CONSOLIDATION OF FACTORS INFLUENCING THE DESIGN OF AN ELECTRICALLY DRIVEN SEED METERING AND DELIVERY MECHANISM FOR HIGH-SPEED OPERATION.

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ABSTRACT

The development of innovative products to address agricultural challenges has become essential for more efficient operations, resulting in increased productivity. In this context, the parameters of Design Influence Factors (DIFs) define the technical and functional guidelines of the machinery, ensuring that the final product fully meets the demands defined throughout its life cycle. This study proposes the consolidation of DIFs applied to the development of an electrically driven seed metering and distribution mechanism for high-speed operations. This provides a foundation for collecting design requirements, ensuring traceability and reliability in technical decision-making. The scope of this work involves identifying these key factors and their respective units of measurement. The following factors were identified: regional maximum and minimum temperatures (°C), solar radiative heat reception (W/m²), rainfall occurrence during the planting season (mm/month), average relative humidity during the planting period (%), soil classification—sandy, medium, and clayey (%), soil vegetation cover index and type (%), proportion of water collected in the soil (%), soil micro-relief roughness measurement (cm), soil penetration resistance index (kPa), minimum turning radius during maneuvers (m), planting overlap in headland areas (m²), type of fine seed crops sown (kg), quantity of large seeds per linear meter (s/m), dynamic friction coefficient of the seed (μd), chemical, physical, and biological materials used as seed coating/treatment (ml), seed angle of repose (°), thousand-seed weight (g), seed uniformity (%), bulk density difference between hybrids (kg/m³), size difference between seeds of other varieties (mm), and shear strength/disaggregation (N). Additional factors include sphericity (%), surface roughness (μm), sieve size (mm), tractor power take-off (PTO) speed (RPM), tractor hydraulic flow (VCR) (l/min), and tractor battery specifications (V) / (A). As a practical example, the vegetation cover index and type (%) led the development team to create a metering and active seed delivery system solution featuring a cleated belt elevator design, helping to reduce the suction of impurities from no-till farming in Brazil. The identification of Design Influence Factors (DIFs) fills a gap in the academic literature regarding the development of electrically driven seed metering and delivery systems. Consequently, the industry can provide new precision machinery technologies under strategic global guidelines, as demonstrated and planned in this work.

Keywords: Informational Design, Factors Influencing Design (FIDs), Product Development Processo.

RESUMO

O desenvolvimento de produtos inovadores para enfrentar os desafios agrícolas tornou-se essencial para a otimização da eficiência operacional e o aumento da produtividade. Neste contexto, os parâmetros dos Fatores de Influência de Projeto (FIP´s) definem as diretrizes técnicas e funcionais do maquinário, assegurando que o produto final atenda plenamente às demandas estabelecidas ao longo de seu ciclo de vida. Este estudo propõe a consolidação dos FIP´s aplicados ao desenvolvimento de um mecanismo de dosagem e distribuição de sementes com acionamento elétrico para operações de alta velocidade. Esta abordagem fundamenta a coleta de requisitos de projeto, garantindo rastreabilidade e confiabilidade na tomada de decisão técnica. O escopo deste trabalho envolve a identificação desses fatores-chave e suas respectivas unidades de medida. Foram identificados os seguintes fatores: temperaturas regionais máximas e mínimas (°C), recepção de calor por radiação solar (W/m²), precipitação pluviométrica durante a época de semeadura (mm/mês), umidade relativa média no período (%), classificação do solo — arenoso, médio e argiloso (%), índice e tipo de cobertura vegetal do solo (%), proporção de água retida no solo (%), rugosidade do micro relevo do solo (cm), índice de resistência à penetração do solo (kPa), raio de giro mínimo em manobras (m), sobreposição de semeadura em áreas de cabeceira (m²), tipo de culturas de sementes finas (kg), quantidade de sementes grandes por metro linear (s/m), coeficiente de atrito dinâmico da semente (μd), materiais químicos, físicos e biológicos utilizados no tratamento/revestimento de sementes (ml), ângulo de repouso da semente (°), peso de mil sementes (g), uniformidade das sementes (%), diferença de densidade aparente entre híbridos (kg/m³), variação dimensional entre sementes de diferentes variedades (mm) e resistência ao cisalhamento/desagregação (N). Fatores adicionais incluem esfericidade (%), rugosidade superficial (μm), granulometria por peneiras (mm), velocidade da tomada de força (TDP) do trator (RPM), fluxo hidráulico do trator (VCR) (l/min) e especificações da bateria do trator (V) / (A). Como exemplo prático, o índice e o tipo de cobertura vegetal (%) orientaram a equipe de desenvolvimento na criação de uma solução de sistema de dosagem e entrega ativa de sementes com elevador de correia de talisca (cleated belt), auxiliando na redução da sucção de impurezas em sistemas de semeadura direta no Brasil. A identificação dos FIP´s preenche uma lacuna na literatura acadêmica sobre o desenvolvimento de sistemas de dosagem e entrega de sementes com acionamento elétrico. Consequentemente, a indústria pode prover novas tecnologias de máquinas de precisão sob diretrizes globais estratégicas, conforme demonstrado e planejado neste trabalho.

Palavras Chaves: Projeto Informacional, Fatores de Influência de Projeto, Processo de Desenvolvimento de Produto.

INTRODUCTION

Soybean (*Glycine max*) is one of the most prominent agricultural crops globally, playing a pivotal role in the Brazilian agricultural economy, where the country stands out as a global leader in both production and export (Colussi et al., 2023). Soybean yield success depends on a multifaceted set of factors, with the sowing stage being among the most critical. Planting efficiency—encompassing both precise seed placement in the soil and spatial distribution uniformity—is essential to ensure homogeneous seedling emergence, vigorous plant development, and, ultimately, the maximization of grain yield.

According to Schuch and Peske (2012), for a specific soybean cultivar to express its full genetic potential, several variables must be considered, with sowing being one of the most significant. Sowing operations must prioritize plantability, which refers to the precise distribution of plants with appropriate spacing per unit area. Inadequate seed distribution can directly compromise sowing quality and interfere with plant development, negatively impacting both overall productivity and the physiological quality of the harvested seeds (Asl; Roudbari; Esmailzadeh, 2019; Xue et al., 2019).

The efficacy of a precision seed meter is typically evaluated based on parameters such as seed longitudinal spacing, seedling emergence rate, distribution uniformity, and plant population density. However, operating at high speeds presents unique challenges, as it can compromise metering precision due to seed dynamics within the seed tube, the impact upon hitting the furrow, and the interaction with the soil surface (Bortoli et al., 2021). Furthermore, varying soil conditions—including texture, moisture content, and compaction—can significantly influence planting performance, necessitating specific adjustments to the seed meter configurations. The need to optimize seed spatial distribution to enhance crop yields is increasingly urgent. High-precision planting systems can not only improve input use efficiency (IUE) but also enable higher operational speeds and greater field capacity—critical factors when navigating the narrow planting windows imposed by climate variability.

New technologies for metering and active seed delivery are undergoing continuous research to enable high-speed sowing without compromising precision. For instance, Wei et al. (2022) engineered a seed delivery device featuring a rotating brush, a U-shaped grooved seed tube, and a flexible brush. Their test results demonstrated that the performance of the rotating brush delivery system significantly outperformed conventional seed tubes, particularly at forward speeds of 15 km/h and above.

Darr et al. (2020), in a five-year study on high-speed planting equipment for maize and soybean, evaluated a 12-row planter equipped with the Precision Planting SpeedTube system and a 24-row planter utilizing the John Deere ExactEmerge system. They concluded that both systems exhibited excellent singulation and spacing uniformity at speeds up to 16 km/h. Furthermore, Chen et al. (2024) developed a high-speed precision metering device incorporating gradient feeding (GF) and control seed (CS) mechanisms for soybean. This design was specifically engineered to improve the quality of feed index at high velocities, facilitating precision planting under high-speed operational conditions.

Olomitutu et al. (2024) evaluated the response of soybean to high-speed sowing in Mississippi, USA, comparing a ground-driven mechanical planter (John Deere 1700 equipped with eSet meters and airbag downforce) against a precision planting system (John Deere toolbar with MaxEmerge 2 row units retrofitted with Ag Leader SureSpeed and SureForce hydraulic downforce) across varying sowing velocities. The authors concluded that increasing speed generally increased plant-to-plant spacing and in-row spacing variability while reducing the final plant population. However, the increased sowing speed did not affect soybean yield. Notably, in 2023, the precision planter operating at 17.7 km/h demonstrated a performance level equivalent to the mechanical planter operating at 9.7 km/h in 2023.

Consequently, Design Influence Factors (DIFs) constitute an essential approach to ensuring that emerging technologies fulfill both technological requirements and customer needs. Defined during the informational design phase, these drivers establish guidelines that govern everything from technical specifications to machine functions. This ensures that the final product introduced to the market responds effectively and efficiently to the demands of precision and sustainable agriculture (Romano, 2003; Marini, 2007).

In this context, this article aims to consolidate the Design Influence Factors (DIFs) within the scope of developing an electrically driven seed metering and delivery mechanism for high-speed operations, specifically tailored for no-till system conditions. By establishing these drivers, this study supports the definition of design specifications, ensuring that decisions made throughout the development process are traceable and reliable. Ultimately, this approach ensures that the resulting technology fulfills the functional requirements of the end-users.

MATERIALS AND METHODS

This study is based on the methodology proposed by Marini (2007) regarding the definition of Design Influence Factors (DIFs), aiming to identify the essential information for the categories within the project scope.

The formulation of these drivers—grounded in the consideration of various environmental elements influencing the product life cycle—was conducted by analyzing the Life Cycle Management (LCM) stages, specifically focusing on the use and maintenance of the technology, following the frameworks established by Marini (2007) and Menegatti (2003).

Initially, the definition of Design Drivers for Agricultural Machinery was integrated into the Reference Model for the Agricultural Machinery Development Process (MR-PDMA) by Romano (2003). These drivers consist of analytical elements responsible for creating a robust foundation for actions and decision-making during the design phase of the PDP. Consequently, they serve as a primary source for decisions that directly impact the technology developed throughout the engineering project (Marini, 2007).

The scope of this work is limited to the identification of these Design Drivers and their respective units of measurement to provide guidance for the Research & Development (R&D) team.

RESULTS AND DISCUSSION

The definition of the Design Influence Factors (DIFs) associated with the project scope involves variables linked to no-till systems. Precision sowing is essential for distributing large seeds, such as soybean, maize, and common beans, at regular intervals with adequate inter-row spacing, even at operational speeds of up to 16km/h.

In view of the scenario for developing an electrically driven seed metering and delivery mechanism for high-speed operations, the following factors related to the operation and maintenance phases were identified and consolidated:

1. Operating Environment

The operating environment imposes diverse conditions that vary by region and directly influence the performance of seed metering, delivery, and furrow deposition. The environmental Design Influence Factors are presented in Table 1.

Table 1. Design Influence Factors related to the operating environment.

DESIGN INFLUENCE FACTORS	DESCRIPTION	UNIT
CLIMATE: TEMPERATURE	Maximum and minimum regional temperatures	°C
CLIMATE: SOLAR RADIATION	Reception of radiative heat from the sun	W/m²
CLIMATE: PRECIPITATION	Presence of rainfall during the planting operation	mm/month
CLIMATE: HUMIDITY	Average relative humidity during the planting period	%

Source: Prepared by the author.

In this initial set of influence factors, geographical characteristics are addressed that can directly interfere with the performance of the belt-type seed delivery meter during planting, thereby affecting plantability.

According to Marini (2007), the temperature range and relative air humidity determine the amount of water vapor suspended in the atmosphere. This can lead to condensation on the equipment's surfaces—small water droplets known as dew. In the case of seed meters, these droplets must not come into contact with the seeds to prevent premature imbibition before the optimal moment. Furthermore, identifying temperature ranges is crucial for selecting materials with the structural robustness to operate in regions ranging from -5°C to 50°C.

Additionally, the solar radiation rate directly affects the equipment's structure. Thermal cycles of heating and cooling, combined with surface condensation and chemical elements present during planting, render the operating environment highly corrosive.

1.1. Soil Characteristics

The characteristics of different soil types exert a direct influence on the performance of pneumatic seed meters. The Design Influence Factors associated with soil characteristics are presented in Table 1.1.

Table 1.1. Design Influence Factors related to soil conditions during planting.

DESIGN INFLUENCE FACTORS	DESCRIPTION	UNIT
SOIL TYPE	Classified as Sandy, Medium, or Clayey	%
CROP RESIDUE	Index and type of soil surface cover	%
SOIL MOISTURE	Proportion of water stored in the soil	%
ROUGHNESS	Measure of soil micro-relief roughness	cm
CONE INDEX	Soil resistance to penetration index	kPa

Source: Prepared by the author.

Soil properties can interfere with the performance of belt-assisted pneumatic meters in several ways, primarily as a function of soil texture and crop residue (commonly known as "straw") remaining from the previous harvest. In pneumatic metering mechanisms—which utilize rubber chambers to generate an internal vacuum working alongside seed discs to capture and singulate each seed—sandy soils pose a specific challenge. These soils heat up more rapidly and contain coarse particles (ranging from 0.05 to 2 mm) that cause premature wear on rubber, nylon, fiberglass, and plastic components through friction, a process known as abrasive wear.

Similarly, the type of soil cover (residue from the previous crop) can negatively affect the seed delivery belt. Since the belt operates at an average height of 3 cm above the soil to ensure optimal seed deposition into the furrow, it may suction impurities, such as cotton lint remaining post-harvest. Furthermore, clayey soils with higher moisture retention can lead to the ingress of small soil clods into the belt system, compromising the entire internal assembly.

Soil roughness, or micro-relief, represents the presence of significant irregularities in the planting area. The Cone Index (measured using instruments and criteria established by the ASAE S313.1 standard) quantifies the soil's resistance to penetration—specifically, its ability to withstand surface pressure without deforming (Marini, 2007). Consequently, these two factors directly impact seed distribution; higher soil irregularity and resistance increase the vibration (chatter) of the row unit where the meter is mounted, causing the entire assembly to oscillate.

1.2. Operating Site

The geometry of the operating site, commonly referred to as the field plot, as well as the crop establishment strategy, exert a significant influence on the implementation and performance of the planting operation. The pertinent Design Influence Factors are shown in Table 1.2.

Table 1.2. Design Influence Factors related to the field plot.

DESIGN INFLUENCE FACTORS	DESCRIPTION	UNIT
CURVE RADIUS	Minimum curve radius during planting passes	m
HEADLAND AREA	Planting overlap in headland zones	m²

Source: Prepared by the author.

Depending on the planting area—particularly when following AB curved paths via autosteer systems—the radius of the curve along the seeder's trajectory directly influences the seeding rate per meter. Smaller curve radii tend to increase seed density (seeds per meter), which hinders crop development due to intraspecific competition for nutrients. Conversely, larger radii tend to result in seed deficits per meter because the travel distance increases while the metering rotation remains constant. To mitigate these effects, advanced seed meter concepts utilize electric motors controlled by GNSS signals to provide curve compensation.

In headland areas, especially in rugged terrains or smaller plots requiring frequent maneuvers and complex field boundaries, automated planting often results in overlap. This doubles the seed density, leading to plant competition where increased density reduces overall productivity and inflates costs through the inefficient use of seeds.

1.3. Crop to be Sown

One of the most critical characteristics to be considered in the design of a belt-assisted pneumatic seed meter is the target crop. It is essential to identify the product's regional positioning and correlate it with the specific crops to be sown to understand the seeding rates and plant populations required. The related Design Influence Factors are presented in Table 1.3.

Table 1.3. Design Influence Factors related to target crops.

DESIGN INFLUENCE FACTORS	DESCRIPTION	UNIT
CROP	Type of crop the meter is designed to sow	kg
SEEDING DENSITY	Number of seeds per linear meter	s/m

Source: Prepared by the author.

These two factors—crop type and density—provide the guidelines for dimensioning the technology's components to ensure high performance. This includes the selection of metering disc kits, the geometry of seed agitators, singulators, and the specific model of the seed delivery belt, given that seed physical characteristics vary significantly according to the crop type.

1.3. The Seeds

Due to the vast diversity of seeds available on the market, physiological quality and morphology are critical to achieving optimal meter performance. The geometric, physical, and chemical properties of the seeds used in the metering systems play a fundamental role in the singulation results provided by the equipment. The Design Influence Factors Drivers related to seeds are presented in Table 1.4.

Table 1.4. Design Influence Factors related to seed characteristics.

DESIGN INFLUENCE FACTORS	DESCRIPTION	UNIT
DYNAMIC FRICTION COEFFICIENT	Measure of one or both surfaces in relative motion and contact	μ_d
SEED COATING	Incorporation of materials (fungicides, micronutrients, insecticides, phytohormones, polymers, and graphite) to enhance performance	ml
ANGLE OF REPOSE	The steepest angle of a granular material heap relative to the horizontal plane	°
THOUSAND-GRAIN WEIGHT (TGW)	Mass of one thousand seeds	g
UNIFORMITY	Coefficient of variation (CV) between grain sizes	%
WEIGHT SEGREGATION	Difference between densities of different hybrids	kg/m^3
SIZE SEGREGATION	Difference between seed sizes of different varieties	Mm
MECHANICAL DISAGGREGATION	Impact force at which the seed may disintegrate	N
SPHERICITY	Measure of the seeds' length, width, and thickness ratios	Ø
SURFACE ROUGHNESS	Measure of standard repeated irregularities on the seed surface	µm
SIEVE (SCREEN SIZE)	Diameter-based separation of seed lots	Mm

Source: Prepared by the author.

The flowability of seeds within the meters and delivery hoses—which may occur via gravity or positive pressure depending on the planter model—depends on the internal friction coefficient of the granular material and its friction against the reservoir walls. According to Mantovani (1999), the friction coefficient of granular material is equal to the tangent of the internal friction angle for that specific material.

Seed coating with chemical products is a widespread practice; approximately 60% of the seed market utilizes Industrial Seed Treatment (IST), while field-applied treatments are known as "on-farm" treatment. This factor, along with sphericity, surface roughness, and moisture content, can increase the angle of repose, potentially degrading meter performance due to restricted seed movement—the higher the angle of repose, the lower the product flowability. To mitigate this, powdered graphite is applied in the field at doses of 3 to 5 grams per kilogram of seeds to enhance flowability and reduce the angle of repose. Mantovani (1999) evaluated seed meter performance across various treatments and graphite applications, observing that graphite functions effectively as a lubricant, significantly decreasing the angle of repose for all evaluated maize sieve sizes.

In pneumatic seed meters, the Thousand-Grain Weight (TGW) and seed uniformity are paramount for determining the required vacuum pressure, which is calibrated based on seed sphericity and mass. Non-uniform seeds with high TGW tend to require higher vacuum levels for precise metering, whereas smaller, more spherical seeds require lower pressure. Spherical seeds offer advantages in pneumatic systems, providing better cell fill in vertical discs, superior adherence to the vacuum system, and a lower percentage of multiples and skips. When high sphericity is combined with lower seed mass, deposition quality tends to improve; however, research indicates lower vigor in small, rounded seeds (Schmidt, 2019).

According to Pereira et al. (2021), assessing the influence of maize biometric characteristics (Round, Medium, and Oblong) on plantability, the best results were obtained with rounded hybrids. These showed a higher capacity for filling the circular cells of the metering mechanism, resulting in superior deposition quality with fewer skips and multiples. Regarding potential mechanical disaggregation, metering disc systems must be designed to minimize seed impact; disaggregated seeds lose germinative capacity and fail to establish in the field.

Furthermore, the quality of sieve-based size classification is a critical factor, widely used by farmers when selecting planting discs. Standardization within a seed lot is vital; lack of uniformity compromises the calibration of pneumatic meters. Smaller seeds may take longer to release from the disc cell, resulting in lower acceleration relative to the ground, while larger, heavier seeds accelerate faster. These discrepancies can lead to simultaneous skips and multiples within the

metering disc when using gravity-drop seed tubes.
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1.4. Power Source

For the operation of the belt-assisted pneumatic seed meter, the design must also account for the required power source and energy demand during the sowing process. Table 1.5 presents the Design Influence Factors related to the power source.

Table 1.5. Design Influence Factors related to the power source.

DESIGN DRIVER	DESCRIPTION	UNIT
PTO SPEED	Rotational speed at which the tractor transfers power to the equipment	rpm
HYDRAULIC FLOW (SCV)	Sustained oil flow from the tractor's selective control valves to the equipment	L/min
TRACTOR BATTERY	Energy supplied directly from the tractor’s battery to the equipment	V

Fonte: Source: Prepared by the author.

The most current power sources available on tractors originate from the Power Take-Off (PTO) located at the rear of the vehicle. The PTO serves as an element for transferring power via rotation to agricultural machinery and implements, whether hitched or trailed—such as a grain seeder. Generally, tractors operate at standard speeds of 540 and 1,000 rpm; these speeds are critical, as higher rotations determine a greater transfer of power to the implement.

Hydraulic flow, provided through the Selective Control Valves (SCVs) at the rear of the tractor, is another method of power transfer. However, with the increasing number of auxiliary systems installed on modern seeders, the availability of free SCVs on tractors is becoming increasingly scarce.

Lastly, energy may be drawn directly from the tractor’s battery in cases where the systems do not require high amperage or voltage, as this source has limited supply capacity. Regarding belt-assisted pneumatic metering technology, the use of SCVs or the PTO is fully sufficient to meet the power demands of the entire electronic system.

CONCLUSION

Throughout the identification of the Design Drivers (DDs), 24 direct factors were established that influence both the development process and the quality of the final product.

These factors enabled the strategic development of specific project components dedicated to sowing conditions at speeds of up to 16 km/h. Notably, the index and type of crop residue (%) guided the development team in creating a dosing and active seed delivery system featuring a cleated belt elevator. This solution helps reduce the suction of impurities in Brazilian no-till systems, resulting in a strategic technology capable of competing on a global scale.

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