

INFORMATIONAL AND CONCEPTUAL DESIGN OF A SOLID FERTILIZER APPLICATION SYSTEM FOR PRECISION AGRICULTURE

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This paper presents the development and results obtained during the informational and conceptual design of a solid fertilizer application system for precision agriculture. Precision agriculture is a new paradigm in the management of agriculture. According to it, the field is not treated as being homogeneous, but instead, treated in accordance to the variability of the factors that affect production (nutrient concentration, humidity, organic matter, pH, and other factors). In precision agriculture fertilizer is applied in variable rates. Additionally, the fertilizer application system must fulfill other customer needs concerning the whole product lifecycle. The transformation process of customer needs into design specifications is held in the informational design phase. Following the informational design, the conceptual design starts with the definition of the function structure and finishes with the selection of the product concept. The methodology used in the informational and conceptual phases was created based on existing methodologies available in literature. Two product concepts are shown at the end of the article. The methodology was considered appropriate as the multidisciplinary aspects of this product were held efficiently and results from informational and conceptual phases were considered satisfactory to follow to preliminary design.
Keywords. *product development, design methodology, fertilizer, variable rate application.*

1. Introduction

This paper presents the informational and conceptual phases of the design of a solid fertilizer application system for precision agriculture. Precision agriculture is a new paradigm in the management of agriculture. According to it, the field is not treated as being homogeneous, but instead, treated in accordance to the variability of the factors that affect production (such as nutrient concentration, humidity, organic matter, pH, and other factors). In precision agriculture fertilizer is applied in variable rates, which means that each sub-region of the field receives different amounts of fertilizer.

In the production of grains, fertilizer is applied during the planting operation with the so called planter. The main macro-nutrients of fertilizer used for planting are Nitrogen (N), Phosphorus (P), and Potassium (K), reason why this type of fertilizer is known as NPK. Many different formulations of NPK are available on market. Traditionally, one amount of NPK (Kg/ha) is applied to the whole field of production based on the average characteristics of soil. This way some regions of the field receive more NPK than what is necessary, while other regions receive less quantities, since soil demands are not uniform, but totally variable across the field. This approach can cause environmental problems, increase costs and diminish productivity.

While designing a solid fertilizer application system for precision agriculture one has to have in mind that applying a certain NPK in variable rate may not be enough to satisfy soil variability. Obviously, changing the amount fertilizer applied causes the amount of all three macro-nutrients to change in the same proportion, however, soil demands for macro-nutrients are usually independent. That way, a fertilizer application system for precision agriculture may have to either apply N, P and K independently, or apply three different formulations of NPK.

Application of three different types of fertilizer can cause product cost to raise in comparison to regular one type fertilizer application systems. Sometimes farmers may be interested in applying only two or even one type of fertilizer, due to price lowering or limited soil variability. If the system can be easily configured to the number of fertilizer types that farmers desire, both farmers and manufacturers can benefit from it. This can be done using a design approach called design for modularity, according to which the product is conveniently divided in independent units known as modules.

Besides the ability to vary the application rate of (one, two, or three types of) fertilizer on-the-go, the system has to fulfill other customer needs in order to become a successful product. Customer needs are usually qualitative and subjective. Thus, to be more useful throughout the design process customer needs have to be converted into design specifications, which are more quantitative in nature. The process that deals with the gathering of customer needs and its transformation into design specifications is called informational design, which is the first phase of the design process (Fonseca, 2000; and Maribondo, 2000).

After informational design, conceptual design aims to, departing from design specifications, create product concepts from which one or more will be selected to be detailed during the preliminary design phase (not included in this article). Conceptual design starts defining product function structure, proceeds to the search for solution principles for each function, and finishes with the creation and selection of concepts (Pahl and Beitz, 1996 e Ulrich and Eppinger, 1995).

Informational and conceptual design methodology and their execution are presented in section 2 and 3 respectively. Section 4 presents the conclusions of the work.

2. Informational design

The objective of this phase is to, departing from design problem, identify customer needs and transform these in a set of goals that product must reach. Such goals are called design specifications.

Customer needs are usually expressed in "customer language" (Ulrich and Eppinger, 1995). Needs such as, "the product should be light" are subjective. During design activity, quantitative information like, "product should weigh no more than 20 Kg" describe product goals more precisely and can be more useful to guide design activity and serve as criteria for decision making stages.

Informational design deals basically with the identification of customer needs and its transformation into design specifications. This is done using a methodology that prescribes step-by-step the roadmap that design team must follow. Section 2.1 describes the methodology used. Section 2.2 presents the execution of the methodology

2.1 Informational design methodology

Classical design methodologies presented by Back (1983), Ullman (1992), and Pahl and Beitz (1996) have a initial phase that, despite their nomenclature, deal with information related to customer needs. The low degree of systematization of the first phase of those methodologies lead Fonseca (2000) to propose a methodology that systematizes the initial activities of design process that compose the so called informational design phase.

Maribondo (2000) proposes a methodology to the whole design process. The initial phase of his methodology is also called informational design. Based in the latest two references a particular informational design methodology was deployed in accordance to the characteristics of the present work. Figure 1 shows the informational design phase used in this work. It is divided in stages, which are divided in tasks.

2.2 Informational design execution

Following is the development of informational design stages, pointing out methods and tools used.

2.2.1 Search for information

This stage aims to bring together all the information necessary to the complete understanding of the design problem. Information sources used were books, articles, web sites, product catalogs and specialists. The mains aspects searched were planters (machine which the fertilizer application system is part of) characteristics, precision agriculture cycle, existing machines for variable rate application, soil fertilizing requirements for grains production, and granular material properties and behavior. These information can be found in the second, third and forth chapters of the first author's master dissertation titled *Development of a Solid Fertilizer Application System for Precision Agriculture*.

2.2.2 Define customer needs throughout product lifecycle

First task to be accomplished here is establishment of product lifecycle, which was done based on Maribondo (2000). After that, customers throughout product lifecycle were defined. No special method is required for this task. Customers are classified in three categories of equal importance: external customers (product final users), intermediate customers (people involved with product transportation, marketing and sales), and internal customers (people involved with product design and production).Table 1 presents product lifecycle and customers identified.

Product attributes must also be defined, as those will be used in the next task. Product attributes were selected among the set of basic attributes proposed by Fonseca (2000): *functioning, ergonomics, aesthetics, cost, safety, reliability, modularity, standardization and environmental impact*. One should note that those do not represent the totality of product attributes, but are the ones to be used in the definition of customer needs.

The identification of customer needs was done with the aid of two methods. Firstly, three types of questionnaires were applied to farmers; directors, engineers and technicians of agricultural machinery manufacturing companies, and agricultural machinery researchers. Questionnaires were designed following the methodology presented by Reis et. al (2003). A total of 39 questionnaires were answered, 24 during personal interviews and 15 through electronic mail.

Secondly, basic attributes defined previously were used in the *customer needs identification support matrix* presented in more details in Fonseca (2000). From a total of 56 needs, 37 were identified in questionnaires and 19 with the use of the matrix. Due to limited space customer list is not show here.

Table 1 – Customers throughout product lifecycle.

Lifecycle phases	Customers
Design	Design team*
Manufacturing	Agricultural Machine manufacturers, Laboratory technicians
Assembly	Agricultural Machine manufacturers, Laboratory technicians
Testing	Design team*
Packing	Agricultural machinery manufacturers
Storage	Agricultural machinery manufacturers
Transportation /Distribution	Agricultural machinery manufacturers and dealers
Sales	Agricultural machinery manufacturers and dealers
Use	Farmers
Maintenance	Farmers
Retirement	Agricultural machinery manufacturers

*- authors and graduate students.

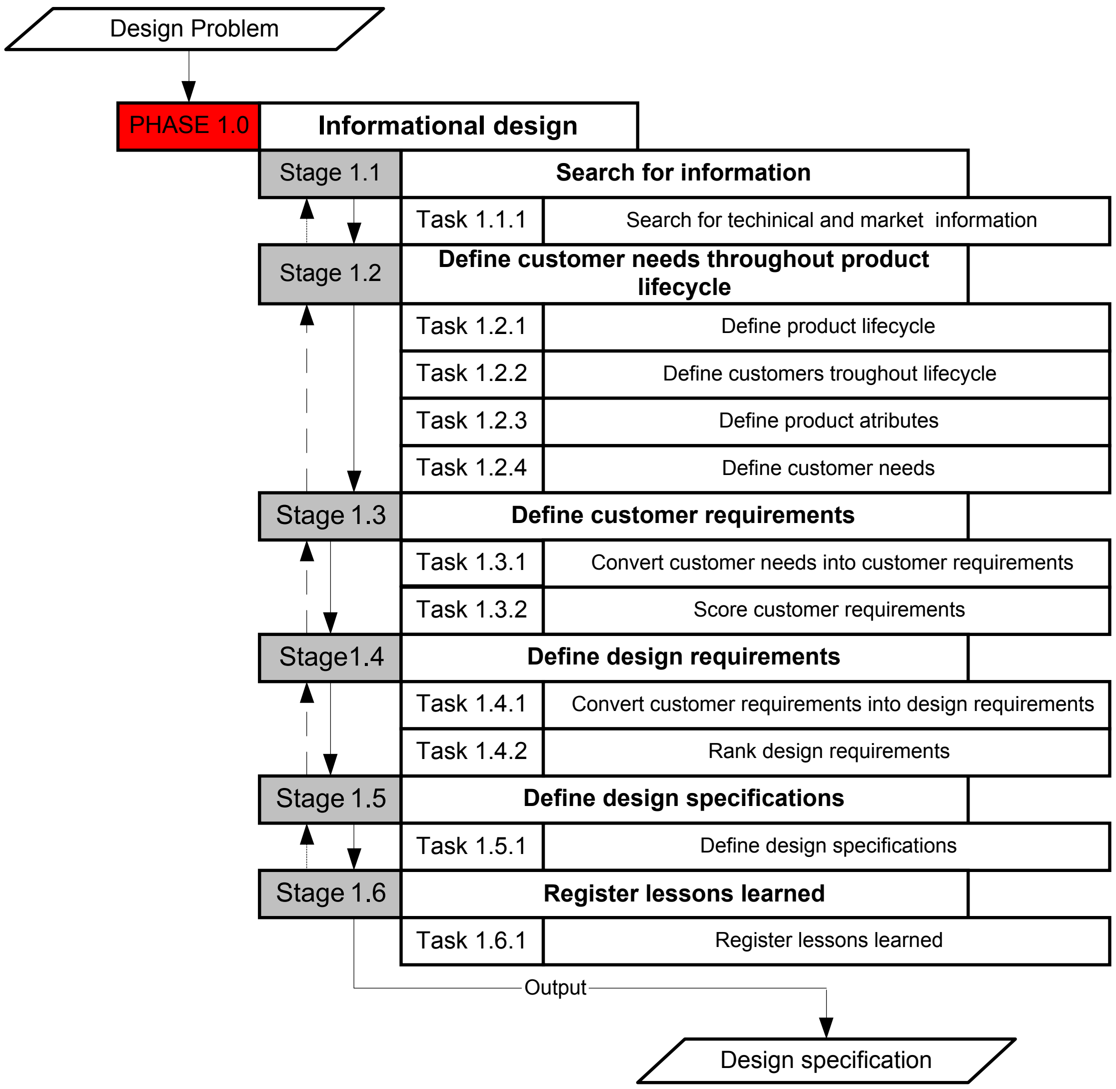

Figure 1 – Graphical representation of the informational design methodology.

2.2.3 Define customer requirements

The conversion of customer needs into customer requirements aims to transform raw customer language into a more technical language. Fonseca (2000) proposes the following systematization:

Every customer requirement is:

- A short phrase composed by the verbs *to be* or *to have*, and one or more substantives, or
- A phrase composed by a verb other then to be or to have, and one or more substantives. In this case the requirement denotes a possible product function.

During the conversion process it is important to look for needs that has the same meaning, avoiding redundancy of requirements and diminishing the amount of data to be manipulated during the next methodology stages. Table 2 shows the list of customer requirements classified according to lifecycle phases.

Table 2 – List of customer requirements classified according to product lifecycle phases.

Lifecycle phases	Customer requirements	Score	Value
Design	1. To have low driving power	8	2
	2. To have standard components and systems	18	3
	3. To have parts available on market	8	2
Manufacturing	4. To be manufactured by conventional processes	19	4
	5. To have low number of components	7	2
	6. To have feeding module with dimensions compatible to human manipulation	18	3
	7. To be easy to manufacture	24	4
	8. To have low production cost	47	8
Assembly	9. To be easy to assembly and disassembly	28	5
	10. To have low time of assembly and disassembly	28	5
	11. To have assembly and disassembly with low use of tools	10	2
Testing /Packing/ storage/ Transportation and distribution	12. To be light	16	3
Sales	13. To be usable by various planter models	32	6
	14. To allow the application of one, two or thee types fertilizer simultaneously	54	9
Use	15. To apply fertilizer in variable rates FG*	62	10
	16. To be usable for plantation of many crops	40	7
	17. To function independently of ground inclination	33	6
	18. To have easy bin filling up	17	3
	19. To maintain fertilizer homogeneity FG	38	7
	20. To avoid lack of fertilizer in bin FG	10	2
	21. To have adequate bin capacity	27	5
	22. To have a precise fertilizer application	62	10
	23. To be safe	57	10
	24. To allow storage of fertilizer application data FG	30	5
	25. To have nice aesthetics	0	1
	26. To have high reliability	49	9
	27. To have long life	6	1
	28. To have easy upgrade	4	1
Maintenance	29. To have easy maintenance	30	5
	30. To have fast maintenance	29	5
	31. To have low maintenance frequency	43	7
	32. To have low maintenance cost	20	4
Retirement (reuse or recycling)	33. To have easy remanufacture and recycling of parts	3	1

* - FG means that requirement is a function generator.

After obtaining the list of customer requirements those must be scored, which means that a value or weigh of importance must be assigned to each one of the requirements . This can be done based on design team or customers opinion and experience. However, this task can turn out to be highly subjective and dependent of personal preferences, which can result in inconsistent scores for requirements. Reis et. al (2002) presents a computational version of the Mudge Diagram, a tool that can be used to systematize the process of requirements scoring. Results of the Mudge Diagram are also show in tab. 2. The large number of scores can make it difficult to understand the importance of each customer requirement, hence, a scale that classifies requirements in ten classes was used. For each class corresponds a value that ranges from 1 to 10 (table 2). The values are going to be further used during the *rank design requirements* task (task 1.4.2).

2.2.4 Define design requirements

Converting customer requirements into design requirements means to decide something physical about the product that will affect it definitely during the rest of design process. Customer requirements usually do not contain measurable physical elements which are essential guide design execution. That way, design requirements must be composed by measurable expressions whenever it is possible, which means that those expressions must be able to be associated to some unit of measurement.

To aid the execution of this task it was used the matrix for obtaining design requirements presented by Fonseca (2000). During this task the properties recommended by Roozenburg and Eekels (1995) for design specifications were considered, they are:
Validity – appropriateness of a requirement on theoretical grounds ;
Completeness – the list of design requirements is complete if it represents the needs of all customers throughout product lifecycle;
Operationality - to have requirements that are measurable;
Non-redundancy – to avoid that a certain requirement is considered more than once;
Conciseness – to keep the requirements list as concise as possible without damaging completeness; and
Practicability – requirements must be able to be tested or simulated.

Design requirements should also be ranked, so that design team knows the priority of "technical parameters", which can guide the many tradeoffs that are to be made during design process. The first matrix of the QFD method (Quality Function Deployment) named House of Quality was used for the ranking of design requirements. This method is presented by Akao (1990) and is widely use in design field. The software WinQFD is a computational implementation of the method (Fonseca, 2000). It makes easier the filling of the House of Quality and automates the calculation of results. The rank of design requirements is shown in table 3 (section 2.2.5) where requirements are listed in order of importance.

2.2.5 Define design specifications

To define design specifications each design requirement should be associated to a target value. According to Roozenburg and Eekels (1995), design specifications dot not define a solution to the design problem, but rather serve as criteria for the evaluation of design alternatives, besides giving direction to the generation of solutions. It should be clear that design specifications are dynamic, they may be changed during design process as new and more information become available. Table 3 shows design specifications.

Table 3 – Design specifications.

Design Requirements	**Target Value**
Time for assembly and disassembly	≤ 20 min
Cost of maintenance	70 % of production cost in 1500h
Cost of production	≤ R$ 600,00 (cost for each line of plantation)
Be safe	
time for maintenance	≤ 10 min (for each fertilizer feeding module)
Application of one, two or three types of fertilizer simultaneously	Yes or no
Easy assembly and disassembly	
Feeder driving torque	≤ 1Nm
System's total mass	≤ 30 Kg (total weigh per line of plantation)
Systems reliability	90% in 1500 h
Feeding module mass	≤ 15 Kg
Number of components	to be defined
Permissible size of sediment particles	≤ 6mm of diameter
Maximum dimension feeding module	≤ 800 mm
Use of tools for assembly and disassembly	≤ 20 % of interfaces
Driving speed	≥ 50 and ≤ 300 rpm
Checking of bin fertilizer level from tractor cabin	Yes or no
Conventional manufacturing processes	100 % of processes
Time for lubrication	≤ 2 min per feeding module
Easy manufacture	
Components available on market	≥ 50 %
Product life	1500 h
Standardized components	≥ 50 %
Storage of fertilizer application data	Yes or no
Fertilizer flow rate	From 0 to 0,115 Kg/s
Nice aesthetics	
Lubrication frequency	≤ 30 h of use
Response time for step inputs	≤ 2 s
Maintenance frequency	≤ 100h
Mass flow rate coefficient of variation	≤ 20%
Maximum ground inclination	≤11°
Necessary changes for upgrade	≤ 20% of components
Fertilizer storage capacity per line of plantation	150 Kg
Bin height	750 mm
Average mass flow error in steady state	≤ 5 %

2.2.6 Register lessons learned

The objective of this stage is to register knowledge gained during the informational design phase, making it available for future works. The following paragraphs describe lessons learned.

The application of questionnaires to various product clients showed to be a very good opportunity to identify customer needs and gather general information about the product to be designed. Questionnaires answered during personal interviews made possible to find out information that were not related to the questions themselves, but surged during conversations with clients. This shows that personal contact with clients is very important especially in the beginning of the design process. Personal interviews were performed during agricultural machinery trade shows.

During the conversion of customer requirements into design requirements, customer requirements, like *easy manufacture*, *easy maintenance* and *be safe*, have a tendency to be deployed into design requirements that are actually recommendations for *design for manufacture*, *design for maintenance* and *design for safety* respectively. This kind of deployment would make the design requirements list too long (and consequently design specifications also). Therefore, during this task, the design team has to have in mind that design requirements are characteristics product should have (or goals to be accomplished), not the way by which these characteristics are to be reached.

3. Conceptual design

Having design specifications, that is, the technical characteristics that product must have, it is possible to step up for the next phase of design process, which has a lower degree of abstraction. In conceptual design product is no longer represented textually, but in a geometric way, making use of drawings, sketches and CAD models.

Informational design deals with gathering and transformation of information. Conceptual design basically deals with search, creation, representation and selection of solutions in a mental process named synthesis. Firstly, solutions are defined in a very abstract form, independent of physical principles and represented by function structures. Subsequently, starts the definition of the product concept, which is a simplified geometrical physical representation of a product.

Section 3.1 presents the conceptual design methodology used in this work. Section 3.2 describes the execution of such methodology.

3.1 Conceptual design methodology

As for the informational design phase, a particular conceptual design methodology was applied. The methodology was created based upon Pahl and Beitz (1996) design methodology with some insights from Erixon et al (1996).

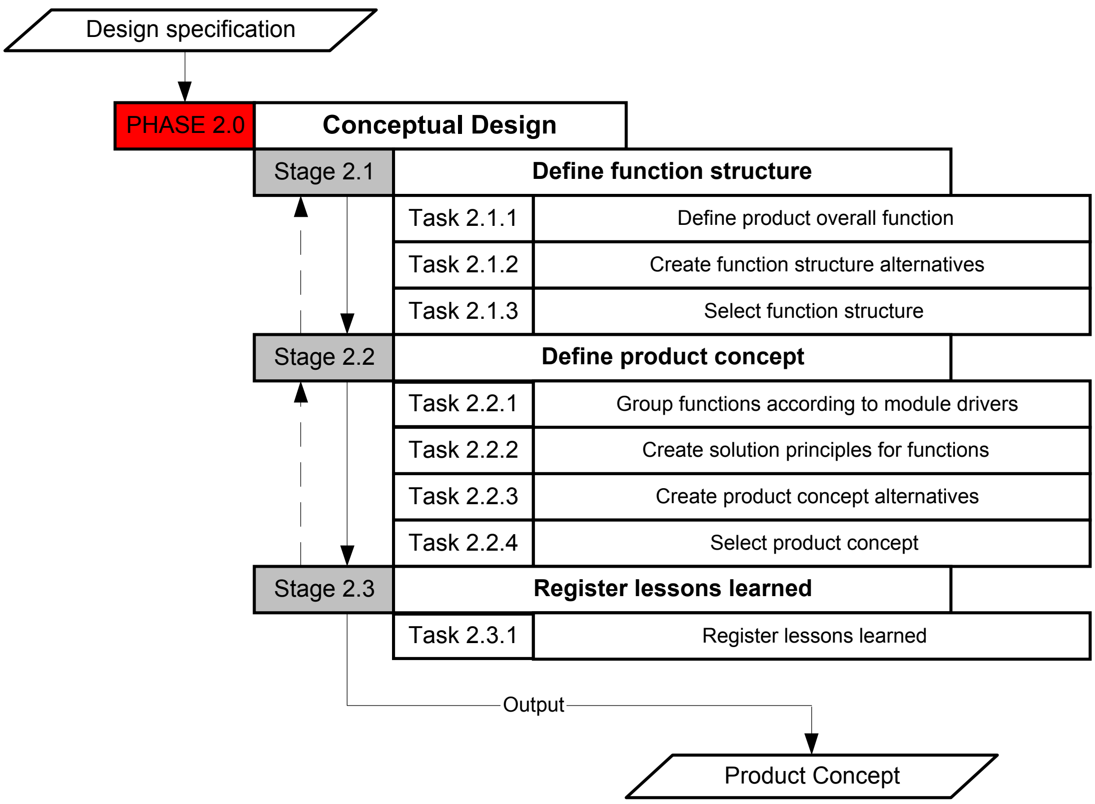

Figure 2 – Graphical representation of the conceptual design methodology.

3.2. Conceptual design execution

Following is the development of conceptual design showing the methods and tools used in its stages and tasks.

3.2.1. Define function structure

Before the creation of product concept it is necessary to define the blueprint of the product according to the functions that it needs to perform. This functional map is called function structure and consists of a set of functions, interconnected by flows, graphically represented in a block diagram (Pahl and Beitz, 1996; Back 1983)

A function can be understood as a relation between input and output with the purpose of performing a task (Pahl and Beitz, 1996). It can also be understood, in a similar way, as the relation between cause and effect of input and output (Back, 1983). Functions are usually defined as a predicate composed of a verb and a substantive like: *apply fertilizer*, *supply power*, or *store fertilizer*.

The three types of flow that are converted in a technical system are matter, energy and signal. According to Stone and Wood (2000), signal is actually a energy flow, but is classified as signal because it carries some type information.

Departing from the design problem it is possible to define a function that expresses the relationships between the product's inputs and outputs. That is the overall function. According to Ferreira (1996), the overall function must express the main product function(s), that is, it must be a summary of what can be expected from the product in a functional way.

It would be rather difficult to find an overall function that directly transforms product input and output, however, it can be decomposed successfully in simpler functions so that the problem can be solved more easily (Back and Forcellini, 2001). The overall function of the fertilizer application system is shown in figure 3.

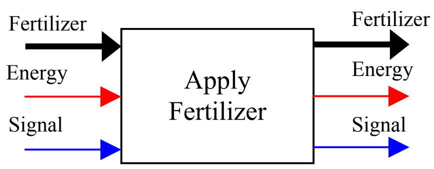

Figure 3 – Overall function of the fertilizer application system.

Following the recommendations of Pahl and Beitz (1996), the overall function was decomposed in six different function structure alternatives. The selection of alternatives was performed firstly with Puhg's (1990) selection matrix. In this method one alternative structure is chosen to serve as a reference to which comparison is made against. This method appears to be very effective in pointing out the weak and strong points of the alternatives, however, changing the reference, the alternatives rank also changed. To confirm the results of Pugh's method, an absolute evaluation method was also used. It uses an absolute qualitative scale for the alternatives evaluation. More information can be found in Roozenburg and Eekels (1995) and Back and Forcellini (2001). The Fertilizer application system function structure is represented in figure 4.

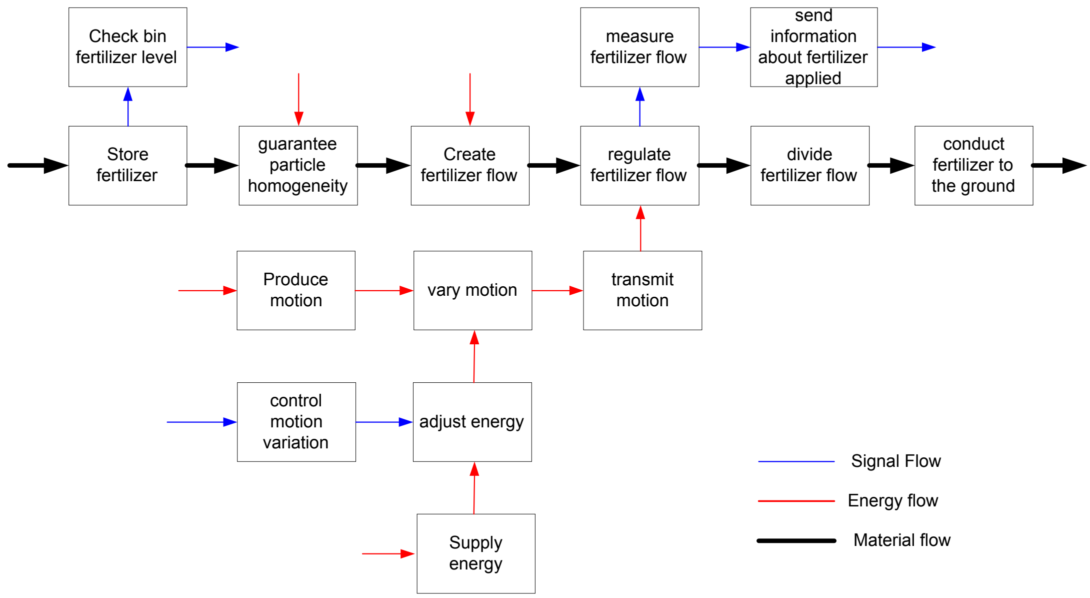

Figure 4 – Function structure of the fertilizer application system.

Actually, the function structure above should be represented (repeated) three times since the system has to handle three types of fertilizer, however it would require much space and would not add much for functional representation.

3.2.2. Define product concept

This stage starts with the grouping of functions according to module drivers. The concept of module drivers is described by Erixon et al (1996). Module drivers can be understood as reasons to modularize a product. Erixon et al (1996) also presents the MIM (Module Indication Matrix), this matrix is used to define which functions can be modularized and which functions can be integrated in the same module.

Grouping of functions make it possible to search for solution principles that integrate functions, instead of trying to integrate functions after individual solutions are already defined (integrate solution principles). This approach tries to minimize some disadvantages that usually arise with design for modularity, such as increase in weight, material costs and redundancies. This step is the first one towards the definition of product modules which is finished during preliminary design.

An example of functions grouped according to module drivers can be seen in figure 5 – morphological matrix (partial). Basically, the morphological method (more information about the method can be found in Back and Forcellini, 2001; and Pahl and Beitz, 1996) lists product functions in the fist column of a matrix and then for each function (or for each group of functions) many different solution principles are represented (figure 5).

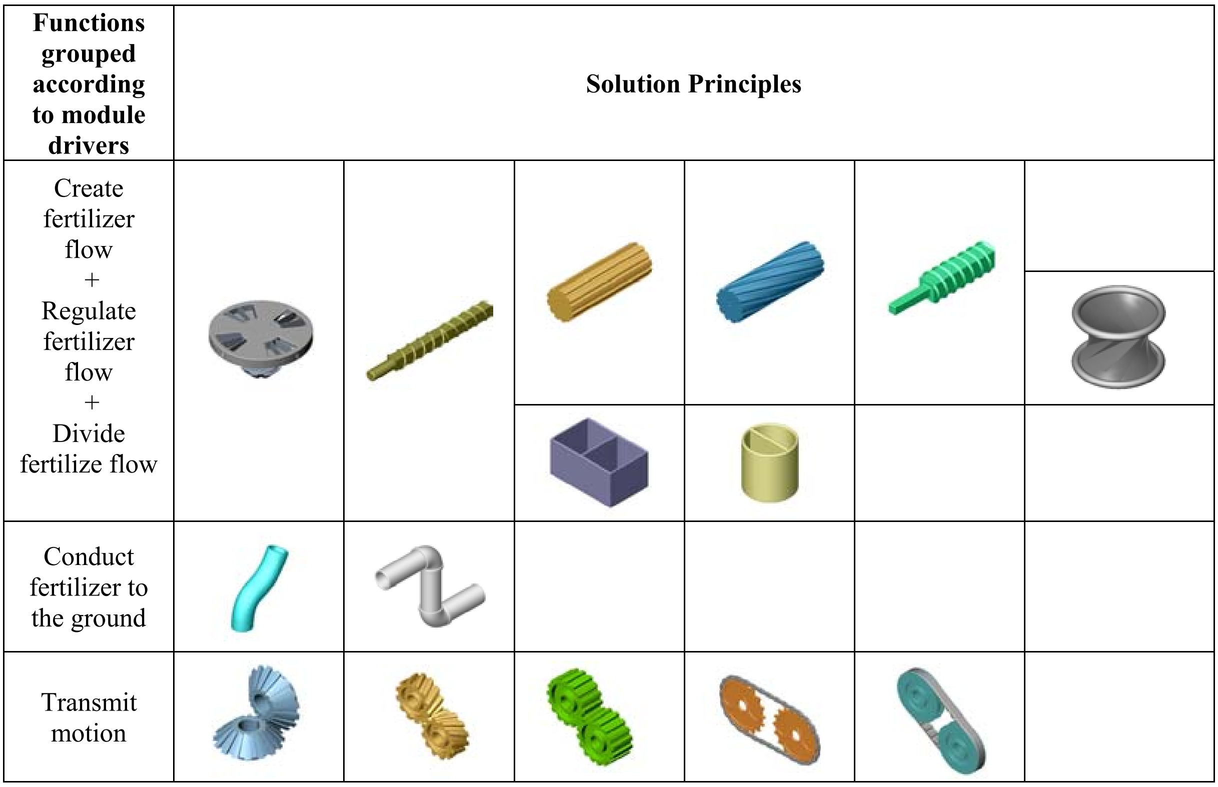

Figure 5 – Part of the morphological matrix.

Current solution principles can be searched in books, catalogs, articles, web sites. New solution principles can be created with the aid of creativity methods like brainstorming, direct analogy, symbolic analogy, synergetic, and TRIZ (Back and Forcellini, 2001). During the creation of new solution principles, the design team should not be concerned about the feasibility of solutions, this can be done afterwards during the creation of concepts.

By the combination of solution principles concepts are created. However, thousands of concepts can be obtained by simply combining solution principles. To obtain viable concepts, compatibility between solution principles has to be assured. One should also note that morphological matrix only represents form, but aspects like energy type, velocities, force transmission, layout, among others are very important to be observed during the creation of product concepts alternatives.

The compatibility matrix presented by Pahl and Beitz (1996) was used to aid the creation of a total of seven alternatives. Subsequently of this task, one or more promising alternatives have to be selected to proceed to preliminary design. Methods for concept selection are described at Roozenburg and Eekels (1995); and Back and Forcellini (2001). The absolute evaluation qualitative method, described in section 3.2.1, was used and the design team decided to select the top three ranked concepts to be further detailed during preliminary design. Due to the lack of space, only two of theme are shown in figures 6 (concept A) and 7 (concept B).

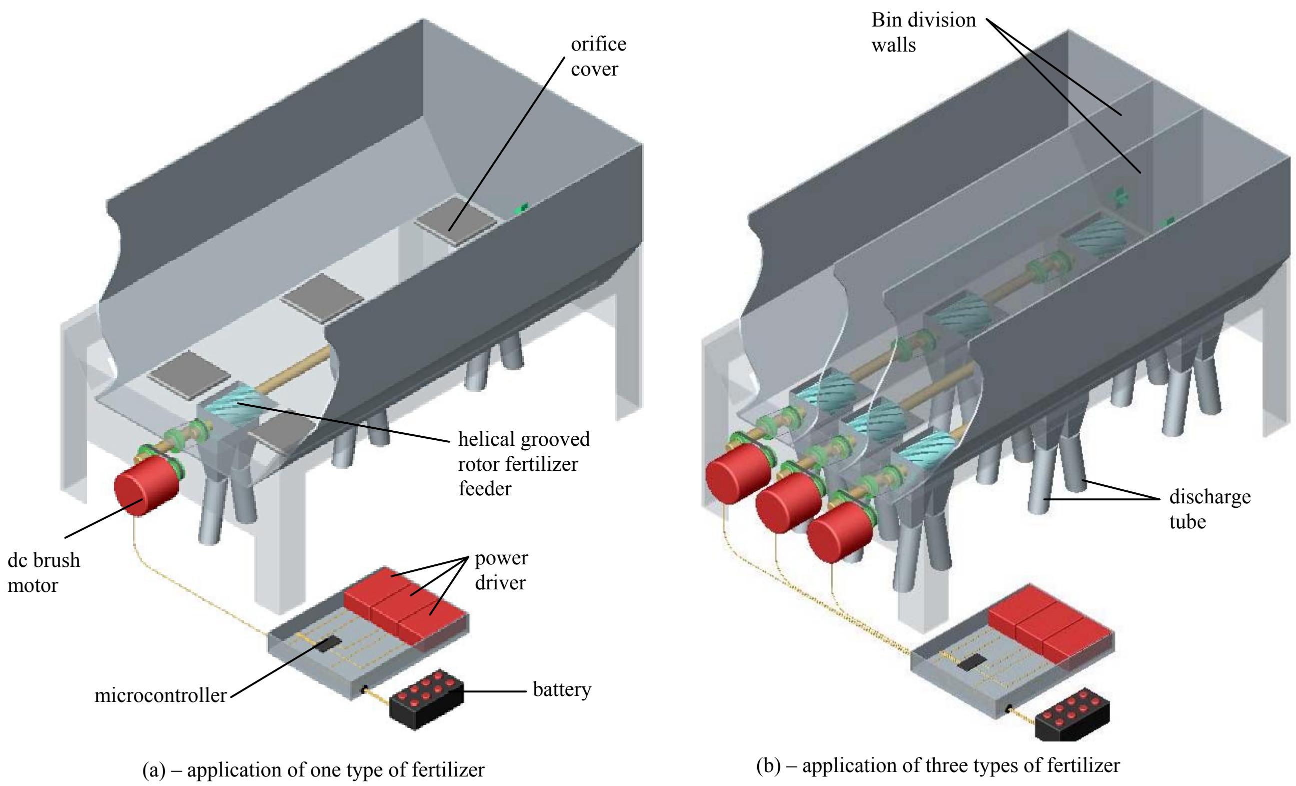

Figure 6 – (a) Concept A configured for application of one type of fertilizer; (b) concept A configured for application of three types of fertilizers.

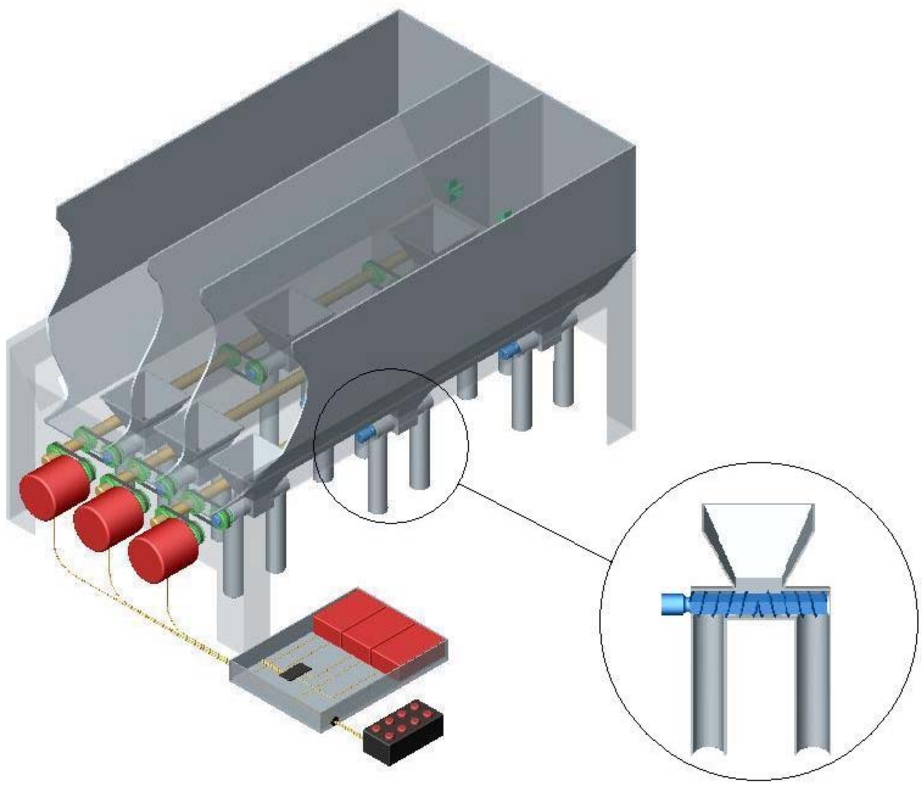

Figure 7 – Concept B with screw feeder in detail.

It should be noted that the main difference between concepts is the type of feeder. Concept A uses a helical grooved rotor and concept B uses a screw feeder.

3.2.3 Register lessons learned

Evaluation methods may give a false confidence to its results. Since the ranking of alternatives is usually based upon scores, one could easily take the highest score alternative to be the best one. However, the ranking of alternatives in conceptual design is usually done based on subjective judgement, and the definition of criteria weigh is also done in a subjective way. Small changes in subjective judgement and weighing can cause the mathematical results of methods to change. Even though, they give a very good direction towards good alternatives. Having this in mind, the design team should see those methods as an opportunity to identify strong and weak points of alternatives, so they can be modified or combined for improvement. Evaluation methods must not be applied in a "blind" way, the question "*why is this alternative better?*" should always be made and final decision must be based on team members' opinion.

4. Conclusions

This paper presented the informational and conceptual phases of the design process of a solid fertilizer application system for precision agriculture. The main outputs of each stage of the methodology were shown. Design specifications considers needs that come from various customers of the whole product lifecycle. Conceptual design supplied seven different concepts being three of them shown here. Concepts A and B were considered to be very promising and will be further detailed in preliminary design. Although the concepts have not yet been built and tested, the design team is confident that they will prove to reach design specifications and be cost effective. CAD models show that the application system can be easily configured to the application of one, two or three types of fertilizer.

From above we can conclude that:

(a) the design methodology was adequate since the design process was conducted in a systematic and organized way, without restricting creativity, the multidisciplinary aspects of the design problem were held efficiently and the main outputs of each phase (design specifications and concepts) were considered valid;

(b) The design for modularity approach allowed concepts to be designed to have a flexible configuration according to the number of types of fertilizer to be applied; and

(c) Variable rate application equipment can be manufacture with reasonable costs since the concepts shown have no highly expensive component, what allows prototypes to be built and tested in laboratory.

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