \tag{1}$$

Suppose the hitch takes more than a minute to complete the movement. In that case, the design engineers should consider changing the material of the hoses, reducing their length (L), or, most importantly, increasing their radius (r), which is more efficient because of the fourth power associated with this variable, according to Hagen-Poiseuille formula for flow rate (2) (Hagen, 1839; Poiseuille, 1846), where Q is the flow, ΔP is the pressure differential and μ is the viscosity.

$$Q = \frac{\pi r^4 \Delta P}{8\mu L} \tag{2}$$

A climatic chamber should be used to perform this test. Inside it, the tractor shall be equipped with an inclinometer to check the hitch speed, at least one pressure transducer of 1-10 bars range in the hydraulic command, and two thermocouples type K, one to get the environment temperature and the other for the hydraulic reservoir temperatures. In this test, it is also necessary to go up and down with the hitch at least five times, both with and without a load attached to it (Appendix A c)).

The expected result is that the hitch does not take more than 1 minute to go up or down. A time delay greater than 1 minute can be harmful to customer usage.

5.3 Hitch Capacity

One of the most important testing parameters of the rear hitch is delivering the specified load on the current product datasheet. A standardized procedure (SAE J283) specifies how the test should run. For this reason, there is no need to create a new procedure.

The instrumentation uses a pressure transducer (250 bar) in both cylinders and the data from the load cell with a 10,000 kgf maximum force (Appendix A d)). Figure 4 shows the device schematic and where the load is measured.

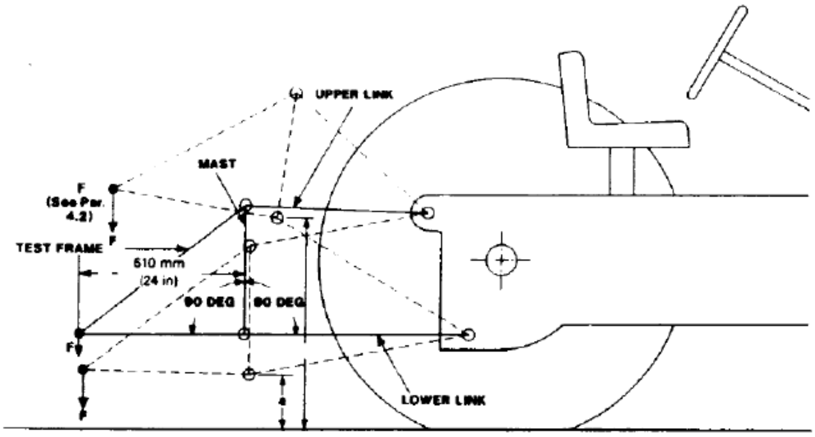

Figure 4 – Schematic showing the device used in the hitch capacity test (Font: SAE J283)

When analyzing the results, the resulting force on each height should be compared to the specified on the product datasheet. The proposal meets the criteria if it is the same or has a higher value than the factsheet. If not, the pump and the cylinder should be analyzed for a possible power upgrade. Although it is essential to note that when the hitch approaches the end of the motion, it loses power drastically, the company may consider some tolerance.

This test is also considered a safety factor. If the tractor's hitch exerts a greater force momentum than the force momentum caused by its weight on the rear axle, the tractor's front can be lifted and turn around the rear axle, resulting in an accident. Therefore, tractors with powerful hitch cylinders must have weights added to their front parts.

5.4 Breakaway Test

The breakaway test is designed to verify if the hydraulic pack can decouple implement hoses in the slices without leaking oil or presenting cracks or failures when a load is applied to each slice.

First, a device with hydraulic connections (the same as the slice) should be attached to one slice. This device should have an S-type load cell with a 1 - 50 kg range connected to both the oil inlet and outlet and finally fixed to a rigid surface (that could resist at least 50 kg). A 1-50 bar pressure transducer must also be connected to the rear remote.

To perform the test, the tractor should be started, and then the slice must be triggered. With oil being pumped through the slice, to cause the breakaway, the tractor should move forward to pull away the device.

After the test, it is advisable to run a crack analysis test on the bracket that supports the hydraulic command because cracks cannot be visible to the naked eye. So, it is essential to clean the part after the test, remove the painting, and apply the chemical products to reveal cracks (according to the standard Dye Penetrant Crack Testing, also known as Liquid Penetrant

Inspection (LPI) (ISO 3452)). If it did not show any cracks, if there were no leaks, and if the system did not fail, the device is approved.

5.5 Noise Test

Changing a rear pack could impact the operator's perception of noise because the cables could root, the fluid could flow at high pressure, or even the rear hitch could raise or lower. So, it is essential to do a noise test from inside the cab.

For the test, a pair of pre-polarized free-field 1/2" microphones (or similar, which attend to the IEC 61094-4 standard) is needed. They should be connected to a data logger and assembled with a device to be fixed close to the operator’s ears, one on the right and the other on the left (Appendix A e)). Two other microphones of the same model should be installed outside the cabin, one in the hood, next to the engine, and the other close to the exhaust.

The background noise should be recorded once the tractor is placed in a quiet area. Then, turn the tractor on and record the noise with selected engine speed rotations (to check if the hydraulics’ noise is covered in all ranges). This procedure should be repeated while activating every lever, once a time, to check for a noisier slice.

The data analysis goal is to evaluate if the tractor with the hydraulic pack activated is noisier than the tractor without pulling the levers and at the same speed. So, the same comparison should be made using the overall noise, regardless of the frequency. If this analysis is inconclusive, doing a band-pass and a band-stop analysis using the 300 - 800 Hz range (the range that the rear pack actuates) is recommended. This procedure should discard all the differences in the noise caused by components other than the hydraulic package, allowing the team to decide if the hydraulic remote is too noisy (more than 85 dB, according to NR-15 standard).

5.6 Impact of the Flow Distributor on the Flow and Hitch’s Lowering Time

This test is designed to check the rear hitch's functioning while turning the flow divider into specific flows and evaluate the rear hitch while using the first slice simultaneously.

The instrumentation is composed of a pliers ammeter to check the current in the solenoid, a thermocouple type K in the hydraulic oil reservoir, a dual-axis inclinometer with a range of at least 90° in one of the hitch arms, and a hose connected in the first slice with a flowmeter with 120 L/min capacity, a pressure transducer with at least 5-250 bar range, a thermocouple type K, and a restriction to regulate the pressure manually. This restriction should be selected based on ease of pressure control, such as a relief valve. Finally, an acquisition cable should be connected to the CAN network to access the tractor data.

The procedure is simple and consists of activating the first slice and locking it with a lever locking device (usually available on stock models), then activating the hitch up and down with the distributor closed, half opened, and fully opened while also applying different pressures to the system using the relief valve installed in the restriction. Also, the system should be tested in all conditions, with and without load (around 1 Ton), and finally, the engine rotation speed must be set at multiple levels from lowest to highest. There should be enough scenarios for the engineer to analyze the impact of the activation of the flow distributor on the oil output, focusing on the possibility that the hitch may not work properly when most of the flow is destined for the slices.

5.7 Effort to Turn the Flow Divider Knob

To validate the flow divider and the knob that activates it, the system must provide the expected flow to the first slice, which is 100% of the flow in case of the flow divider fully opened and 0% when it is closed. Not only that but turning the manifold should be an easy task, not harming the operator's experience. The manifold should be easy enough to turn in all the functioning ranges expected to the rear pack, so if the tractor is designed to work with planters that can demand 200 bar hydraulic pressure, the manifold should be possible to turn quickly from 0 to 200 bar in the slice.

The instrumentation is done by using a hose with a flowmeter with 120 L/min capacity and a pressure transducer with at least a 5-250 bar range going out of the first slice and going back to the inlet of the same slice, a thermocouple tyke K in the hydraulic reservoir, an adjustable restriction (example: relief valve) in the first slice. Using a load cell to check the load necessary to turn the manifold is also recommended. Still, in some cases, due to the irregular shape of the knob, this instrumentation can be too complicated for the small area available, so, the team will possibly have to rely on their interpretation if the knob is or is not possible to turn.

To execute this test, the first step is to activate the first slice and verify if the flow indicated in the flowmeter matches the flow specified by the design prototype. Then, let the slice activate until the hydraulic oil temperature is at least 60°C (working temperature). After this, the manifold will be closed until it reaches a 10 L/min flow in the flowmeter, and the pressure will be manually regulated at 10 bar. At this point, already acquiring data, the flow divider should be opened to the maximum flow, then closed to 10 L/min again. Then, the recording should stop, setting the initial pressure to 20 bar, and doing it all again. This process should be repeated until the maximum pressure is achieved with 10 bar steps.

When analyzing the results, the focus should be on the flow provided by the first slice when fully opened and on the ability to open and close the manifold manually, making sure that it is ergonomically viable and possible in all specified pressure ranges, also due to the high temperatures on the hydraulic pack parts during the machine functioning (can get hotter than 90°C), which can cause burns in the operator if the manifold is poorly designed.

5.8 Levers Activation Force Characterization

The activation of the slices can be difficult. It depends on many mechanical parts that can vastly differ from one model to another just by some small differences in the design.

The instrumentation required for this test is an S-type load cell with a range of around 1–25 kgf, attached to a device to facilitate the push-pull movement and at the other end to another device to fix the load cell in the lever (Appendix A f)). Measuring the distance from the load applied to the center of the lever turning axis is essential to ensure the arm size is the same. The load should be applied around 5 cm down from the top of the lever, simulating the mean force caused by the operator's manual activation of the lever.

To execute the test, the engineer should turn the data loader on and, with the tractor also on, activate each lever in every stage available, repeating the movement multiple times and avoiding applying too much force after the lever engages in every stage.

When analyzing the data, the engineer should calculate the average effort to engage the lever in each stage and save the values in a table, paying attention to possible outliers. It is important to remember that when activating the lever manually, at the moment it engages in a position, it stops resisting the operator force, creating a valley in the plot (Appendix B), followed by another peak caused by the delay of the operator to stop applying load to the lever, which means that only the first peak should be considered, as it is this one the responsible for activating the position.

The levers are expected to require less than 10 kgf to be engaged in any position, forward or backward. If the force needed is higher, the design team should consider changing components on the rooting that transfer the motion to the slices.

6. COSTS ANALYSIS

There are many variables that should be considered when calculating the costs of a validation project. As this project is meant only to evaluate laboratory tests, expenses related to field tests will not be considered. It is possible to break down the costs into the following categories: 1) cost of instruments (I); 2) cost of labor hours (l); 3) cost of tractor hours (T); 4) cost of opportunity (O); 5) cost of devices (d); 6) cost of Data Acquisition equipment (DAQ) and 7) parts (P). Also, as the variables can fluctuate, the total cost will be given by a range of costs, not an exact value. So, the total cost of the project (T_C) will be estimated according to the following equation:

$$T_C = I + l + T + O + d + DAQ + P \tag{3}$$

Beginning with the cost of the instrument, to calculate this, it is necessary to search for everyday prices for the data acquisition instruments used, but the usage of the same instruments in multiple tests should also be considered, for example, the pressure transducers used in one test can be used in other tests too if the range required is the same. Not only that but it is expected that after the project, the instruments will still be functional, so it can be considered as a CAPEX (capital expenditure) rather than an OPEX (operational expenditure), which means that it can be an investment for the validation team to be used in future projects. Usually, all costs related to the design and validation of a prototype would be considered as CAPEX, but, as we see from a validation team perspective, CAPEX will be regarded as investments for the long term, and OPEX will be considered costs that will not be returned.

Sensors and data acquisition equipment prices can fluctuate considerably depending on the buyer's relationship with the sensor fabricant, precision and quality preferences, and long-term goals. Approximations were made by reaching out to the suppliers and using the factual prices observed when executing a similar project

Although most of the costs of the instruments can be diluted through multiple projects, some of the costs will still be meaningful, not only for the instruments that may be broken or damaged during the tests but also to account for the depreciation of those instruments. Calculating the depreciation of instruments is challenging, especially knowing that this will vary considerably according to the team's ability to use the instruments correctly and thus preserve them. It considers the cost of each Pressure Transducer, Inclinometer, Load Cell, Flow Meter, Ammeter, String Pot, Power Supply, Thermocouple, and Accelerometers, accounting for a total investment of R$77,921.36. As for the data acquisition equipment, it is proposed to use HBM Quantum models (MX1609 thermocouple amplifier, MX640B universal amplifiers, CX22B-W data Recorder) and a piezoelectric microphones Kit with an HBK Datalogger accounting for a combined total of R$ 321,000.00.

Also, devices will be used in some of the tests, but they are mostly straightforward, and they all can be locally designed by the engineer and manufactured by the mechanic; in this case, an approximation of R$3,200.00 for all the devices can be used (with the extra work hours by the engineer and mechanic already considered on the labor costs).

Knowing that the instruments, Data Acquisition equipment, and devices will still be usable after the project, a depreciation method shall be used to evaluate the value that each instrument will lose during the project. The method picked was Hélio's Caires (1978), which was chosen because it included variables to weigh wear and maintenance. Helio's method considers that the depreciation is a function of the equipment age (in this case 0) (t), life cycle (η), work regime (τ), and maintenance practice (M), according to equation (4):

$$D_{(\tau,\mu,\eta,t)} = \frac{A}{1 + Be^{(\phi_{(\tau,M)} \cdot C \cdot \left(\frac{t}{\eta}\right))}} \quad (4)$$

where A is equals to 0.1347961431, B is $(A - 1)$, C is 3.579761431, and e is the Euler Number, approximated to 2.7182. $\phi_{(\tau,M)}$ is a function of the work regime and maintenance practices (equation (5)), both allowing the following values: 0, 5, 10, 15 and 20, meaning a null work, light, regular, heavy or extreme and an inexistent maintenance, deficient, regular, rigorous or perfect accordingly. For both cases, 15 will be used because of the controlled space of the laboratory with competent professionals while simultaneously challenging and testing the limits of the machine.

$$\phi_{(\tau,M)} = 0{,}85308170 \cdot e^{0{,}067348748 \cdot \tau - 0{,}041679227 \cdot M - 0{,}001022860 \cdot M \cdot \tau} \quad (5)$$

Table 2 shows the results of the depreciation calculations. Besides the high investment, much of the equipment's value is preserved.

Table 2 – Results of depreciation of equipment, according to Helio Caires Method (Font: the author)

	Estimated Duty Cycle [years]	Cost Value	Residual Value	Depreciation	Residual Value
Thermocouple	1	600.00	35,5%	387.29	212.71
Pressure Transducer 50 bar	5	13,800.00	88,2%	1,626.90	12,173.10
Pressure Transducer 300 bar	5	11,500.00	88,2%	1,355.75	10,144.25
String Pot	5	2,000.00	88,2%	235.78	1,764.22
Inclinometer	5	2,000.00	88,2%	235.78	1,764.22
Ammeter	5	1,000.00	88,2%	117.89	882.11
Load Cell 50kg	5	3,100.00	88,2%	365.46	2,734.54
Load Cell 10 Ton	5	5,900.00	88,2%	695.56	5,204.44
Flowmeter	3	36,000.00	79,4%	7,412.32	28,587.68
Piezeleric Microphones + HBK Datalogger	10	121,000.00	94,4%	6,835.98	114,164.02
Datalogger	10	200,000.00	94,4%	11,299.14	188,700.86
Fonte de Corrente	10	2,021.36	94,4%	114.20	1,907.16
Simple Device	5	1,200.00	88,2%	141.47	1,058.53
Complex Device	5	2,000.00	88,2%	235.78	1,764.22
Accelerometer	5	15,000.00	88,2%	1,768.37	13,231.63
	Total	**417,121.36**		**R$32,827.67**	

For the labor costs, the mean salary from an engineer, an intern, and a mechanic from Brazil was considered, and then the value was transformed into an hourly wage, which was used to calculate labor costs. For each test, several hours were assigned for each of the collaborators, considering the complexity of the test in terms of preparation, instrumentation, execution, and analysis, as well as the need for device development and, finally, the assisted execution time of each test, the table with the hours considered is found in the appendices. The total cost of labor was calculated to be around R$ 15,960.00.

When calculating the tractor hours costs, there are several related costs. Edwards's work (2015) will be adapted to represent a more accurate approach to Brazilian current prices.

Edwards suggests considering hourly costs as a function of some variables. The ownership costs sum up the depreciation, interest, taxes, insurance, and housing. From this, the only one that matters to the manufacturer is the depreciation, which will be discussed as the cost of opportunity, the repair and maintenance costs, the fuel costs, lubrication costs, and labor costs (which were already addressed before). Edwards calculated the price of repair and maintenance to be $\$8.33/h$, using an exchange rate of R$$5.00$ = $\$1.00$, which results in R$$41.65/h$. For the other costs the following equation (6) will be used. Where $0.166\,L/h$ is used as the consumption for diesel engines, $150hp$ will be used as a proxy for medium power agricultural tractors maximum horsepower, and the fuel price R$$6.52/L$ (Brazil's average in June 2024), giving a result of $162.34\ R\$/h$.

$$Fuel\ Costs\ Per\ Hour = Consumption \cdot Maximum\ Horsepower \cdot Fuel\ Price \qquad (6)$$

For lubrication costs, Edwards (2015) estimates that it accounts for 15% of the fuel costs, but, considering that in a testing laboratory environment there will be many failures regarding assembly, leakages, wrong components, among other systematical errors, we will use a safety of 2, giving:

$$Lubrication\ Costs = \ Fuel\ Costs \cdot 0.15 \cdot 2 \rightarrow Lubrication\ Costs = \ 48.70 R\$/h \qquad (7)$$

To calculate the opportunity costs, it is necessary to know how much the company profits from each tractor and how much will be lost in selling the tractor for a discount, given that it was used on tests and can be already damaged. To approximate the profit on each tractor, it will be considered the mean of the historical mean gross profit margin from the following companies, which are publicly traded and share this data with the market: AGCO Corp, John Deere, and CNH Industrial. This results in a gross profit margin of 26.15%. Also, the price of each tractor can vary depending on the region and the customer. Still, the mean price of the following models will be considered as a proxy of the value of an 150 hp agricultural tractor: MF 6714R, JD 6R 155 and NH T6 155, with an average cost of R$$526{,}666.67$. Considering the mean profit margin, for example, if the tractor is later sold at just half of the usual profit margin, the company will be indirectly losing in average R$70,294.67 per tractor.

At least two parts kits will be needed, with the complete hydraulic rear remote (including rooting and levers), one for the tractor tests and one for the bench tests. The kits average R$15,000.00 per kit, resulting in more than R$30,000.00 in OPEX costs.

Considering that the project will last four months and the tractor will be used for 50 hours (estimated given all tests), the expected total investment for a complete validation will be R$ 877,594.25. However, considering that most CAPEX investments will be preserved, the project's total cost falls to just R$ 174,634.33. It is also worth noting that reducing the number of tests does not significantly affect the total cost of the project, with a Partial Validation (only Tier A and B tests) resulting in a R$ 154,186.61 cost and a Basic Validation (Tier A tests) of just two months, resulting in R$ 115,038.82.

7. PROJECT MANAGEMENT METHODOLOGY

To manage a project of this complexity, it is advisable to adhere to the PMBOK methodology, which delineates the project into phases: Initiation, Planning, Execution, Monitoring (the latter two co-occurring), and Closing. However, as industries aim for greater efficiency and projects become more urgent, it is beneficial to integrate certain principles from the Scrum methodology (Schwaber & Sutherland, 2017).

7.1 Initiation

This phase commences when the validation team is convened to undertake the project. Initial steps significantly enhance the team's later efficiency. The engineer should meet with the requisition team to grasp the scope fully. Discussions should cover the changes in parts, the primary differences from the baseline, scheduled time to market, target markets, the project budget, the primary stakeholder, and potential modifications the part might undergo during validation if the design is not finalized.

7.2 Planning

In the planning phase, the engineer assembles the validation team. The size of the team may vary based on the project's urgency and complexity; typically, a long yet straightforward project might only need one engineer and possibly an intern to assist and facilitate knowledge transfer. Including a mechanic on the team is also prudent to prevent a potential shortage of technical expertise. Consistency in the team composition throughout the project is best practice as it minimizes errors and enhances problem-solving and communication. With the team in place, the engineer should familiarize himself with the system operations, educate the team members, secure necessary components and instruments unavailable, and plan a detailed test roadmap.

7.3 Execution

Execution involves putting the planning phase's roadmap into action, which includes setting up the necessary machinery, equipping the DUT, instrument calibration, conducting the tests, analyzing data, and reporting to stakeholders. Test modifications or additional verifications may probably be requested, necessitating procedure adjustments or fine-tuning parameters. The engineer is responsible for overseeing all testing activities, with the mechanic present to handle the machinery and assembly, always with an eye on safety and risk.

7.4 Monitoring

The monitoring approach varies depending on the project's stage, team size, difficulty, and urgency. However, it is recommended that the engineer consistently manage the project with utmost diligence. Applying Scrum practices, tests can be grouped into Sprints based on similarities, with the catalog of tests serving as the Backlog. During these Sprints, daily scrum meetings help the team focus on tasks completed, pending issues, and collaborative problem-solving. Post-Sprint, the team should assess potential improvements for subsequent Sprints and relay results and recommendations to stakeholders. This method is particularly effective for complex, fast-paced projects but may introduce unnecessary overhead in slower, update-sparse projects due to Scrum's inherent focus on agility.

7.5 Closing

Closing is the project's final step, which is the phase the project enters when all the tests are completed and the decision to launch the product as proposed (and as modified during the feedback) or not. At this point, the engineer has to ensure that all the projects and all the tests are documented, uploading all the data to the company's database. It is not necessary and not shared in prominent industries. However, a good team manager action is to promote feedback meetings with the project execution members, letting them know what they did well and where they failed, and suggesting where they can improve for future projects. The engineer could also seek feedback from the other stakeholders and ask the team members where he could have done better. When the projects are concluded, all the instruments and machinery must be returned to the company's storage, and the budget should be closed.

8. CONCLUSIONS

With this work, we conclude that although a validation project is complex, demanding, fast-paced, and expensive, it is possible to manage it successfully with some study and preparation. The most important part is not the technical knowledge needed to execute and analyze tests but the ability to manage and deliver the project quickly. The roadmap of tests includes all the necessary procedures to validate the hydraulic rear remote, emphasizing the importance of standardized procedures, already instructing on how to prepare for each test, how to use the measure instruments, how to run it, and what to expect from the results. Sadly, it was impossible to detail every test and include deeper information about them, or even past results, to facilitate the comparison. Still, the main goal was to give the engineers a guideline and a few hints on what they should expect from a project like this. Appendix C made a worksheet available to further help engineers manage their projects.

Most engineers may disregard the project management methodologies at first look. Still, the most challenging part of such important projects is to manage all the variables and needs of the team simultaneously, knowing how to communicate to the stakeholders and how to prepare the validation team. The simple act of executing the tests only takes around 100 hours in total, but the reason why such a project takes so long is that there is always something to prepare before each test, either it being arranging parts, a workbench, devices, instruments, a tractor, getting the procedures validated by all stakeholders, etc. It usually takes even more than that; it is not hard to see validation projects last for years, and the main cause of this prorogation is the rework, which can only be prevented with communication and good project management.

Finally, the cost analyses prove that although the project could seem quite expensive, it is an investment for any company; every agricultural machinery manufacturer should consider having a well-equipped validation team, allowing the company to be innovative and launch products more often. Most of the equipment needed can already be available because none of the instruments or equipment are niched; it only consists of standard high-precision instruments, so the cost of the instrument could be reduced. Not only that, but the cost analysis shows that it is not wise to test only parts of the product because it may increase the costs of warranties and does not reduce the project's cost significantly. The last clear thing is that it is worth to test multiple tractors simultaneously. Thus, it is cheaper to use the same concept across various models and possibly multiple power ranges when developing a new system because much of the costs and time spent on one tractor can be applied to a second one.

For future work, it would be great if a similar methodology were developed for field validation projects as well. In addition, defining limits and approval criteria for tests would also greatly enhance the current methodology. However, the most important addition would be a way to validate the work done, putting it into practice in future projects, and, equipped with consumer data, refine the methodology in order to delve deeper into the tests that would be most effective for product quality, or even develop new tests.

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APPENDIX

Figure A – a) The string pot fixed in the levers with the string connected to the cursor, giving the exact moment the operator activates the hitch; b) One inclinometer sensor connected to the hitch links, allowing the acquisition of data on the hitch's range of motion; c) 500kg load attached to the hitch links during the climatic chamber tests; d) Configuration of the hitch capacity test, acquiring load and pressure (with a pressure transducer) data on various height points; e) Noise test instrumentation inside the cab; f) Usage of a small S-type load cell to acquire load data while pushing and pulling the lever (Font: the author)

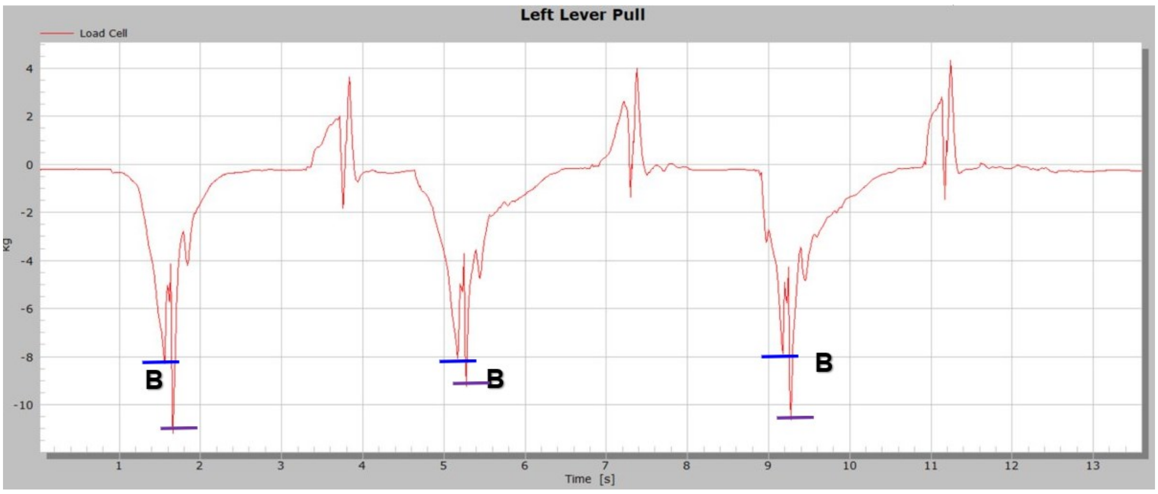

Figure B – Example of Load x Time plot of the force characterization test, showing peaks when activating the lever, followed by a valley when the lever gets to a neutral position, and a second peak, the result of an extra force by the operator after the lever engages (Font: the author)

Table C – Worksheet with the complete testing form for the project management and reporting (Font: the author)

Testing Form: Hydraulic Rear Remote			
Project Name:		Project Leader – Site – email:	
Validation Engineering Leader – Site – email:		Teams involved - Sites:	
Supplier		Start Day:	
Part Name – Part Number:		Time to Market:	
Model Characteristics			
Tractor Model:		Powertrain Model:	
Power (hp):		Engine Model:	
Fuel Type:		Engine Rotation Range [RPM]:	
Engine Cooling:		Number of Cylinders:	
Dry Weight:		Warranty Period:	
☐ Platform	☐ Cab	☐ Does have ROPS	☐ Front Hydraulic
Advertised Hitch Capacity [N]:		Advertised Flow Capacity [L/min]:	
Top Speed [km/h]:		Number of Slices:	
Hydraulic Oil Tank Capacity [L]:		Hydraulic Oil Type:	
Minimum Temperature [°C]:			
Time Tests			
Without Load			

Downward Time [s]:		Reaction Time (up) [s]:	
Upward Time [s]:		Reaction Time (down) [s]:	
With Load		Load [kg]:	
Downward Time [s]:		Reaction Time (up) [s]:	
Upward Time [s]:		Reaction Time (down) [s]:	
Climatic Chamber		Temperature [°C]:	
Without Load			
Downward Time [s]:		Reaction Time (up) [s]:	
Upward Time [s]:		Reaction Time (down) [s]:	
With Load		Load [kg]:	
Downward Time [s]:		Reaction Time (up) [s]:	
Upward Time [s]:		Reaction Time (down) [s]:	

			Hitch Capacity			
1st Measure	Height [cm]		Load [N]		Pressure [bar]	
2nd Measure	Height [cm]		Load [N]		Pressure [bar]	
3rd Measure	Height [cm]		Load [N]		Pressure [bar]	
4th Measure	Height [cm]		Load [N]		Pressure [bar]	
5th Measure	Height [cm]		Load [N]		Pressure [bar]	
6th Measure	Height [cm]		Load [N]		Pressure [bar]	
7th Measure	Height [cm]		Load [N]		Pressure [bar]	
8th Measure	Height [cm]		Load [N]		Pressure [bar]	
9th Measure	Height [cm]		Load [N]		Pressure [bar]	
10th Measure	Height [cm]		Load [N]		Pressure [bar]	

	Breakaway Test		
Force to Decouple [N]		Cracks found with Dye Penetrant?	☐ Yes ☐ No

	Flow Divider Tests		
Knob fully opened – Without Load		**Engine Speed [RPM]:**	
1st Slice Flow [L/min]		Pressure on the Rear Remote[bar]	
2nd Slice Flow [L/min]		Hitch got up?	☐ Yes ☐ No
3rd Slice Flow [L/min]		Time to up [s]	
Knob fully opened – With Load			
1st Slice Flow [L/min]		Pressure on the Rear Remote[bar]	
2nd Slice Flow [L/min]		Hitch got up?	☐ Yes ☐ No
3rd Slice Flow [L/min]		Time to up [s]	
Knob 66% opened – Without Load			
1st Slice Flow [L/min]		Pressure on the Rear Remote[bar]	
2nd Slice Flow [L/min]		Hitch got up?	☐ Yes ☐ No
3rd Slice Flow [L/min]		Time to up [s]	
Knob 66% opened – With Load			
1st Slice Flow [L/min]		Pressure on the Rear Remote[bar]	
2nd Slice Flow [L/min]		Hitch got up?	☐ Yes ☐ No
3rd Slice Flow [L/min]		Time to up [s]	
Knob 33% opened – Without Load			
1st Slice Flow [L/min]		Pressure on the Rear Remote[bar]	
2nd Slice Flow [L/min]		Hitch got up?	☐ Yes ☐ No
3rd Slice Flow [L/min]		Time to up [s]	
Knob 33% opened – With Load			
1st Slice Flow [L/min]		Pressure on the Rear Remote[bar]	
2nd Slice Flow [L/min]		Hitch got up?	☐ Yes ☐ No
3rd Slice Flow [L/min]		Time to up [s]	
Knob Closed opened – Without Load			

1st Slice Flow [L/min]		Pressure on the Rear Remote[bar]	
2nd Slice Flow [L/min]		Hitch got up?	☐ Yes ☐ No
3rd Slice Flow [L/min]		Time to up [s]	
Knob Closed opened – With Load			
1st Slice Flow [L/min]		Pressure on the Rear Remote[bar]	
2nd Slice Flow [L/min]		Hitch got up?	☐ Yes ☐ No
3rd Slice Flow [L/min]		Time to up [s]	

Effort to turn the Flow Divider's Knob

Restriction [bar]	Possible to open	Possible to close	Temperature [°C]	Flow [L/min]
10	☐ Yes ☐ No	☐ Yes ☐ No		
20	☐ Yes ☐ No	☐ Yes ☐ No		
30	☐ Yes ☐ No	☐ Yes ☐ No		
40	☐ Yes ☐ No	☐ Yes ☐ No		
50	☐ Yes ☐ No	☐ Yes ☐ No		
60	☐ Yes ☐ No	☐ Yes ☐ No		
70	☐ Yes ☐ No	☐ Yes ☐ No		
80	☐ Yes ☐ No	☐ Yes ☐ No		
90	☐ Yes ☐ No	☐ Yes ☐ No		
100	☐ Yes ☐ No	☐ Yes ☐ No		
110	☐ Yes ☐ No	☐ Yes ☐ No		
120	☐ Yes ☐ No	☐ Yes ☐ No		
130	☐ Yes ☐ No	☐ Yes ☐ No		
140	☐ Yes ☐ No	☐ Yes ☐ No		
150	☐ Yes ☐ No	☐ Yes ☐ No		
160	☐ Yes ☐ No	☐ Yes ☐ No		
170	☐ Yes ☐ No	☐ Yes ☐ No		
180	☐ Yes ☐ No	☐ Yes ☐ No		
190	☐ Yes ☐ No	☐ Yes ☐ No		
200	☐ Yes ☐ No	☐ Yes ☐ No		

Relief Valve got Activated?	☐ Yes ☐ No	Pressure [L/min]		Reduction [L/min]	

Current Impact on Flow

Without Load		Engine Speed [RPM]:	
Current [A]	Hitch went up	Pressure on the Rear Remote [bar]	Pressure on the Cylinder [bar]
0,25	☐ Yes ☐ No		
0,50	☐ Yes ☐ No		
0,75	☐ Yes ☐ No		
1,00	☐ Yes ☐ No		
1,25	☐ Yes ☐ No		
1,50	☐ Yes ☐ No		
1,75	☐ Yes ☐ No		
2,00	☐ Yes ☐ No		
2,25	☐ Yes ☐ No		
2,50	☐ Yes ☐ No		
2,75	☐ Yes ☐ No		
3,00	☐ Yes ☐ No		
3,25	☐ Yes ☐ No		
3,50	☐ Yes ☐ No		

With Load		Load [kg]:	
Current [A]	Hitch went up	Pressure on the Rear Remote [bar]	Pressure on the Cylinder [bar]
0,25	☐ Yes ☐ No		
0,50	☐ Yes ☐ No		
0,75	☐ Yes ☐ No		
1,00	☐ Yes ☐ No		
1,25	☐ Yes ☐ No		
1,50	☐ Yes ☐ No		
1,75	☐ Yes ☐ No		
2,00	☐ Yes ☐ No		
2,25	☐ Yes ☐ No		
2,50	☐ Yes ☐ No		
2,75	☐ Yes ☐ No		
3,00	☐ Yes ☐ No		
3,25	☐ Yes ☐ No		
3,50	☐ Yes ☐ No		

Force Characterization

Lever	Position 1 [kgf]	Does Lock?	Position 2 [kgf]	Does Lock?	Position 3 [kgf]	Does Lock?
1st Lever		☐ Yes ☐ No		☐ Yes ☐ No		☐ Yes ☐ No
2nd Lever		☐ Yes ☐ No		☐ Yes ☐ No		☐ Yes ☐ No
3rd Lever		☐ Yes ☐ No		☐ Yes ☐ No		☐ Yes ☐ No

Levers Endurance

Target Duty Cycle [cycles]:				
Lever	Axis Diameter Before [mm]	Did if fail?	Axis Diameter After [mm]	Cracks found with Dye Penetrant?
1st Lever		☐ Yes ☐ No		☐ Yes ☐ No
2nd Lever		☐ Yes ☐ No		☐ Yes ☐ No
3rd Lever		☐ Yes ☐ No		☐ Yes ☐ No

Effort to activate after the Endurance Test:

Lever	Position 1 [kgf]	Position 2 [kgf]	Position 3 [kgf]
1st Lever			
2nd Lever			
3rd Lever			

Electro Dynamic Shaker - Endurance

Part	Target Hours	Hours Endured	Cracks found with Dye Penetrant?
Rear Remote			☐ Yes ☐ No
Support Bracket			☐ Yes ☐ No
Cylinder			☐ Yes ☐ No