Influencing factors in agricultural machinery design

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Abstract: The competitive demands of the agricultural sector create a push for increasing complexity regarding customer needs for agricultural machinery. Therefore, systematic and structured approaches become essential to supporting the development of innovative and effective products. This paper aims to lay out an information framework towards the understanding of influencing factors within the design specification. The methodology for this paper comprises: i) review of contributions on engineering design knowledge and agricultural machinery design; ii) development of the framework supported by a structured representation structure; and iii) use of implementation examples in displaying the technique. The following conclusions were attained: the influencing factors comprise relevant characteristics of product lifecycle environments after the production stage; the information model for the influencing factors is built on classes and attributes which allows selective deployment after project needs; and, the influencing factors constitute relevant information on the environments the machine is to be designed for, therefore playing a significant role in the definition of the design specification.

Keywords: influencing factors, machinery design, design specification.

1. Introduction

Agricultural activities have permanently evolved with regard to planning and execution, allowing for capacity increases in production through sensible management. Though such developments influence field productivity, current results can be improved if focus is placed on improving operative instruments. Operational complexity in the crop field has created new demands for information in the agricultural sector (MIALHE, 1996). That will certainly require agricultural machines to bring improved performance and capabilities; those perceived as more robust, reliable and safe will determine future development trends.

To reduce development costs and increase chances of market success on product development, there is need to understand customer needs and operational characteristics. For such reason, the industry needs to take hold of engineering knowledge in order to drive innovation and profit. However, a significant portion of the agricultural machinery industry is caught in need of capacity to channel available knowledge into innovative designs that better meet customer demands. In order to create such capacity, the use of systematic and structured design approaches would enable the industry to integrate engineering knowledge in developing new solutions; that would allow companies to improve their competitiveness by supporting them to bring out better products.

2. Motivation and aims

We understand there is need for sharpening the awareness to the influence of characteristics whose control is out of reach for engineers. Focusing on the agricultural machinery sector, those characteristics do not only interfere with product performance, but determine the ability of the product to meet customer demands.

In response to that challenge, we look to improve the understanding on influencing factors in design and their role in consolidating the design specification. To serve that objective, this paper shall accomplish the following aims:

- presenting a classification of the influencing factors on agricultural machine design;
- modeling the process by which information is gathered and assembled; and
- formalizing the influencing factors as subset model of the design specification.

3. Research approach

Being the aim of this research to provide an operating framework supporting the definition of influencing factors in design, the approach used applied both modeling and implementation steps towards this goal. Considering those objectives, three approaches were used in this work.

For the modeling part, two approaches were employed: (a) Exploration research: considering the problem of consolidating what role the influencing factors in design play in the development process, a state-of-the-art review was carried out to support the constitution of fundamentals; and (b) Descriptive research: starting over with the gathered knowledge, the influencing factors in design were characterized and modeled through the definition of the component elements and their inter-relations.

As the theoretical framework was made ready, its implementation was the logical step to follow. The model was implemented under a partnership with an agricultural machine manufacturer in which a real machine design was used as a template for diagnosing the results from using the model. The approach employed in this step is: (c) Case study: involves applying the new model with a case unit, in order to evaluate the potential contribution yielded to better practice by its usage in the design process.

4. Background

Influencing factors in design have been first stated in the field of agricultural machinery, within an operational point of view, as the set of parameters that influence up to its performance (CHRISTIANSON; ROHRBACH, 1986). However, that definition needed a statement better specifying its scope, because its original scope overlaps with the broad definition of design specification (ULRICH; EPPINGER, 1995; PAHL; BEITZ, 1996; FONSECA, 2000). Still within that broad scope, the influencing factors in design have been characterized as taking form of measurements (ROMANO, 2003).

That interpretation meets a quality and certification point-of-view (MIALHE, 1996), by stating they constitute relevant information for decision-making by the agricultural machine lifecycle stakeholders. The sentence 'influencing factors in design' means those factors constitute product lifecycle properties that induce specific design considerations in the development of the solution. Furthermore, in opposition of the own product design characteristics that constitute the design specification (ULRICH; EPPINGER, 1995), it shall focus on the product lifecycle properties that project members do not have means to control. Therefore, the influencing factors in design, if adequately stated in measurable way as similar to product design specification statements, may constitute a partial set of the design specification.

4.1. Fundamentals

The operation environment (MIALHE, 1996) consists on the interaction between the so-called production characteristics and the operational characteristics of an agricultural machine; that characterization applies to the location where the machine works its intended function.

Product characteristics correspond to constructive and physical characteristics and properties of the product, broadly defined within the design specification: in a direct drill seeder, for instance, the seed and fertilizer hopper capacities, total width, number of rows and row spacing, among others, constitute product characteristics; operational characteristics correspond to physical, static or dynamic properties of other elements from the product lifecycle environment, specifically related to the use phase: in the same example, working speed, seed spacing, fertilizer dosing, furrow width, among others, influence on the expected operational performance.

The operation environment comprises how the machines perform in the field. These characteristics interact with the operation environment in two sections: operations management and technical issues (MIALHE, 1996). That environment can be understood as a set of elements that mediate those two sets of characteristics while the machine is in use, as shown in the Figure 1.

The first one comprises criteria to following and evaluating the product performance in use: in direct drill seeding, seeding operation characteristics like crop variety, crop season, useful seeding time, working hours and equipment adjustments make up for managing and evaluating the seeder performance. The second involves the physical elements taking part on the operation, whose basic properties can only be controlled from the physical transformation that meets the machine purpose: in the seeder again, certification standards, field relief, soil properties and field environment play significant role in determining functional product performance. Those sections (MIALHE, 1996) guide the gathering of useful information to establishing the design specification. However, they cannot be controlled by operators in the field, much less by engineers involved in developing the agricultural machine. Because of that, they have to be fully understood, and designed for, so that development efforts yield successful products.

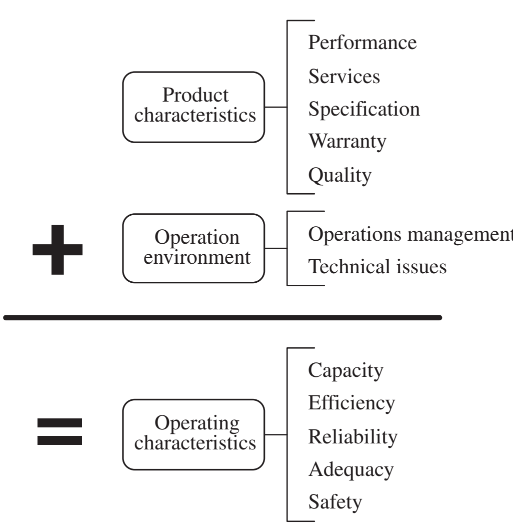

Figure 1. Definition of operating characteristics (MIALHE, 1996).

The deliverables yielded by the designing macrophase (ROMANO et al., 2005) within the joint product/project lifecycle consist in information defining how the agricultural machine should be manufactured and produced. Among the definitions from the designing macrophase, the necessary materials, their transformation processes, finishing, dimensions and assembly are defined for making the prototype and further adjustments towards market delivery. In the seeder example, its hoppers could be made from polyethylene or stainless steel: polyethylene would determine the usage of roto- or injection-blow-molding; sheet metal and bending would better apply to stainless steel. Other hopper characteristics determined are: the number of and distance between support points, the joints employed (nuts and bolts, dovetails or assembly fits), physical dimensions and useful volume for seed and/or fertilizer storage.

Because such characteristics have significant relationship with the operational performance because of the operation environment, that has a significant relationship with the developed design specification, in two matters: the definition of 'must have' requirements linked to the needs of the product lifecycle stakeholders: in the seeder example, the most significant ones are number of rows, row spacing, hopper capacity, furrow width, seed spacing and distribution; and, the establishment of information on the product lifecycle environments, especially after manufacturing and delivery: for the seed drill, significant characteristics in this scope are terrain relief, soil type, and crop system (dry crop, flooded crop or cattle/crop integration, for instance), among others.

Considering all those elements, Figure 2 shows the influencing factors as resulting from the interaction between operation environment and product lifecycle.

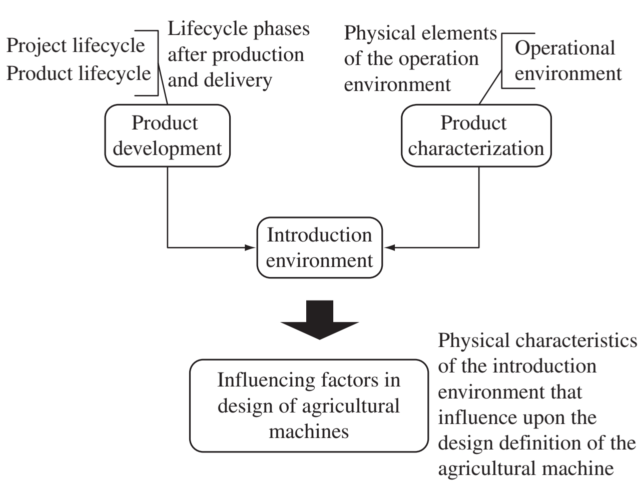

Figure 2. Influencing factors as interaction between development and characterization (MARINI, 2007).

Product development matters join up with product characterization issues in the introduction environment. It is constituted of the product lifecycle environments the machine shall be designed for, and take place within the usage phase. However, it may include different matters in order to enable commercialization in other markets.

A seed drill manufacturer wants, for instance, to export its machine to other markets. The total width of the machine is significantly wider than the available width as regulated in the export market. In order to enable the machine to be used there, the manufacturer may consider a machine design allowing a narrow configuration. That is an example on how influencing factors determine requirements the design shall meet, therefore playing a significant part the design specification.

4.2. State-of-the-art review

The state-of-the-art review involved two broad knowledge areas: design of mechanical systems, and agricultural machines and mechanization. While the first area is related to engineering design and product development knowledge, the second area characterizes machinery and operations within the agricultural engineering knowledge scope.

Within design of mechanical systems, design specification (ULRICH; EPPINGER, 1995; PAHL; BEITZ, 1996), and technical systems (HUBKA; EDER, 1992; PAHL; BEITZ, 1996) were considered as top-level topics to guide the exploration research. Those topics were examined using two knowledge sections as criteria: design metrics comprise the definition of design specification information as translating the needs of stakeholders on product lifecycle phases to specification and configuration properties of a developing system (FONSECA; 2000); and, information modeling involves the structuring and systematization on gathering and processing information within an enterprise modeling approach (BERIO; VERNADAT, 1999). Those contributions supported defining a representation structure derived from the reference model for the agricultural machinery development process (RM-AMDP) (ROMANO et al., 2005).

It opens up product development knowledge to integrate with operation, field and machine characterization as from agricultural engineering knowledge, as shown in the Figure 3.

Considering specific agricultural engineering knowledge on machines and mechanization for agriculture, two top level topics were used as guidance: agricultural mechanics (MIALHE, 1996) characterizing basic structures and field performance; and, specific operations management for agriculture (MIALHE, 1974).

Two knowledge sections were used as criteria: machines and performance, following research on field performance testing of machinery, their description based upon brief

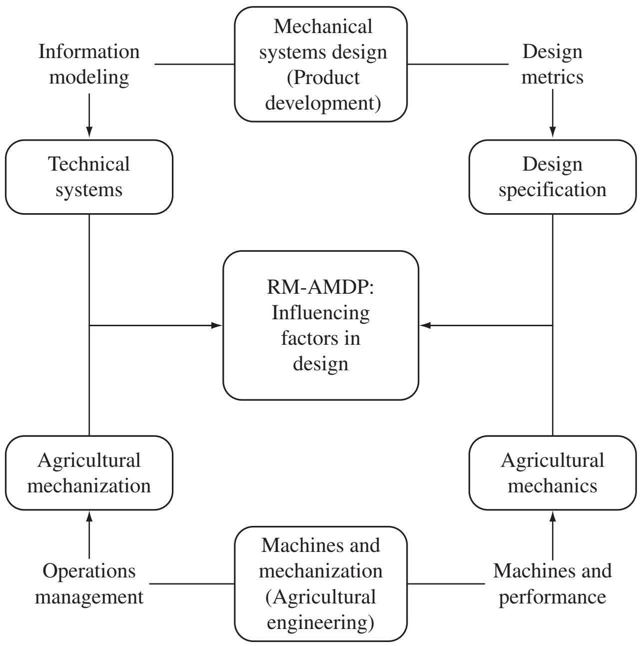

Figure 3. Knowledge areas supporting the fundamentals of influencing factors in design.

characterization of structures and components, and their influence on improving crop results (…); with regard to operations management, a review was made on factors to determine operational efficiency and crop yield, looking to follow best practice on mechanized operations to improve management of the crop growth process.

In addition to that, a third area explored comprised research works applying engineering design knowledge to developing innovative agricultural machinery, such as the precision seed meter (REIS, 2003) and a precision-agriculture prepared line-feed fertilizer distributor (MENEGATTI, 2004). Those works evidenced the application of engineering design knowledge to develop new technical solutions in agricultural machinery, and could be evolved by augmentation of current tools. An example is the introduction of a safety focus on current engineering design tools, relating engineering design knowledge to performance and safety regulations (ALONÇO, 2004).

4.3. Information representation structure

Considering the process to gather information on influencing factors in design, an information model definition should serve the purpose of making the process explicit, i.e., one should know how it is done from observing a given representation. A graphic representation structure has been proposed in supporting that goal (ROMANO et al., 2005). The process modeling for the influencing factors in design does employ a fundamental structure based upon considerations from the IDEF0 functional model (NIST, 1993) to representing processes. The representation structure for the RM-AMDP is implemented within a spreadsheet model with a unified visual layout of all information sets, to be read as shown in Table 1.

In reading the spreadsheet format, the following information stands out in each column: inputs comprise information that results from a concluded process, formerly executed; activities describe the current process in terms of project breakdown structure; tasks describe the project function to be carried out within current activities; domains describe the corporate knowledge competences required to carry out the task; mechanisms suggest tools, approaches or methods that can be used to gather and build up the intended information; controls suggest approaches, methods or documents used to validate the achieved information towards achieving activity goals; and, outputs describe the resulting consolidated information to be used on further tasks to proceed with the development project (ROMANO et al., 2005).

5. Definition of influencing factors

The consolidated model for defining the influencing factors in design has four core sections and two satellite sections. The core sections are those where the influencing factors are directly gathered and processed to support the design process; satellite sections are those that should be referenced while working the influencing factors or should directly reference the influencing factors in following the design process.

This paper focuses on the core sections of the information model for the influencing factors: the development scope section, the operation characteristics section, the certification requirements section and the current machines section. Table 2 shows the information sections and their original references in the RM-AMDP (ROMANO, 2003). The process of gathering information to define design guidelines to developing the agricultural machine shall include establishing the influencing factors (MARINI et al., 2006). They can be divided in four main information sections. That division is made in following each main unit to determine the origin of influencing factors: development scope, certification requirements, operation characteristics, and current machines in the target market (MARINI, 2007). These classes have been derived from aligning the RM-AMDP proposition with existing knowledge on both areas covered by the state-of-the-art review, as shown in the Figure 3.

5.1. Information sections and the product lifecycle

Each of these sections is related to both product and project lifecycles, as their information applies to both contexts. For that reason, they can be characterized on how broad and useful they apply to gathering the influencing

Phase 3 - Conceptual design						
Inputs	**Activities**	**Tasks**	**Domains**	**Mechanisms**	**Controls**	**Outputs**
Phase exit approval form	To communicate the start of conceptual design phase	To communicate the design specifications approval to the product development te	PM	E-mail	Communications management plan	Communication of design specifications approval
		To call the product development te for 1st conceptual design phase meeting with the purpose of presenting the project plan	PM	E-mail	Product development te member list	Call for 1st meeting
Project plan	To update budget needs		PM, AF	Cash flow S chart	Development budget	Cost estimates
Call for 1st meeting Design specifications Updated project plan Project Documentation System	To undertake te orientation and present the updated project plan	To present the updated project activities list	PM, All	Product development te meeting	Project activities list	Presented project plan
		To present the new product development te members	PM		Product development te member list	
		To present the updated development schedule	PM, All		Project development schedule	
		To clarify doubts, fine-tune project details and to close the meeting	PM, All		Project plan	
Project plan Cost estimates	To execute project plan activities	To provide resources for project plan execution	PM		Development budget	Physical and financial resources
Marketing planning	To monitor market variations which may influence the design concept development	To monitor market needs	MK	Market survey	Product, market and technology strategies	Marketing planning
		To update the marketing plan	MK	Marketing planning	Product, market and technology strategies	
		To enclose the marketing plan with the project documantation system	PM	Project documentation system	Quality management plan Communications management plan	
Client/user requirements Design requirements Influencing factors	To establish the functional structure	To define the overall (purpose) function	PD	Oriented abstraction	Design-influencing factors	Overall function
		To establish (deploy) subfunctions and alternate functional structures	PD	Functional structure deployment directives	Design requirements	Alternate functional structures
		To define third-party developed subfunctions	PD, SU	Expert judgment	Core competences	Third-party developed subfunctions
		To identify, select and involve third-parties for the development of subfunction solution principles	PD, SU	Expert judgment invitation for bid, request for quotation, request for proposal, invitation for negotiation and contractor initial response	Third-party involvement strategy	Involved thirdparties
		To analyze and select the suitable functional structure	PD	Decision matrix for selection	Design requirements	Functional structure
		To enclose the activity informations to the project documentation system	PM	Project documentation system	Quality management plan Communications management plan	Involved thirdparties Functional structure

Table 1. Functional elements from RM-AMDP representation structure (ROMANO et al., 2004).

Influencing factors in design – RM-AMDP						
Input	Activity	Task	Domain	Mechanism	Control	Output
Development scope declaration; Work breakdown structure (WBS); 1st competitive benchmarking on current machines	To define the influencing factors in the design of the agricultural machine	Analyze the development scope declaration and the work breakdown structure 1	PD	Expert judgment	Marketing planning	Influencing factors in the design of the agricultural machine
		Analyze the 1st competitive benchmarking on current machines 2	PD	Benchmarking	Market restrictions	
		Consider necessary regulatory requirements to enable production and commercialization 3	MK, PD, QU, AF	Expert judgment	Law and standards	
		Define experimental and/or inspection procedures needed for certifying conformity to required regulations	PD, QU, DP		Certification standards	
		Identify required items to certifying and homologating the machine	PD, QU, DP		Government laws to homologation	
		Identify safety standards related to the developing design	SY, QU		Safety law and standards	
		Gather information on agricultural operation (mechanical and agronomic parameters) 4	MK, PD, DP	Experiments (simulation, lab, field tests) Studies (evaluations, case studies, field tests) Records (operation controls, maintenance, warranty history)	Work breakdown structure (WBS)	
		Add the influencing factors in design to the project documentation system	PM	Project documentation system	Quality management plan Communication management plan	

Table 2. Influencing factors in design: original RM-AMDP prescription (ROMANO et al., 2004).

factors in design on through the agricultural machine lifecycle. Figure 4 characterizes how the influencing factors in design apply to both product and project lifecycles in the development of agricultural machinery.

The development scope analysis has global influence in the agricultural machine development because its information determines the essential characteristics of the machine. That comprises defining the purpose of the machine as well as its main working features: a fertilizer spreader, besides of just spreading plant nutrition, may have to provide even metering independent of speed, allow different fertilizers to be used, enable distribution at different field relieves, and so on. In order to achieve such attributes, different working principles shall be designed to carry out the required functions. Because of that, they also define the direction to be taken in gathering information on the other categories.

The analysis of operation characteristics comprises looking at physical field characteristics that determine working parameters for the operation the machine is to perform. That requires analyzing the field and its main characteristics: significant issues for the fertilizer spreader are field relief, crop growth stage, row spacing, field area, climate and others. Functionality and adjustments shall be provided in the machine so that it will cope with the field environment while achieving its performance requirements.

The analysis of current machines comprises gathering the existing knowledge on theory and current solutions for meeting the design scope initially defined. A design benchmarking study is made on machines with similar purpose, looking to compare construction parameters to bring significant contribution to knowing what and how to design. On feedstock distributors, for instance, other machines are compared so that to figure out the options available to the customer in the market, how they perform and what costs they require. The certification requirements category involves the lookup and processing of information on criteria from client markets whose satisfaction provides clearance so that the manufacturer can sell the machine. An example for this is the set of certification requirements set by the European Commission in order to award a machine the CE mark, therefore authorizing its commercialization in markets within the European Union.

6. Modeling the data

The modeling approach used to define the influencing factors in design on their components and inter-relations took the following objectives into account: a) to make explicit the lifecycle elements to be characterized and the relevant information types that make part of the model; and b) to provide guidance on the procedures to be carried out, from the definition of information requirements for their processing. Figure 5 shows the basic hierarchy of information within the proposed model for influencing factors in design.

The representation structure of the RM-AMDP has been used as main template to support the data modeling process. Each section, following the content from Table 2, constitutes a basic set of information, which is deployed

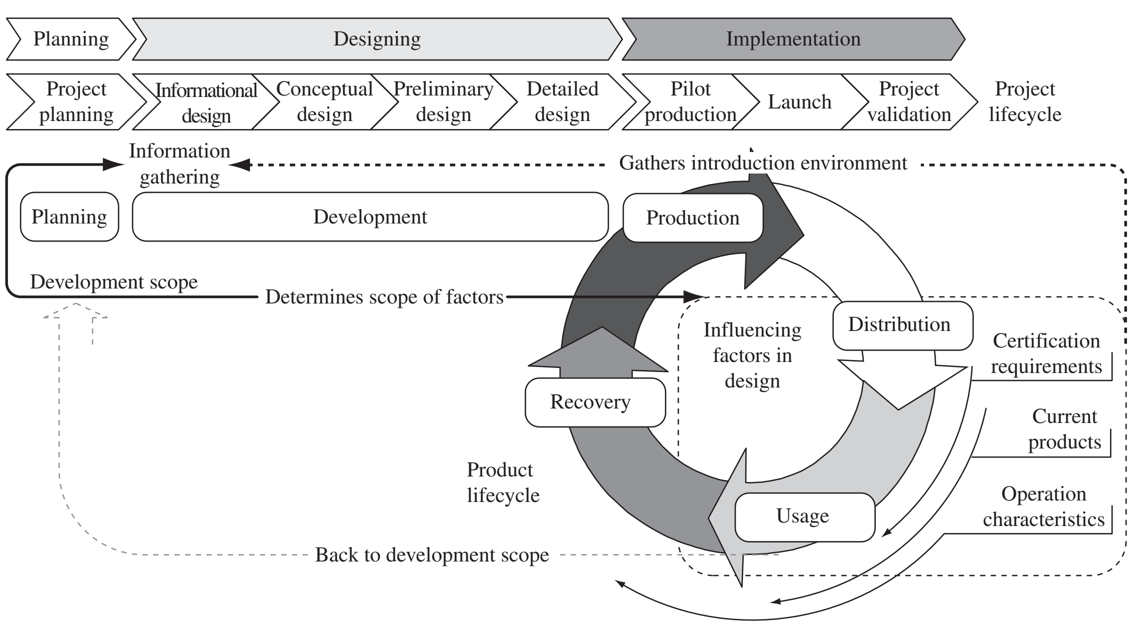

Figure 4. Representation of influencing factors on product and project lifecycle (MARINI, 2007).

according to the proposed hierarchy according to its respective knowledge. Each section is deployed in classes, and those in properties. Such properties come from the lifecycle environments when the machine is introduced to its operation environment.

They are fundamental instructions that guide the processing of information for the influencing factors, because they can be processed as qualities (attributes of an element) or specifications (measurable properties of an element) as seen by engineers. In modeling the influencing factors information, two approaches are used: deploying the sections onto properties that are described and characterized as qualitative or quantitative, depending on their characteristics, as in Table 3; and, building a task dependency model to display the information and resource requirements for gathering the influencing factors, which is displayed in the Table 4.

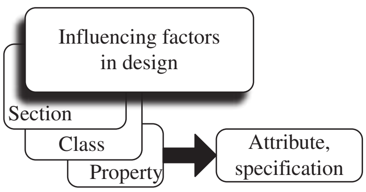

Figure 5. Influencing factors in design: Information hierarchy.

Axx [Section, class] Class name	Axxx [Section, class, property] Property	The description presents the information communicated (referred by verb) and the subject of that information (referred by noun).	
		Information on an influencing factor in qualitative description form	[“a”] Attribute, auqlity
		Information on an influencing factor presented in quantitative measurement form	[++] Specification
		Information on an influencing factor in qualitative form to be derived towards quantitative form	[“a”] → [++] Attribute → Specification

Table 3. Influencing factors in design: Basic structure for section deployment.

In deploying the sections, each element of the structure model is identified by a sequential code number, where each character identifies the subject (section, class, property). Each lifecycle element from the introduction environment related to a given section is defined as a class.

Properties constitute the basic units within the information model. Their processing is then understood as a function in the generic form.

Each subject is then described on the communicating action, and on described characteristic. Subject characterization is then described as qualitative [“a”] – to describe attributes – or quantitative [++] – to describe specifications. The attributes shown can also be defined as measurements. The functional task model for the influencing factors information follows the representation structure from the RM-AMDP, hereby formerly mentioned.

The inputs consist of consolidated information, which is already known and has been recorded from carrying out other activities within the same project, or similar activities from other projects. Properties are characteristics of an element or

Axx	Input	Property	Domain	Mechanism	Control	Output
Class name	Input information	Axx1 Typical dimensions	XX	Tool, method or practice to obtain Axx1 and Axx2 properties	Validation information for Axx1 only	[”a”] Qualitative information about Axx1
					Validation information for Axx1 and Axx2	
		Axx2 Obstacles to traffic and displacement	XX, YY			[++] Quatitative information about Axx2
				Tool, method or practice to obtain Axx2 only	Validation information for Axx2 only	
	Input information	...	...	...	...	...
		Axxn Obstacle dimensions	ZZ	Tool, method or practice to obtain Axxn only		[”a”] → [++] Qualitative to quantitative definition for Axxn

Table 4. Basic structure of task model and information dependencies for the influencing factors.

a set of elements within the scope of a given class. Domains follow the corporate competence areas as defined in the RM-AMDP, directly involved in carrying out the task. Mechanisms comprise resources, tools or methods used to processing the input information. Controls are similar resources to mechanisms whose role is to validate the processed information according to given task objectives. And, outputs are information to constitute the whole set of influencing factors in design, in the form of attributes or specifications, that could compose the design specification along with customer needs or design requirements, respectively.

7. Influencing factors: implementation

The information model has been successfully built following the data modeling directives as defined in the representation structure for the RM-AMDP. This topic has two parallel threads: it shows the dependency network among the information in performing the analyses of the influencing factors in design; and, it provides structural examples from selected information classes within the model, implemented in a case study. That exercise focuses on using the model to identify influencing factors in design for a machine whose purpose is to perform an agricultural operation.

The chosen machine is a centrifugal fertilizer spreader, whose design has been analyzed on the possible influencing factors to affect its development and on the links with its conceptual design definition. That machine has also been analyzed with regard to its functional concept, which has been declared in overall level and structurally deployed in functional chains (MARINI; ROMANO, 2007). The focus here is to show how the information model has been built and implemented, in order to gather and display what are the factors that matter to orienting further design efforts. The model implementation is hereby demonstrated in one class per section, where each class is described in its elements and their data inputs, then shown in its case study implementation.

The resulting information in the case study examples is shown following the task model of the influencing factors in design, as displayed in Table 4. Many inputs for the model were collected following product test reports, as well as from input given by engineers in the academy and industry, and were then organized following the dependencies shown.

7.1. Development scope example

The development scope analysis constitutes the first information section of the influencing factors. Most of its information comes directly from the project scope definition, to be carried out in the planning phase, as shown by Figure 6. Those influencing factors are fundamental because they determine all other lifecycle and design issues to be considered and dealt with during the design process.

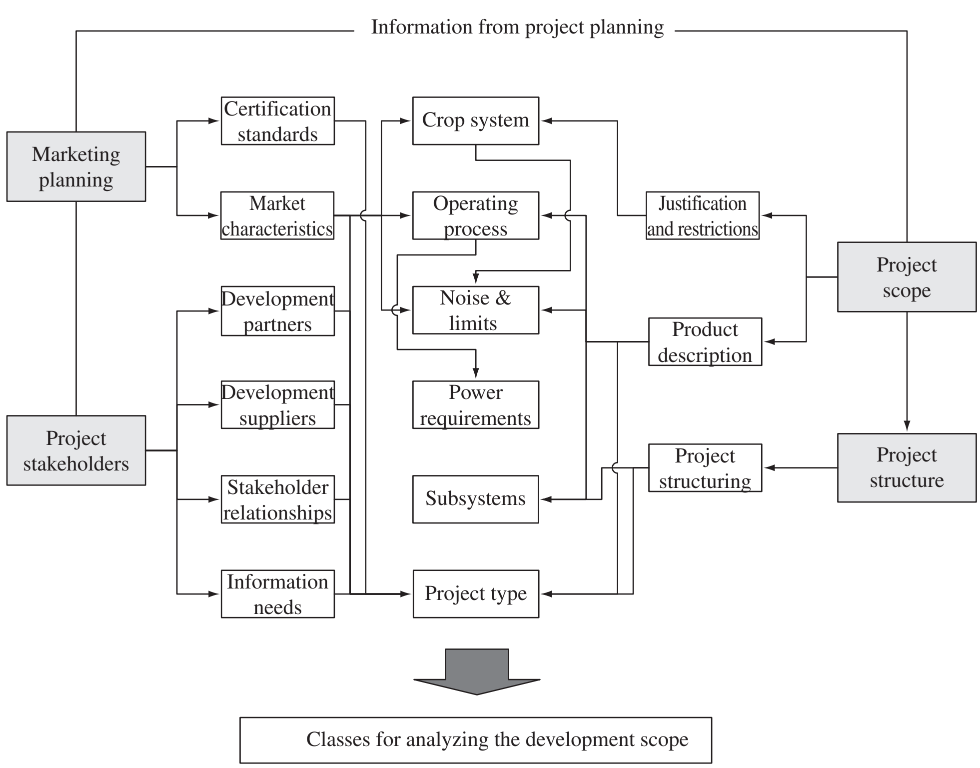

Figure 6. Information links to development scope classes.

The inputs for the classes in the development scope section come mainly from the project planning macrophase, where items such as marketing planning, project scope, project stakeholders and project structure play a significant role in providing guidance to defining how the development scope influences upon the design and development of the agricultural machine. This section comprises the following classes: crop system, operating processes, noise and limits, power requirements, subsystems, and project type.

The crop system class (Table 5 at right) comprises properties related to the crop species, the step the machine performs and how the crop is maintained, among others. There, the first property describes the markets for commercializing the machine; the crop species focus and the crop season shall be defined. Other important matters are: the infra-structure (row-crop, orchard, grassland, etc.) used to maintain and grow the crops; and, the crop management technique, which determines crop growth practices (direct seeding, minimal tillage or conventional). Finally, the intended agricultural operation shall be declared following the step from the crop growth process where the machine shall operate. Information appearing on mechanism refers to data sources, while controls refer to information already elaborated within the project.

The operating process is the second class within the development scope section for the influencing factors in design. It has the role of guiding the collection of data related to operational characteristics the machine shall meet. The

A11	Input	Property	Domain	Mechanism	Control	Output
Crop system	Project justification and restrictions (A931)	A111 Intended markets	AF, MK	Project documentation system	Business strategy plan	["a"] Identifies locations whose agricultural production constitutes consumer markets
	Market offer characteristics (A913)	A112 Species of interest	PD, MK	Field research	Product description (A932)	["a"] Identifies the plant species the machine shall be designed for
		A113 Crop season		Field research	Cultivation-climate zoning (A111) Intended markets Specialized literature	["a"] Identifies the crop season and its span, for the species of interest
		A114 Crop configuration	PD, MK	Specialized literature Field research	(A111) Intended markets Species of interest (A112) Vital crop cycle (A113)	["a"] Characterizes how the plants settle up in the crop field
		A115 Crop technique	PD, MK	Machine inspection Specialized literature Field research	(A111) Intended markets Agronomic prescription documents	["a"] Characterizes the practice system to prepare and implement crops
		A116 Agricultural operation			Crop process stages (A112) Species of interest Vital crop cycle (A113)	["a"] Identifies briefly the action the machine performs on the crop

Table 5. Task model for crop system class.

noise & limits class has the purpose of defining the elements and circumstances that may affect product quality, either by controlling the machine (the agents) or by taking part of the operation (the environment). The power requirements class shall define the way the machine is to be dependent on power, in terms of self-supply, autonomy, capacity, coupling and basic definitions on load regimes. The subsystems class shall guide the development process by assigning different roles to subsystems, namely: overall system, crop processing, power transmission and operation control. And, the project type class influences on development priorities by specifying knowledge level, system complexity and organizational risk of failure.

An implementation example of the crop system class is shown on Table 6.

The example on crop system properties shows the crop system class and its properties, following the section deployment structure. In addition to the information field, an extra description field has been added in order to allow providing extra information on the given property. Information for implementing the model shall be collected on the project documentation system where available. However, most of them shall be collected from specialized sources with focus on crop growth and management. Field research is strongly indicated to gather further information on those items.

7.2. Operation characteristics example

The operation characteristics class describes the field environment where the machine is going to work on. Its input information comes mostly from the development scope class, as in Figure 8, because it has already determined which types of field and crop are going to be attended by the machine under development. The operation characteristics class has the purpose of further specifying the field characteristics, so that to provide clear guidance on field environment characteristics that may determine whether a developing design is fit to certain customer needs within a given market sector. This section comprises the following classes: climate and environment, soil, plant, agents, field and coupling.

The field class (Table 9) comprises properties related to the physical field configuration in typical overall dimensions, row spacing and inline curvature, as well as obstacles and field maneuvering section characteristics. In first place there is need to understand typical physical dimensions of fields the machine shall attend to in terms of area, length and corner angles.

Class	Property	Info	Description
A11 Crop system →→ 	A111 Intended markets	South	Rio Grande do Sul, southern and nortwestern Santa Catarina, Paraná
		Southeast	São Paulo, Minas Gerais
		Center-west	Mato Grosso, Mato Grosso do Sul, Goiás, Tocantins
		Northeast	Western Bahia, southern Maranhão, southern Piauí
	A112 Species of interest	Annual grain crops	Winter and summer harvesting seasons: Soyabeans, Maize, Wheat, Rice, Beans, Barley, Oat, Sorghum, Sunflower, Rape, Cotton
	A113 Crop season	Winter	September to November
			Depend on regional agricultural-climate zoning as from technical prescriptions
		Summer	April to June
	A114 Crop configuration	Row-crop arrangement	Small and medium-sized plants, short spacing between plants and narrow spacing between plant rows
	A115 Crop technique	Conventional	Seeding after soil tillage by inversion and displacement, without plant cover
		Minimum tillage	Seeding after soil tillage by soil shearing, with plant cover
		Direct seeding	Combination of shallow soil shearing and seeding, with plant cover
	A116 Agricultural operation	Distribution of crop nutrition/ correction	Minaral fertilizers and correctors, powdery, grain and cristaline

Table 6. Implementation example on crop system properties.

Likely obstacles to machine traffic and displacement shall be then described in their characteristics and dimensions. Following on, row-crop spacing is another important matter to determine basic dimensions for the machine, such as wheel track and tire width. Inline curvature is important as to determine the degree of maneuverability and accuracy needed from other machine systems, such as the header assembly in a combine harvester. The field maneuvering property describes the space available in row-crop heads for turning.

The soil class is the second within the operation characteristics section for the influencing factors in design. It has the role of guiding the collection of data related to soil characteristics of locations where the machine shall operate, if they affect operational performance. The plant class has the purpose of gathering the information on the specific crop plants that may affect operational efficiency and performance, which the machine has to be designed for.

The crop agents class describes nutrition/protection agents the machine may distribute, work with, or be exposed to. The field class works on characterizing the operation field, its topography and configuration. And, the coupling class shall describe available coupling configuration properties from other machines the developing design shall be designed for to adequately couple with.

An implementation example of the field class within the operation characteristics is shown on Table 10. That example follows the section deployment structure, defining the property in the info column and making a further specification in the description column.

The typical field dimensions, like width, length and slope are the first to be described. Obstacles and their dimensions are worked in the next step, being generally described on their constitution and dimensions. Thos dimensions can be first estimated to be further evaluated through filed research. That also applies to field layout characteristics, such as inter-row spacing, inline row curvature and head maneuver dimensions. Here, most of them can be approached with a first estimation, but shall be further specified by using geographic information systems on sample fields.

7.3. Certification requirements example

The certification requirements constitute the third information section for the influencing factors in design of agricultural machinery. The development scope provides significant guidance on the information to look for about certification requirements, as shown by the information links representation on Figure 7. The purpose for carrying out analyses on this class is to gather statements in technical standards and regulations that influence on designing the physical configuration of the machine.

They restrict the options to follow in designing the machine because they state determined characteristics required by law and regulation bodies to enable selling the machine on the intended markets by homologation. Meeting these requirements also improves legal safety because of covering lawsuit risks on the case of accidents with damages to real estate, environment, and human injury. The section comprises the classes: coupling and physical dimensions, process requirements, control requirements and safety requirements.

The coupling and physical dimensions class describes the standards and specifications that define specific requirements to designing the coupling interfaces of the machine with other implements or specific dimensions the machine must meet for its sale to be enabled on the target market covered by that requirement. The process requirements class describes practices, methods and specifications to be met so to ensure proper quality and performance in meeting the requirements from target markets; the control requirements class brings on standards and specifications requiring specific control measures, devices or configurations to be used in order to ensure operational performance.

The safety requirements class (Table 7) comprises properties related the document sources and their geographic levels, the organizations responsible for the document, the standard identification and the sections and statements that create safety requirements the machine under development shall be designed for. The example shows up the standards information in a broad scope, beginning with the document origin and the responsible organization. Information appearing on mechanism refers to data sources inside and outside the project scope, while controls refer to information already elaborated within the project.

Then the standards are cited in their designations and scope, on whether it is a method, practice, definition, specification, and where, in the agricultural machine design, it applies.

A further level of specification on certification standards is to declare the statements making requirements the machine is to be designed for, to be collected from the document text body. Other two properties shall be considered: the access safety scope comprises characteristics and dimensions the machine has in protecting the user/operator from moving part hazards; the information safety scope characterizes on whether signs and instructions are visible and adequate in order to avoid safety hazards in the machine.

An implementation example of the safety requirements class is shown on Table 8. That example follows the section deployment structure. In addition to the information field, an extra description field has been added to provide more information.

The intended market may require the agricultural machine to be in conformity with different standards from a number

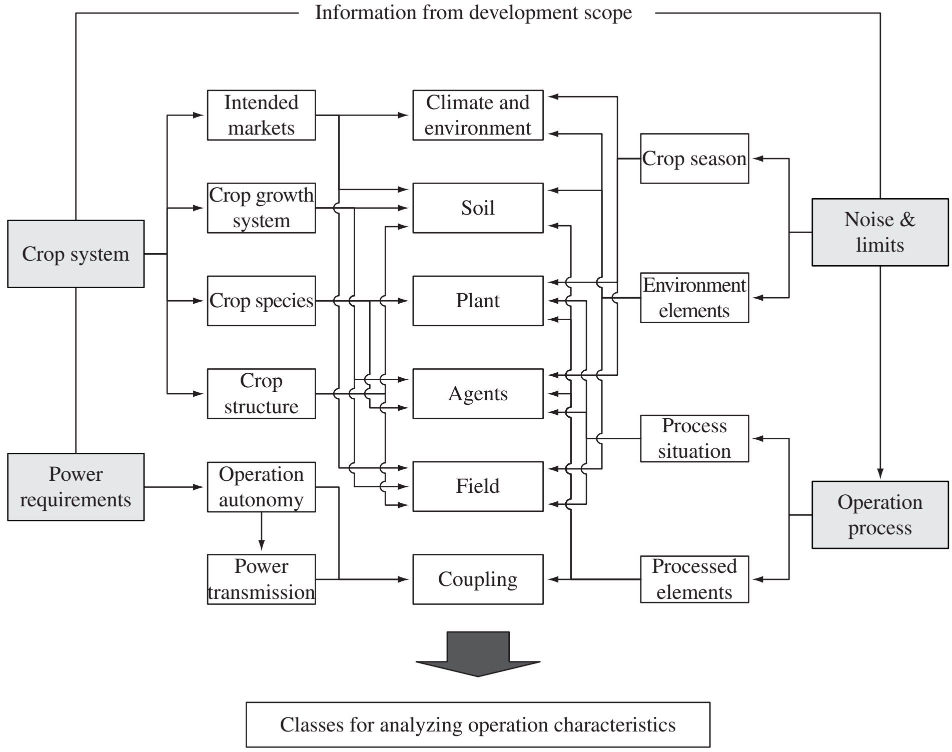

Figure 7. Influencing factors: Information links to operation characteristics classes.

A25	Input	Property	Domain	Mechanism	Control	Output
Field	(A111) Intended markets Crop configuration (A114)	A251 Typical field dimensions	MK, PD	Maps analyses Geographic information systems Field research	Crop field characteristics	[++] (m, ha) Identifies the physical dimensions of the crop field.
		A252 Obstacles to traffic and displacement	MK, PD		Operation risks (A136) (A231) crop growth stage (S227) Surface relief	["a"] → [++] (m) Identifies the crop field or the local fraffic characteristics that restrict machine dimensions.
		A253 Obstacle dimensions		Field research	(A112) Species of interest (A115) Crop technique	[++] (cm, m) Identifies the height or depth of displacement or traffic obstacles.
		A254 Inter-row spacing	MK, PD	Specialized literature Expert judgment Agronomic prescription documents	(A112) Species of interest Physical dimensions (A25)	[++] (m) Identifies the transverse spacing between crop rows.
		A255 Inline row curvature	MK, PD	Field research Geographic information systems Site-specific management	Crop technique (A115) Typical field dimensions (A251)	[++] (m) Identifies the typical curvature radius of machine displacement inline with crop rows.
		A256 Head maneuver dimensions				[++] (m) Identifies dimensions of maneuvering space within the crop field

Table 7. Task model for field class properties.

Class	Property	Info	Description
A25 Field →→ 	A251 Typical field dimensions	Delimited crop area	Up to 1200 ha per delimited field in southern and southeastern regions (Brazil); up to 5000 ha per delimited in center-western and northeastern regions.
		Length	Varies on the area: use GIS tools in field areas with typical layout in the region.
		Width	Varies on the area: verify geographical information ion typical field areas.
	A252 Obstacles to traffic and displacement	Height: Civil works	Porches, electrical networks, viaducts, entry gates in outdoor and storage buildings, among others.
		Width: Transit ways	Roads with frequent traffic of civil vehicles or authority fiscalization.
		Length: Maneuvering heads	Area restrictions to maneuvering in field crops or civil construction in the property.
	A253 Obstacle dimensions	Height	Up to 3,50 m (estimated).
		Width	Up to 3,20 m (with authorization, estimated).
		Length	Up to 10 m (estimated).
	A254 Inter-row spacing	Varies depending on crop species	See specific agronomic prescriptions for better information. Typical range estimate is between 50 cm and 1,5 m.
	A255 Inline row curvature	Displacement radius the machine moves	Varies on area geometry: use geographic information tools and site-specific management in typical areas.
	A256 Head maneuver dimensions	Available area for making row head maneuvers	Varies on area geometry: use geographic information tools and site-specific management in typical areas. Estimating 5 m to maneuvering for inverting row crop displacement.

Table 8. Implementation example on field properties.

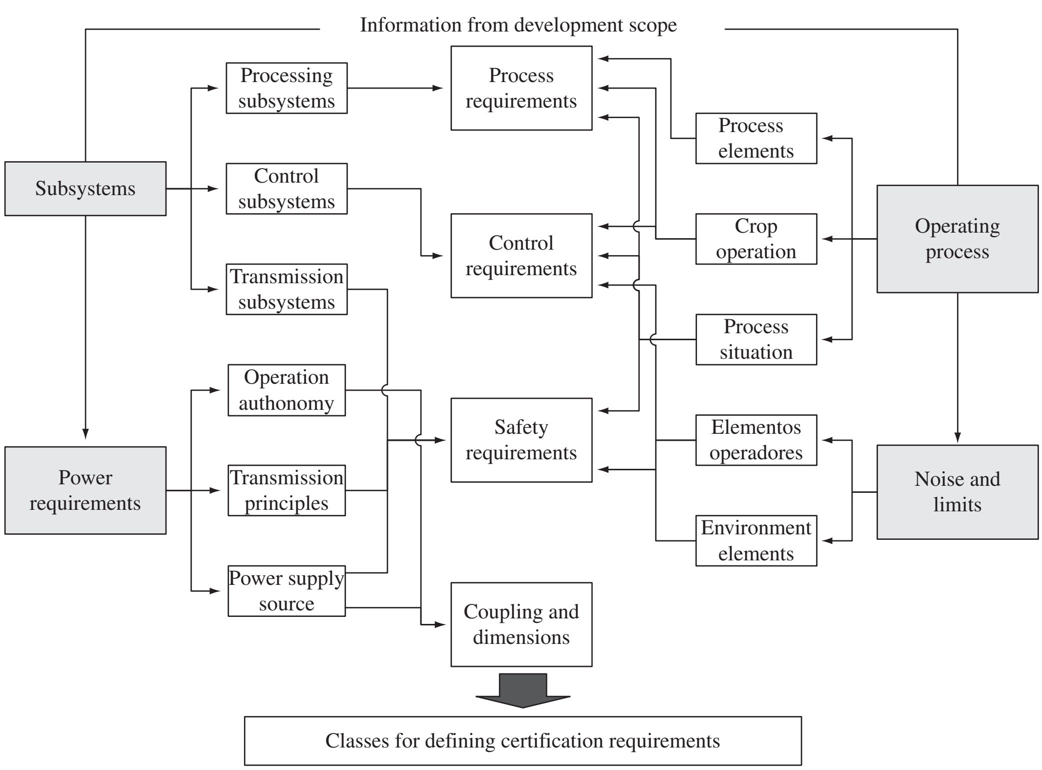

Figure 8. Influencing factors: information links to certification requirements classes.

A34	Input	Property	Domain	Mechanism	Control	Output
Safety requirements	Certification requirements (A912) Product description (A932) ISO 3339 designation (A121) Operation autonomy (A141) Transmission principles (A144) Coupling types (A147)	A341 Document origin	AF, SY, PD	Field research	(A111) Intended markets	Identifies the original location from the normative statement
		A342 Document issuer		Project documentation system	Document origin (A311)	Identifies the organization that issued the document
		A343 Technical regulation		Project documentation system	Crop configuration (A114) Operating agents (A132) Operating risks (A135)	Identifies the document designation code
	Technical regulation (A313)	A344 Mandatory features	PD, SY	Local market law Local market jurisprudence Technical standards Normative decrees Expert judgment	Process situation (A114) Operation description (A125) Operating risks (A135)	Identifies recommandations or requirements on design features for the machine
	Technical regulation (A343) Mandatory features (A344)	A345 Access safety			Operating agents (A131) Environment elements (A132) Available operating time (A134) Operating risks (A135)	Identifies requirements to accessing hazardous locations in the machine
		A346 Information safety				Identifies requirements for information on hazardous locations in the machine

Table 9. Task model for safety requirements.

of technical bodies. That information shall be described in the first two properties, so the requirement statements can be further described in terms of the evident documentation. Here, the documentation is described in general terms, where in practice the declaration of documented statements is encouraged wherever possible.

7.4. Current products evaluation: proposition

The current products evaluation involves gathering information about the existing competitive machines within the market sector as defined by the development scope. The purpose of adding this section to the influencing factors in design is to compare properties from current machines that the intended customer can opt for as guidance to defining the degree of scale and the functionality features the developing design shall have. The comparative analysis shall focus on the subsystem level, and shall consider all other information sections containing influencing factors in design.

In total, that section has nine classes. The first class analyzes the physical dimensions of existing products in the intended market. The power generation class evaluates the attributes the machine has on power generation, and its ability to supply the necessary energy to the operation. The power transmission class analyzes the power transmission system and its characteristics of power delivery to performing the agricultural task; the coupling class describes coupling configurations and their attributes. Two classes work on comparing operational capacity in terms of supply and processing capacity, respectively. The three last classes have the purpose of analyzing and comparing performance among the existing machines. Such work involves thorough benchmarking between existing products in a given market profile. The Table 11 shows the task model proposition for the supply capacity class.

The task model provides foundation for the procedure to collecting the relevant information on the influencing factors in design related to the current products in the market. The

Class	Property	Info	Description
A34 Safety requirements →→ 	A331 Document origin	Switzerland	Intrernational geographic level
		Brazil	Internal market level
	A332 Organização emissora	ISO	International Standardization Organization
		ABNT/NBR	Brazilian Association for Technica Standards
		NR/MTb	Brazilian Government - Ministry for Job Relations - Regulation Norms
	A333 Norma declarante	ISO 4254-1	Tractors and machines for agriculture and forestry - safety: general requirements.
		ISO 4254-9	Tractors and machines for agriculture and forestry - safety: Technical measures to ensure safety, Part 9: Seeding and crop nutrition distribution equipment.
		ISO 12140	Agricultural machinery - trailed equipment - drawbar coupling.
		NBR 11380	Tractors and agricultural implements: safety protection for PTO shaft - method.
		NR-31	Regulation norm for health and safety: job safety on agriculture, feedstock, forestry, and aquaculture.

Table 10. Implementation example on safety requirements.

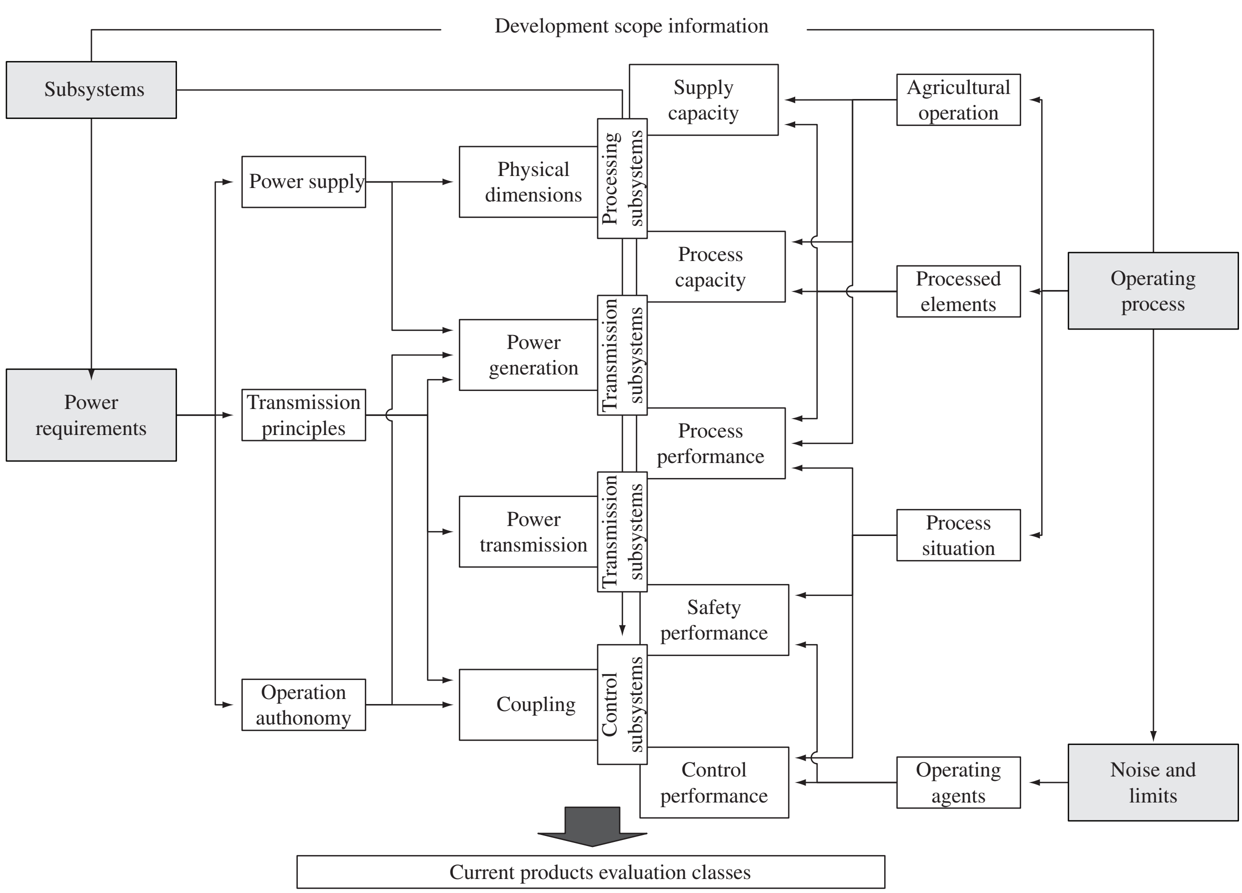

Figure 9. Influencing factors: information links to current products classes.

A45	Input	Property	Domain	Mechanism	Control	Output
Supply capacity	Agricultural operation (A116) (A122) Processed elements (A134) Available time processing subsystem (A152)	A451 Supplied elements	PD, MK	Machine analyses Benchmarking Reverse engineering	(A112) Species of interest Elements: plant (A235) agente (A241)	["a"] Identifies the elements to be processed by the machine
		A452 Supply capacities			Properties (A234, A244) Dimensions and values (A315, A316) Dimensions (A412, 413, 414) (A442) Power-supplied action Mass (A411) (A213) Slope Penetration resistance (A224) Typical field dimensions (A251)	[++] (kg, dm^3) Identifies the capacity dimensions available to provide the processed elements
	Processing subsystem (A152) Supplied elements (A451)	A453 Element variety	PD, MK	Machine analyses Benchmarking Reverse engineering	Elements: plant (A235) agent (A241) Number of settings (A444) Variety of settings (A447)	[++] (n) Identifies the number of elements to be supplied simultaneously
	Control subsystem (A154) (A441) Transmission subsystem Supplied elements (A451)	A454 Rate adjustment	PD, DP	Machine analyses Benchmarking Reverse engineering Product testing	(A442) Power-supplied action Variety of elements (A453) Control (A335, A336)	[++] (n) Identifies the number of adjustments to determine supply rates
		A455 Supply rate			Evaluation parameters (A326) Adjustments (A425, A447) (A445) Speed range Storage capacity (A452)	[++] (kg/s, dm^3/s) Identifies the supply rate of agricultural elements on through the process

Table 11. Task model for supply capacity.

properties consider common traits of existing machinery in important performance parameters to defining design specifications for the product currently under development. Most of the mechanisms specified in the task model can be carried out in the process by specifying the adequate resources for the procedures. They shall be executed in order to compare the target performance for the current development and the performance yielded by the current products.

8. Discussion

8.1. Influencing factors and design specification

This discussion has been derived in principle by the discovery of different terms with similar scope. Whereas performance and environment variables determining product success have been called 'design specification' under engineering design knowledge (ANDREASEN; HEIN, 1987; ULRICH; EPPINGER, 1995) the same variables were called 'influencing factors' under the agricultural engineering domain when referring to design and development of agricultural machinery (CHRISTIANSON; ROHRBACH, 1986). Even though the latter definition appears in a publication on design, it could be characterized as applying an analysis focus as opposed to the synthesis focus often declared in engineering design. The first step for mending fences between both domains on such definitions is to make clear the scope to which they apply.

A starting point has been made under the definition of the RM-AMDP (ROMANO et al., 2005). That contribution proposed considering both areas to take advantage of engineering design knowledge to developing agricultural machinery. Its definition for influencing factors is seen here as taking support from the original in the agricultural engineering domain. However, it rethinks its scope in using primary definitions from product characterization toward testing and certification (MIALHE, 1996).

If the making of design specifications is underpinned on considering the needs of stakeholders in the product lifecycle during product development (FONSECA; 2000), the influencing factors may come as a complementary definition. When considering the propositions on influencing factors in design of agricultural machinery (ROMANO, 2003, MARINI, 2007), those factors constitute a subset of the design specification when translated to quantitative information. Therefore, it is possible to envision the role of influencing factors in defining the design specification. If they can be transformed in quantitative information, they also can be turned into design requirements, as it happens with customer needs, within a context shown in Figure 10.

Because the operations management scope comprises knowledge and practice employed to carrying out agricultural operations and decision-making in crop management, it significantly determines the definition of customer needs to those the agricultural machine is supposed to attend. That also applies when the performance of technical resources is associated to demands from operations management; such information shall be mostly interpreted as customer needs. If technical issues on operation environment and resources are considered alone, they mostly induce the definition of influencing factors in design.

8.2. Influencing factors towards practice

While the proposed contribution has an eminent theoretical character, some considerations are needed to make it fit into a practical framework. Some discussion is nevertheless needed on what the influencing factors are, in order not to lose pace with practice.

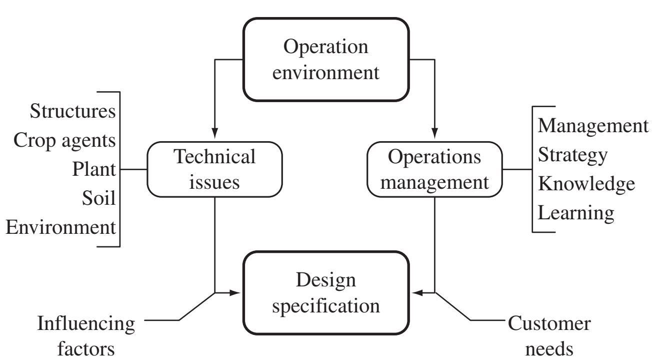

Figure 10. Influencing factors and customer needs as subsets for the design specification on agricultural machinery.

From the experience on the case study, it is possible to say that gathering information on influencing factors in design is somehow similar to the process of building the design specification. Because of that nature, it was possible to achieve the process representation of the influencing factors in a task model form. If the product documentation system can provide most of the information used as controls, the same does not happen when considering the necessary resources for carrying out the activity.

Under support from engineers with significant experience on practices about design and evaluation of agricultural machinery, engineering practices (tools and techniques) were sought and evaluated on their applicability towards gathering information on the influencing factors in design. The results of such work are seen mainly on the task models for gathering the influencing factors in design, whose samples are brought up in this paper. The tools are divided in four resource groups: a) surveyance; b) agronomical; c) design; and d) management. Surveyance tools measure field dimensions and characteristics to their usage in agriculture; agronomical tools prescribe how to keep and manage crop cycles, from seeding to harvest; design tools prescribe ways to translate specialized information into useful design input; and, management tools are those related to ensuring the development project keeps on track with its goals. Table 12 shows design resources as a sample.

The specification of those resources supports improving current development process by its systematic character, which can be improved with the discovery of new approaches and tools to carrying out the tasks to gathering information on the influencing factors.

Because there is awareness about those resources in industry, it is possible to implement such improvements in short time. Where similar procedures are employed in practice, the structuring and systematization of the process supports improvements on increasing the certainty of the information towards the definition of design requirements within the design specification. Such implementation guidelines can also be augmented by method innovations inside industry, to improve the degree of specification that the design requirements carry to the design process.

9. Conclusions

The models for classifying and gathering the influencing factors in design are composed in sections, classes and properties. The information classification is carried out with support of a section deployment model (Table 3, while the information gathering is supported by a task model (Table 4). Such prescriptions, described all over this paper, provide a set of guidelines to support designers in translating information on the lifecycle environments to

Classe	Propriedades	Descrição
Design resources →→	ISO 3339 standard	A technical standard that defines an universal classification for agricultural machinery (MÁRQUEZ, 2001)
	Expert judgment	Analysis procedure based upon tacit and explicit knowledge comprising a body of knowledge on a specific area
	Machine inspection	Visual inspection of agricultural machinery, carried out by static inspection on site; or, technical documentation review (operating manual, part lists, etc.)
	Product testing	Agricultural machine testing, to be carried out by observing actual product performance: live working demonstrations; performance testing evaluation; and, in-field operation evaluation (evaluation means a report is included)
	Preliminary Hazard Analysis	Methodology to identify hazards to improve operational and/or design safety (BLOSWICK; SESEK, 2004) with four steps: (1) Identify hazardsous conditions; (2) determine causes of incidents; (3) determine potential effects from incidents; and, (4) establish requirements to hazard control
	Benchmarking	Methodology to compare existing products with pre-defined criteria towards defining performance goals for the developing design
	Reverse engineering	Detailed study of the physical configuration of a system or a machine, by the acquisition of a complete unit, its disassembly and measurement of relevant dimensions
	Machine evaluation	Performance analysis of a machine or a subsystem under declared and controlled conditions as defined in regulations and technical standards
	Field research	One or more team members make visits to specific locations representing likely operating conditions for the agricultural machine. Data collection procedures are carried out in site, such as area inspection, photography, interviews and GPS data collection, among others

Table 12. Design resources for prescription in task model.

design specification format. The specification of resources supports designers in following the task model, giving them discretion to use and augment the systematic modeling of influencing factors to their advantage.

Considering the role of the class-properties models in the constitution of this contribution, it is possible to conclude the aims of this paper were achieved. The proposed models constitute support to implement systematized practices to gather information on influencing factors in design, and process it towards usage in the development of improved, innovative agricultural machinery.

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