



TECHNICAL NOTE:

INFORMATIONAL PHASE OF THE DEVELOPMENT OF EQUIPMENT FOR ANALYSIS OF DIRECT SHEAR AND PRE-COMPACTION OF THE SOIL

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ABSTRACT

Given the real need for advances in studies such as the relationship of soil-machine dynamics, it is clear that there are almost no innovative systems developed to attend this demand. The design of agricultural machinery and equipment can be facilitated by having information and mechanisms that allow the prediction of the mechanized-set behavior in real work situation, especially regarding the traction effort demanded by the tractor, due to the energy demand of the equipment that interact directly with the soil. Obtaining this information usually requires high-cost imported laboratory equipment. Thus, the objective of this work was to obtain the design specifications for the development of a direct shear and soil pre-compaction analysis equipment with low manufacturing cost. The Phases Methodology was used to obtain the necessary parameters, in the informational phase of the desirable aspects for each design requirement. Through a step-by-step analysis, it was possible to obtain customers' needs, together with the establishment of the desired criteria, and the design requirements for the new product development was generated. The use of the Phases Model allowed the transformation of customers' requirements into the design requirements, enabling hierarchization by degree of importance and thus enabling the execution of future steps.

Palavras-chave:

Física do solo
Metodologia de projetos
Desenvolvimento de
máquinas agrícolas

FASE INFORMACIONAL DO DESENVOLVIMENTO DE UM EQUIPAMENTO PARA ANÁLISE DE CISALHAMENTO DIRETO E PRÉ-ADENSAMENTO DO SOLO

RESUMO

Tendo em vista a real necessidade de avanços em pesquisas, a exemplo a relação da dinâmica máquina-solo, percebe-se que quase inexistem sistemas inovadores desenvolvidos para o atendimento dessa demanda. O projeto de máquinas e equipamentos agrícolas pode ser facilitado quando se conta com informações e mecanismos que permitem a previsão do comportamento do conjunto mecanizado em situação real de trabalho, especialmente no tocante ao esforço de tração demandado ao trator, devido à solicitação energética dos equipamentos que interagem diretamente com o solo. Para obtenção dessas informações geralmente se necessita de equipamentos de laboratório importados e de alto custo. Dessa forma, o objetivo do trabalho foi de obter as especificações de projeto para o desenvolvimento de um equipamento de análise de cisalhamento direto e pré-adensamento do solo com baixo de custo de fabricação. Utilizou-se da Metodologia de Fases para obtenção dos parâmetros necessários, na fase informacional, de aspectos desejáveis para cada quesito de projeto. Por meio da análise, passo a passo, foi possível a obtenção das necessidades de clientes, juntamente com o estabelecimento dos critérios almejados, paralelamente, gerou-se os requisitos de projeto para o desenvolvimento do novo produto. O uso do Modelo de Fases permitiu a transformação dos requisitos de cliente para os de projeto, possibilitando a hierarquização, por grau de importância e, assim, possibilitando a execução de etapas futuras.

INTRODUCTION

Market dynamics are affected by several factors that range from the consumers' socioeconomic conditions to the ability of a company to introduce an innovative product for consumption (CONTO *et al.*, 2016). Therefore, there is a need of methodological proposals that include innovation factors, making the market broad and competitive.

Back *et al.* (2010) recommend the use of appropriate methodologies that have a global view of the product to be developed, in order to obtain the definitions and specifications of the design, and then generate the necessary methods to evaluate them. According to Rozenfeld *et al.* (2006), the product development model is divided into macrophases, subdivided into phases and activities, where macrophases have three subdivisions: pre-development, development and post-development. In this model, the macrophases are divided into: design planning, informational design, conceptual design, detailed design, production preparation and product launch (SCHESTER *et al.*, 2015).

Costa and Toledo (2016) state that pre-development is the initial phase of the new product development process and it is directly related to the strategies adopted and the innovative capacity. The informational design phase serves as a basis for optimizing future resources and enhancing actions in the tasks to be performed in the following phases, especially when it comes to family farming, according to the designs by Stefanello *et al.* (2017), Custódio *et al.* (2018) and Spagnolo *et al.* (2019), who developed, respectively, a human-powered seeder, a bed-shaper and a mineral-and-organic-fertilizer depositor for low-power tractors and a thermal-weed control machine, therefore evidencing the effectiveness of the methodology.

Soil Mechanics (SM) is defined by Das (2014) as the branch of Science that deals with the study of the physical properties of the soil and the behavior of soil masses subjected to various types of forces, including the maximum shear stress. According to Knappett and Craig (2014), the shear strength of a soil is the maximum stress that the soil mass can withstand without suffering a failure in the plane, rupture occurs. It can be expressed by the Coulomb equation, as shown in Equation 1 presented by Barbosa and Lima (2013).

$$\tau = C + \sigma_n \operatorname{Tg}\varphi \quad (1)$$

Where:

τ = Shear strength (kPa);

C = Apparent cohesion (kPa);

σ_n = Surface normal stress (kPa); and

φ = Angle of internal friction ($^{\circ}$).

The parameters C and τ are intrinsic characteristics of the soils (SAYÃO *et al.*, 2009). Vargas (1989) describes that τ is the maximum shear stress supported by the soil, σ_n is the total normal stress on the sliding surface or "failure" to which it is subjected, including the neutral stress. C is the apparent cohesion of the soil and, according to Knappett and Craig (2014), it is denominated the cohesion intercept (C') when there is a better adjustment in the curves defined by the Mohr envelope, in this case, using graphical representations through the definition of lines, where the linear coefficient becomes independent of the normal stress.

From the line conformations in the Cartesian plane, Mohr's criterion is similar to Coulomb's, making it to be denominated Mohr-Coulomb's criterion (SAYÃO *et al.*, 2009). Then, φ emerges, which is the angle of internal friction of the soil, defined as the angle that the normal strength forms with that resulting from the strengths that the earth mass is subjected.

Basically, there are two ways of determining the efforts acting on soil mobilization tools considered symmetrical and narrow. According to Serpa and Magalhães (1997), they are those in which the depth-width ratio is equal to or less than six: **(a)** According to Santo *et al.* (2010), one way is with the use of quantification instruments adapted to the implementation in order to collect the values of the active efforts. **(b)** Another way is through mathematical prediction models for this purpose, among which, those proposed by: Reece (1964), Hettiaratchi and Reece (1967), Godwin and Spoor (1977), McKyes and Ali (1977), Perumpral *et al.* (1983) and Serpa and Magalhães (1997), which allow equations with soil parameters and the mobilization tool.

It is important to observe that the mathematical models, presented above, use information that originates from the determination of the shear

strength of the soil, such as: the angle of internal friction, apparent cohesion of the soil, maximum normal stress and maximum shear stress. The knowledge of the physical parameters of the soil and its respective importance degree in the mathematical models of prediction of the tractive effort can be an assistance in the conduction of designs and development of machine elements, guiding the designers team in the improvement and adaptation of the implements aimed to meet the needs of family-based farming.

Because of the need to know precisely the physical parameters of the soil (internal friction angle, cohesion, pre-thickening stress and shear strength), which interfere in the machine-soil relationship, as well as its contribution in the design of new mechanized equipment addressed to agriculture, given that the equipment needed to determine these parameters is imported and of high cost (which can reach converted values of up to ± R\$ 350,000.00). Hence, it is vital the development of a shear equipment directly from the ground, with low manufacturing cost, especially to Brazilian public educational institutions, which often lack financial resources to purchase equipment for laboratory analysis.

It is understood that the high costs of purchasing this equipment is one of the main obstacles that public institutions of technical and higher education encounter to advance in their research on the dynamics of the soil-machine relationship, because if they do not have them in their laboratories, they are restricted to field-tests, which in turn need adequate climatic conditions, release of funds, available personnel, among other indispensable factors.

In this way, the objective of this work was to obtain the design specifications for the development of a direct shear analysis and pre-compaction equipment with low manufacturing cost.

MATERIAL AND METHODS

Successive meetings were held with the design team, where first, the product-life-cycle phase

(PLCP) and the customers involved in the process were stipulated. The informational design phase, shown in Figure 1, was guided by the research and by the successive meetings of the team formed by researchers from the Federal University of Pelotas (UFPel) and the Federal Institute of Education, Science and Technology of Rio Grande do Sul (IFSul), who in addition to structuring the next step (s), built knowledge on the topic, identifying possible solutions to the design issues.

The second step in the process of ranking the requirements of the design consisted of determining the ranking of the items that obtained the highest valuation when compared to the crossed requirement through the Mudge Diagram.

To determine the Quality Function Development (QFD), the QFD-SACPRO software, developed by NeDIP (2017), was used, which allowed the sequential ranking of the Design Requirements. The first step of this stage was to identify the design's customers and, according to Spagnolo (2014), they were divided into three levels: internal, intermediate and external, which were inserted within the PLCP.

The survey and identification of customer's needs were obtained in three stages: (1) Survey of preliminary information on the need to develop equipment for analysis of direct soil shear as an aid element in the design of agricultural machinery, such as the degree of knowledge of customers about the proposed equipment. (2) Obtaining necessary information (requirements) to support the construction process of a laboratory equipment for soil shear analysis. (3) Classification and determination of customer's needs.

First, a qualitative research was carried out in order to identify the basic needs and desires of the customers regarding the design of a laboratory soil shearing machine. Then, an open qualitative questionnaire with six (6) questions was built on the Google Forms® virtual platform, which aimed at the prior analysis of the knowledge on the topic, as well as the primary requirements of the machine systems, as well as possible advances after the construction of a prototype, if there was a demand for it. After the application of the first questionnaire,

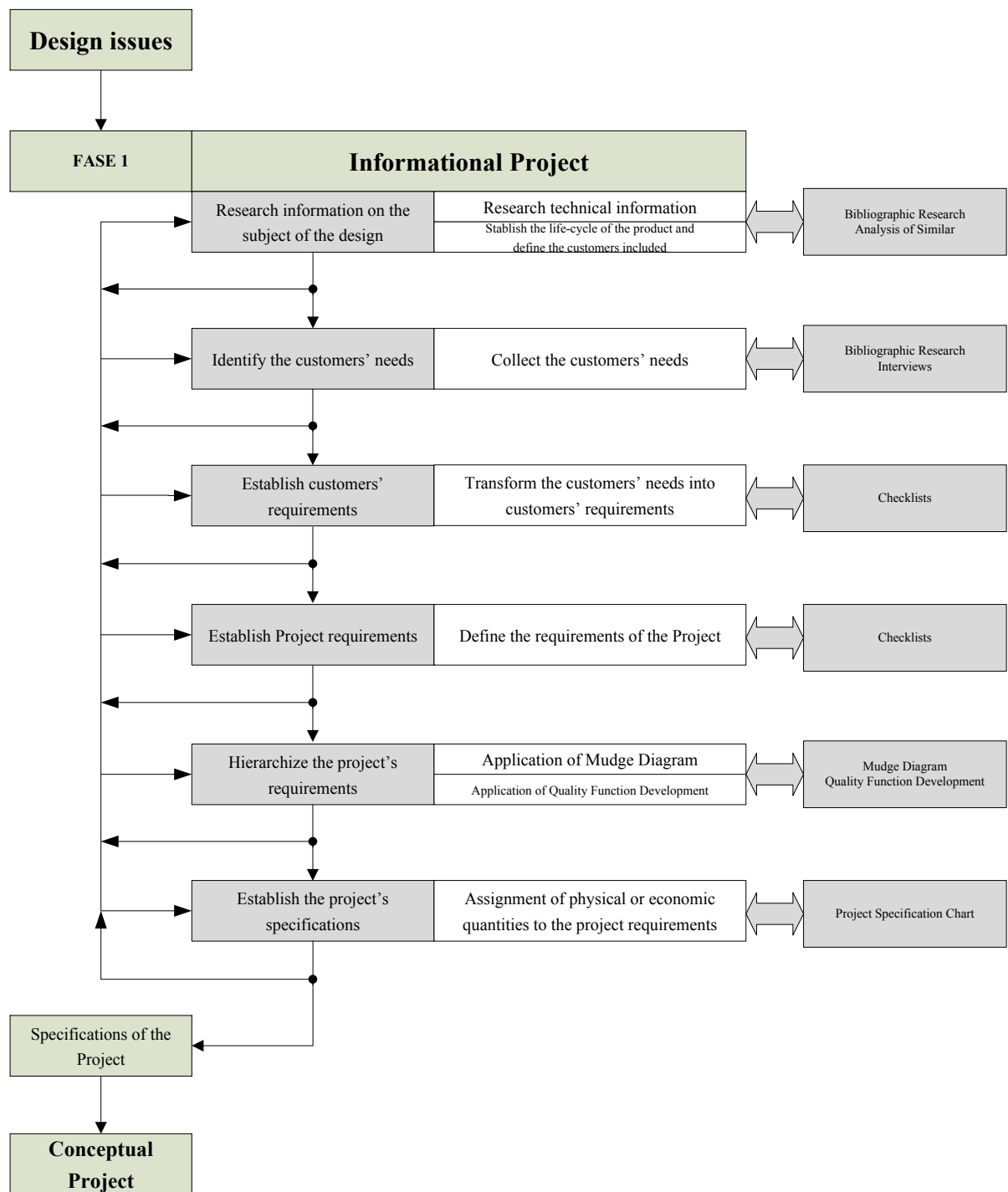


Figure 1. Informational design step

a new semi-structured form of twenty-two (22) questions, of qualitative-quantitative character, was applied in order to list and classify the needs of the customers regarding the technical requirements of the equipment: dimensions of the equipment, variation in the acquisition and maintenance cost, type of mechanisms involved and data acquisition systems.

At the same time, the informational design was guided through extensive research on the history of the dynamics of the soil-machine relationship, as well as materials, components and patents for laboratory equipment for the execution of compression and direct shearing of the soil, aiming to substantiate the existence of a low-cost design that meets this proposal.

RESULTS AND DISCUSSION

In relation to the customers’ needs, the investigation allowed to identify that a shearing and pre-compaction equipment of the soil can result in countless gains of a scientific nature. However, the high cost of acquisition makes it impossible to approve projects with the scientific development agencies. However, requirements such as precision in the determination of results, sweeps of driving forces of the systems and versatility of soil types to be tested, also emerged as a requirement to be considered in the design.

Consequently, it was possible to classify and order customers’ requirements according to their hierarchical valuation, resulting in the key factor for the proper transformation and project requirements, as shown in Table 1.

The class-ranking allowed to have an expanded dimension, in terms of the expectations of the potential customers of the product under development, since the need for accuracy of the equipment, versatility in the application of loads and the processing of the data obtained in the tests resulted in Class 10, that is, these criteria would be the first to be considered if there was a demand for the equipment to be purchased. Another important

finding was the manufacturing cost, which ranked sixth in the class rank and 07.99% in preference (when compared to the global total) of the decision makers; the low percentage value may be an indication that: once the technical specifications of the design and operation are met, the equipment will have potential for acquisition, but it should not exceed the value of R\$ 15,000.00 (maximum value for manufacturing, in the preference of the decision makers). A strong component, in the interviewees’ view is due to the fact that the equipment is automated because in addition to representing agility in the operating processes, it guarantees reliability in the data test reading. The maintenance cost was considered an insignificant factor, as an equipment of this type usually presents robustness (less breakage rate) with a greater impact on durability (06.08%), resulting in a more reliable design, therefore, better accepted in the consumer market. Figure 2 shows the QFD, which shows the relationship between customers’ requirements and design’s requirements.

The activities detailed in Table 2 will serve as a work basis in the next phase of the design, that is, the conceptual design whose objective is to obtain the physical quantities of the product.

Table 1. Requirement classes of the ranked customers

No. of the order	Life-cycle phase	Customers’ Requirements	Class	Score / (%)	Project requirements
1 st	Design	Test accuracy	10	40 (15.21)	Load resolution / displacements
2 nd		Variation in the vertical forces	10	37 (14.07)	Vertical speed variation
3 rd		Data processing	10	37(14.07)	Operation time
4 th	Use – Operation	Variation in the horizontal speed	9	36 (13.69)	Horizontal speed variation
5 th		Testing of different soil types	8	31(11.79)	Operating capacity
6 th	Commercialization	Low manufacturing cost	6	21(07.99)	Manufacturing cost
7 th	Design	Automatization	4	16(06.08)	Operating time
8 th	Use – Maintenance	Durability	4	16(06.08)	Useful life
9 th		Low operation cost	3	10(03.80)	Operating cost
10 th	Use – Operation	Simple operation	3	9(03.42)	Easy operation
11 th	Use – Adjustment	Simple adjustments	2	5(01.90)	No. of adjustments
12 th	Use – Maintenance	Simple maintenance	1	4(01.52)	Time of adjustment
13 th	Design	Compactness	1	1(00.38)	Compact
14 th	Commercialization	Low maintenance cost	1	0(00.00)	Maintenance interval

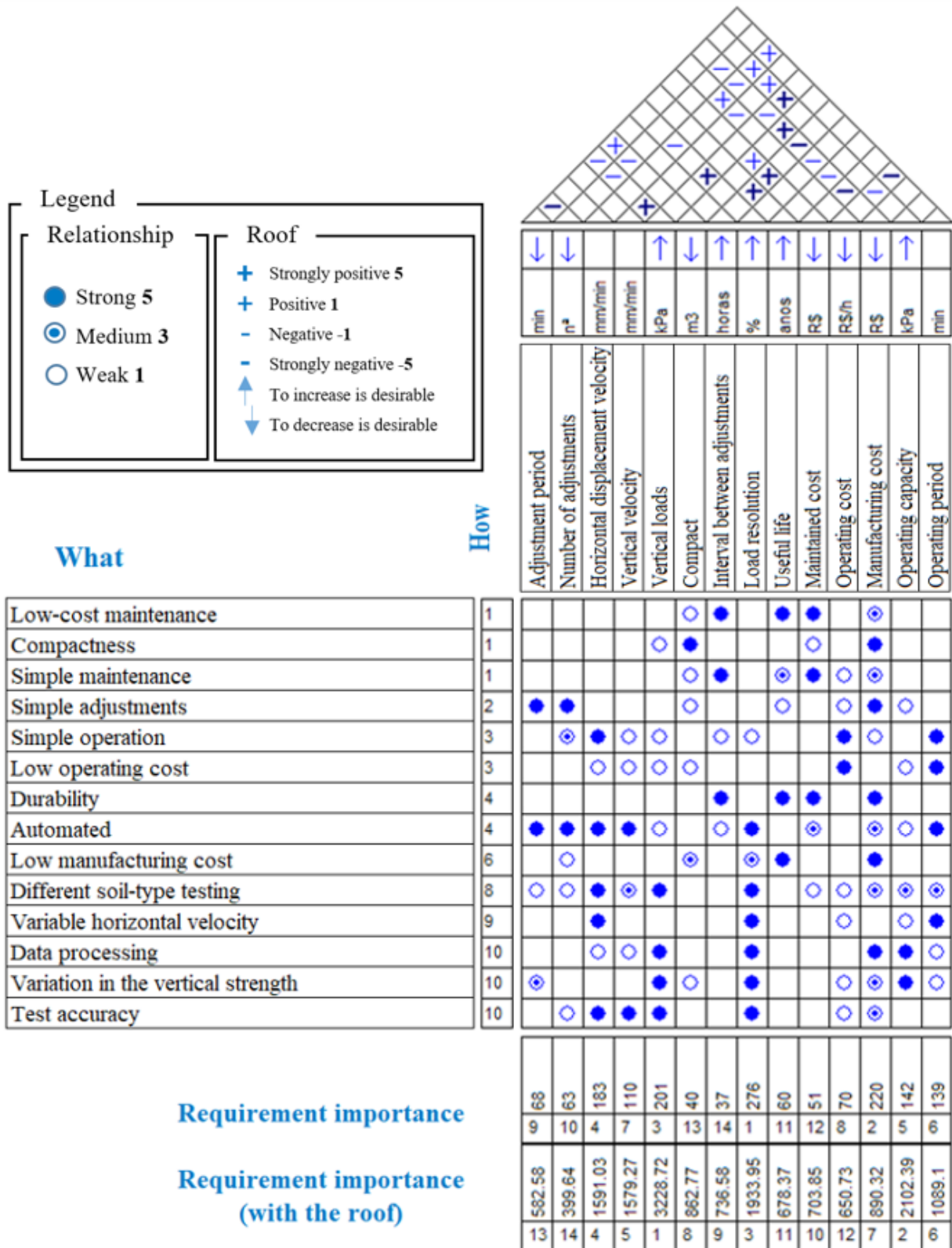


Figure 2. Quality Function Development referring to the development of equipment for analysis of direct shear and pre-compaction of the soil

Table 2. Design specifications of the Quality Function Development (Without the roof)

Order number	Requirement	Target value	Evaluation method	Undesirable aspects
Upper-third				
1 st	Load resolution	Every 1 second	Measured in bits	To have a longer interval that cannot be captured by the signal acquisition system.
2 nd	Manufacturing cost	≤ R\$ 15,000.00	Sum of the values spent with processes, design, labor and input	Impair performance, reducing functions, impairing systems and decreasing the quality of the materials used
3 rd	Vertical loads	≤ 1,000 kgf	Laboratory trial	Performance of non-static loads according to the project specification
4 th	Horizontal movement speed	From 1 +/- 0.2 mm.min ⁻¹	Timing during laboratory test	Temporal oscillations in the incompatible course of the control programmed in the system or outside the design range
5 th	Operational capacity	x ≤ 1,000 kgf y ≤ 1,000 kgf	Laboratory trial	The load application systems (vertical and horizontal) should have a capacity lower than that recommended in the project
Middle third				
6 th	Operation time	45 min	Timing during laboratory trial	Operating time (per sample) ≥ 1 hour
7 th	Vertical velocity	≤ 1min	Timing	Long period at application of the load on the sample
8 th	Operation cost	≤ 1.00 R\$.h ⁻¹	Sum of the generated values to produce a tested sample	Generation of a high cost, with an impact on the budget of academic papers
9 th	Adjustment time	15 min	Timing	Longer time to execute the needed adjustments for the pre-operating tracts
10 th	No. of adjustments	It has no. ≤10	Counting	High number of adjustments that will increase the time needed to for the safely execution of adjustments
Lower third				
11 th	Useful life	≥ 50 years	Prediction through specific rules and laboratory tests	Use of low resistance and poor-quality materials
12 th	Maintenance cost	≤ 200.00 R\$.year ⁻¹	Sum of the generated value according to the need of maintenance per annual operation cycle	It must have parts and components susceptible to breakage and rapid wear
13 th	Compact	≤ 1.00m ³	Measurement	Loss or reduction in the quality of the functions, necessity of changing further design
14 th	Maintenance intervals	6 months	Use of techniques and practices during the design to ensure the goal achievement	Appearance of corrective maintenance, rise in the manufacturing cost due to the use of better-quality material

The ranking of the design requirements was divided into three parts: (1) upper third - Most Important Requirements (2) medium third - Important Requirements (3) lower third - Less Important Requirements, followed as recommended by Fonseca (2000), which allowed to infer the undesirable aspects of the equipment, leading the design team to search for appropriate ways to evaluate each requirement, in view of the target value stipulated by the team.

However, in the following phases (preliminary and detailed design), the target values may be modified according to the verification of the design team, by meeting the requirements and adaptations pertinent to the demands that are found during the project deployment in order to meet the customers' needs.

CONCLUSIONS

- The methodology used in here allows to clearly define the customers' needs regarding the technical specifications for the development of a direct shearing and pre-compaction equipment with low manufacturing cost (\leq R \$ 15,000.00).
- The ranking of the requirements, according to their degree of importance, associated with the respective impact on the design is an important decision-support tool, as it supports the design team in the adoption of certain operating strategies, which in turn will have direct impacts on the final cost of the product. However, it is emphasized that this design defends the idea of disseminating low-cost technology aimed at Brazilian institutions of technical and higher education.

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REFERENCES

BACK, N.; OGLIARI, A.; DIAS, A.; SILVA, J. C. da. Projeto integrado de produtos: Planejamento, Concepção e Modelagem. São Paulo: Manole, 2010.

BARBOSA, M. C. R.; LIMA, H. M. de. Resistência ao cisalhamento de solos e taludes vegetados com capim vetiver. **Revista Brasileira de Ciência do Solo**, v. 37, n. 1, p. 113-120, 2013.

CONTO, S. M. de; ANTUNES Jr., J. A. V.; VACCARO, G. L. R. A inovação como fator de vantagem competitiva: estudo de uma cooperativa produtora de suco e vinho orgânicos. **Gestão & Produção**, São Carlos, v. 23, n. 2, p. 397-407, 2016.

COSTA, M. A. B.; TOLEDO, J. C. de. Analysis of predevelopment models and activities: a systematic bibliographic review. **Gestão & Produção**, São Carlos, v. 23, n. 4, p. 704-717, 2016.

CUSTÓDIO, T. V.; SPAGNOLO, R. T.; OLDONI, A.; REIS, A. V. dos; MACHADO, A. L. T. Functional structure of a bed shaper and fertilizer depositor for low power tractors. **Engenharia na Agricultura**, v. 26, n. 2, p. 133-139, 2018.

DAS, B. M. Fundamentos de Engenharia Geotécnica. 7.ed. São Paulo: Cengage Learning, 2014.

FONSECA, A. J. H. **Sistematização do processo de obtenção das especificações de projeto de produtos industriais e sua implementação computacional**. 198 f. Tese de Doutorado - Programa de Pós-Graduação em Engenharia Mecânica, Universidade Federal de Santa Catarina, Florianópolis, 2000.

GODWIN, R. J.; SPOOR, G. Soil failure with narrow tines. **Journal of Agricultural Engineering Research Silsoe**, v. 22, n. 3, p. 213-228, 1977.

HETTIARATCHI, D. R. P.; REECE, A. R. Symmetrical three-dimensional soil failure. **Journal of Terramech**. v. 4, n. 3, p. 45-67, 1967.

KNAPPETT, J. A.; CRAIG, R. F. Mecânica dos Solos. 8 ed. Rio de Janeiro: LTC, 2014.

McKYES, E.; ALI, O. S. The cutting of soil by narrow blades. **Journal Terramech**, v. 14, n. 2, p. 43-58, 1977.

NÚCLEO DE DESENVOLVIMENTO INTEGRADO DE PRODUTOS (NeDIP). **Software**. 2017. Disponível em: <http://www.nedip.ufsc.br/site/index.php?link=softwares>. Acesso em: 10 jan. 2017.

PERUMPRAL, J. V.; GRISSO, R. D.; DESAI, C. S. A soil-tool model based on limit equilibrium analysis. **Transactions of the ASAE, St. Joseph**, v. 26, n. 4, p. 991-995, 1983.

REECE, A. R. The fundamental equation of earthmoving mechanics. **Fundamental Equation of Earth-Moving Machinery Mechanics**, v. 179, n. 6, p. 16-22, 1964.

ROZENFELD, H.; FORCELLINI, F. A.; AMARAL, D. C.; TOLEDO, J. C.; SILVA S. L.; ALLIPRANDINI D. H.; SCALICE R. K. Gestão de Desenvolvimento de Produtos: uma referência para a melhoria do processo. São Paulo: Saraiva, 2006.

SANTO, A. C. do E.; REIS, A. V. dos; MACHADO, A. L. T.; BATISTA, V. J.; OLDONI, A. Desenvolvimento de um dispositivo para medição de esforços em hastes de semeadoras de plantio direto. **Engenharia Agrícola**, Jaboticabal, v. 30, n. 2, p. 288-298, 2010.

SAYÃO, A.; SIEIRA, A. C.; SANTOS, P. Reforço de solos: Manual Técnico. São Paulo: Maccaferri do Brasil Ltda, 2009.

SERPA, F. M.; MAGALHÃES, P. S. G. Estimativa de esforços em ferramentas estreitas para o preparo de solos. **Engenharia Agrícola**, Jaboticabal, v. 17, n. 1, p. 62-73, 1997.

SCHESTER, C. H.; SCHESTER, J. J.; OLIVEIRA, A. S. de. Aplicação do diagrama de Mudge e QFD utilizando como exemplo a hierarquização dos requisitos para um carro voador. **Gestão da Produção, Operações e Sistemas (GEPROS)**, v. 10, n. 1, p. 197-213, 2015.

SPAGNOLO, R. T. **Máquina para o controle de plantas espontâneas pela aplicação de calor**. 172 f. Tese de Doutorado - Programa de Pós-Graduação em Sistemas de Produção Agrícola Familiar, Universidade Federal de Pelotas, Pelotas, 2014.

SPAGNOLO, R. T.; OLDONI, A.; CUSTÓDIO, T. V.; REIS, A. V. dos; MACHADO, A. L. T. Conceptual design of a thermal weed control machine. **Ciência Rural**, v. 49, n. 3, e20180673, 2019.

STEFANELLO, G. MACHADO, A. L. T.; REIS, A. V. dos; MORAIS, C. S. de; OLDONI, A. Design requirements of a human-powered planter. **Ciência Rural**, v. 47, n. 6, e20160743, 2017.

VARGAS, M. Introdução à mecânica dos solos. São Paulo: McGraw-Hill, 1989.