THE FUNCTION STRUCTURE AS A TOOL FOR ANALYSING AN EXISTING CONCEPT OF A CENTRIFUGAL FERTILIZER SPREADER

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Abstract. *It is known that nowadays a good portion of the manufacturers still use cut n' try techniques in designing and producing machinery for agricultural purposes. It can be perceived that design uncertainty is large, and this issue needs solution. In order to meet this purpose, this article focus on the application of the function structure, in gaining deeper knowledge on the current mode of operation of a trailed centrifugal fertilizer spreader. Doing it would yield improvements on the coherence between the physical machine configuration and its intended functions, bringing better understanding of the product architecture. First, this system was deployed in a hierarchy of subsystems according to the existing assemblies. The operation event chain was then deployed through static and dynamic inspections in the operation field. This event chain provided further knowledge in stating the overall functions for systems with fixed and variable fertilizer application rate. The function structure was then deployed in two phases for the fixed application rate case, an intermediate level with partial functions and an improved level with elementary functions, which was accomplished from the thorough study of the physical processes in the machine organs. The insights gained in this process include: the possibility of assessing critical functions for the machine to perform the overall task; the accessibility for establishing modes of operation and function exclusions in order to avoid bad interactions among entity flows; the ability of intervening in the product production management in modifying the assembly structure onto an organization by function; and, the possibility to derive new concepts which can better meet design specifications for the variable rate application version. The findings allow to state that the manufacturing organization will be able to verify the coherence of its product architectures by using this set of methods.*

Keywords*: Mechanical systems, engineering design, function structure, conceptual analysis, product architecture.*

1. INTRODUCTION

According to McColly & Martin apud Mialhe (1974), agriculture is the art and science dedicated to the exploration of plants and domestic animals which includes their breed, growth, preparation and disposal in the market to the final customer. In agriculture, technical knowledge is used in order to achieve such goals, with the application of three major knowledge branches as biology, engineering and economy. Mialhe (1974) states the value of engineering in serving the agricultural production process as dealing with technical problems linked to the execution of agricultural operations as to the maintenance of adequate conditions for plant and/or animal growth.

Those problems define the purpose for designing products to fulfill the needs and requirements of agricultural applications. This purpose, it can be said, is to perform an intended transformation, using energy, material and information for satisfying interests from agricultural business stakeholders. Those interests motivate a set of needs that the agricultural technical system must purposefully satisfy, a definition similar to that from Hubka and Eder (1992). As looking at the agricultural production process with more attention, it can be perceived that nowadays the majority of the agricultural operations are done by specialized machinery. Those are technical objects whose main transformation is done upon energy with the purpose of accomplishing a given agricultural operation. Then, the definition of technical system, as stated by the authors and also by Pahl and Beitz (1996), does make sense for agricultural machinery

Taking into account that most of the current role of this country worldwide is based in the production of agricultural goods within mechanized processes, the engineering design of agricultural machinery (hereafter, AM) deserves great attention from researchers, practitioners, entrepreneurs and government authorities. By knowing that most of the AM manufacturers currently practice cut-n'-try design techniques, an effort is needed to encourage and diffuse the usage of advanced engineering design practices in this sector. As being designed this way, several AM design analyses are by-passed before transforming design information into physical components, assembling them and testing.

Often these tests prove to be unsuccessful, so the design goes back to design and engineering personnel in order to be reviewed and modified for getting taylored according to field considerations. It can be perceived that design uncertainty is large in designing such machinery, and this issue needs solution.

Looking to participate in this effort, we present results of research work whose realization was agreed between research personnel from the Federal University of Santa Maria and a well-known Brazilian AM manufacturer. This one applies the function structure with the purpose of gaining deeper knowledge on the current mode of operation of a trailed centrifugal fertilizer spreader.

It means to use it as a tool for analyzing an existing concept of such mechanical system, with respect for the typical lack of records about how the machine was designed regarding its functions. Doing it would yield improvements on the coherence between the physical machine configuration and its intended functions, bringing better understanding of the product architecture. This article aims to present the results of this case study effort, and some purposeful insights taken from the case in gaining further knowledge about the process and the machine.

Section 2 displays a knowledge review on the definition of function structures and their usage in recent research works which focused in AM development; section 3 describes the AM to be analyzed in terms of its purpose and main subsystems, and deals with the process of defining the technical process and declaring the overall function statement; section 4 displays the systematic used for deploying the overall function into auxiliary function chains, and exhibits how the deployment into elementary functions has been accomplished; and, finally, section 5 discusses the insights gained from the process, in using the function structure to analyze an existing machine.

2. KNOWLEDGE REVIEW

So far, there have been published many valuable contributions on the field of engineering design research with regard to the definition of the function structure of technical systems. This case study was done by using the function structure establishment approach as described by Pahl & Beitz (1996). and exhibited in the Figure 1.

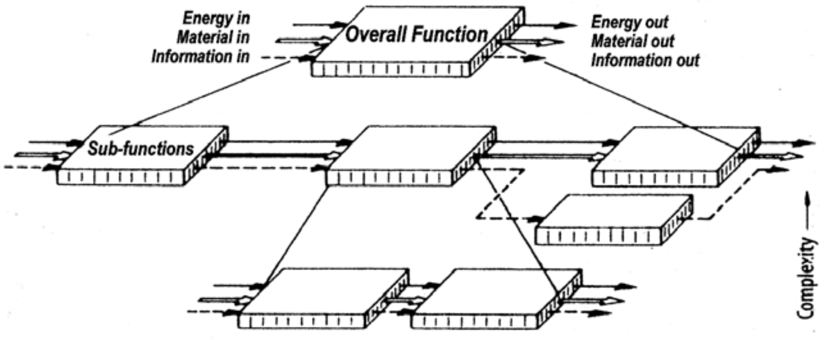

Figure 1. Overall function and sub functions for the technical object (PAHL & WALLACE, 2001).

The authors define the technical function as the relationship between inputs and outputs of a system. This point of view is mainly derived from the systems engineering approach which was created in the end of the 60’s and is described by Jones (1992), as a system was first to be designed regarding the flow of entities through processing tasks inside a given boundary in which the system currently works. This systems engineering approach, as stated by Pahl & Beitz (1996), has been adopted by some other authors in the field, such as Ulrich and Eppinger (1995). Hubka et al. (1988) and Hubka & Eder (1992) declare their approach by using the same method, but in a slightly different way.

Instead of declaring the global function directly, Hubka et al. (1998) declare first which they call the process structure. This one is composed from the tasks the system must perform in order to accomplish its purpose. According to Hubka & Eder (1992), this process structure corresponds one-by-one to the function structure, as the last one stands for the implementation – in the system – of the capabilities needed therein to accomplish the system’s purpose. According to Pahl & Beitz (1996), the overall function is to be established by the abstraction of the problem to be solved. It means that the task to be performed must be defined independently of any stereotypic thinking driven by current working principles. This satisfies the statement from Pahl and Wallace (2001), by which a function is intended to define the system purpose in a way which does not depend on the solution. Based on a block diagram representation with its respective entity flows of energy, material and information, the global relationship between system inputs and outputs will be defined regardless of solution.

The network of input/output relationships in this statement lacks transparency, so the global function is to be deployed taking into account the physical processes which are needed to accomplish the main transformation. Kanafojski and Karwoski (1976), whose book is specifically focused in design considerations, explained AM processing abilities in terms of task sequences for describing the evolution of crop harvesting machinery, besides describing kinematic and dynamic studies of mechanisms in agricultural machinery. A brief mention of engineering design practice can be found in Mialhe (1996), as the way which separates handcraftsmanship from production processes with high complexity, which demand more elaborate procedures in order to deliver the AM to the customer.

Dos Reis & Forcellini (2002) use the function structure in order to evaluate four basic design concepts for planters, which resulted from the study of several brands of large-seed precision planters and irrigated rice planters. One of the conclusions of such study is that none of the concepts performed the “deliver seed” function in an adequate way.

Romano (2003) suggests the usage of this technique for starting the development of agricultural machinery concepts. Taking into account a revision of agricultural machinery textbooks made by Marini et al. (2006), it can be stated that few references in the field take into account this engineering design technique in the development of agricultural machinery. Among the exceptions, the research works done by Dos Reis (2003) and Menegatti (2004) may be considered as examples which pave the way into establishing an advanced and coherent body of knowledge in designing agricultural machinery with the function structure technique.

The latter had its initial developments – informational and conceptual design phases – showcased by Menegatti et al. (2003), displaying basic considerations on the function structure synthesized for an inline fertilizer distributor. This work intends to establish better knowledge on how this tool could contribute to a better understanding of two aspects which play a fundamental role on defining the scope of AM development processes: the first is the AM purpose and the elements involved in accomplishing it; and, the second is the chain of tasks it is supposed to execute in order to accomplish the benefit of its customers.

3. AN AGRICULTURAL MECHANICAL SYSTEM

3.1. Purpose and technical process

The trailed fertilizer spreader analyzed in this study, displayed in the Figure 2, is an assembly of components which is used with the purpose of transporting lime (powdery), crystalline and granular fertilizer inside its hopper and applying it onto a soil that needs to have its nutrient concentrations corrected.

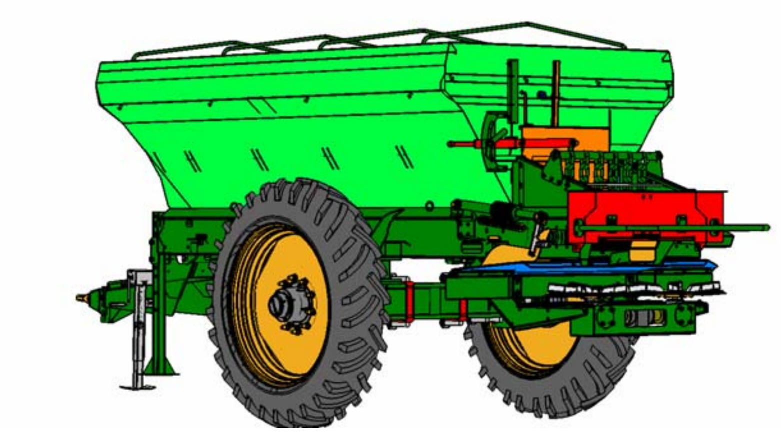

Figure 2. Physical construction of the trailed fertilizer spreader.

This work involved the analysis of an existing machine, which applies the fertilizer through the working principle of spinning, conical discs. The evaluated equipment has two physical configurations available for the discs: one with two adjustable vanes for granular fertilizer, which also can be set up for application on top of high-grown crops; and, other with six fixed vanes for application of lime and other powdery fertilizers.

The fertilizer spreader was first decomposed into subsystems, taking into account the information contained within its part catalogs, which were provided by the manufacturer. The machine decomposition structure is exhibited by the representation of Figure 3. It has led to a first stage of understanding on how the equipment effectively worked in spreading the fertilizer onto the soil. The information were collected through systematic search in part catalogs, product manuals and static observations on the product prior to use.

The coupling subsystem comprises the organs which serve to the purposes of engaging the spreader with its power/traction source and controlling its direction after power source maneuvers. The transmission subsystem includes the organs which process the received power onto carrying the fertilizer load, wheel-driving the fertilizer conveyor and power-driving the spreading organs. The hopper subsystem encompasses the grain tank assembly and sieves used for lowering the pressure load on the fertilizer conveyor track. The conveyor subsystem comprises the conveyor track assembly, the conveyor ground wheel-drive and the fertilizer flow aperture. And finally, the spreading subsystem includes the fragmenting chains (for lime only), the fertilizer deflectors, the triple transfer case and the spinning discs with their vanes.

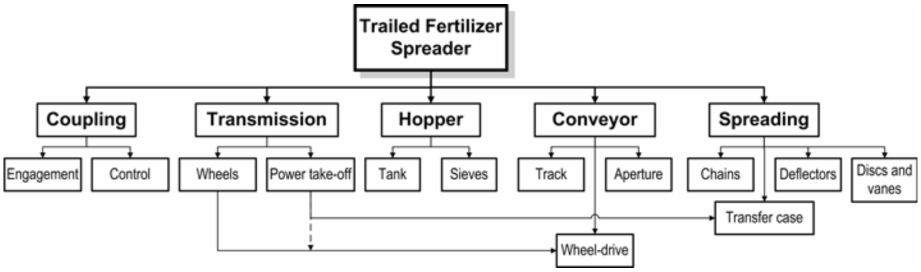

Figure 3. Decomposition structure for the trailed fertilizer spreader.

A second stage on analyzing the spreader has been done by interpreting the decomposition structure into a basic event chain for the operation, according to the directions given by Mialhe (1974) and mentioned by Marini et al. (2006) as basis for the study of AM function. The author defines the agricultural operation in a way which allows for choosing either the task sequencing and analysis or the more thorough examination in terms of partial operations of a specific task inside the operational context. The second approach was chosen, decomposing the task of applying fertilizer in order to synthesize the partial operations to be performed by the machine while working, as exhibited in the Figure 4. This event chain led to a better understanding on how it performed its basic operations.

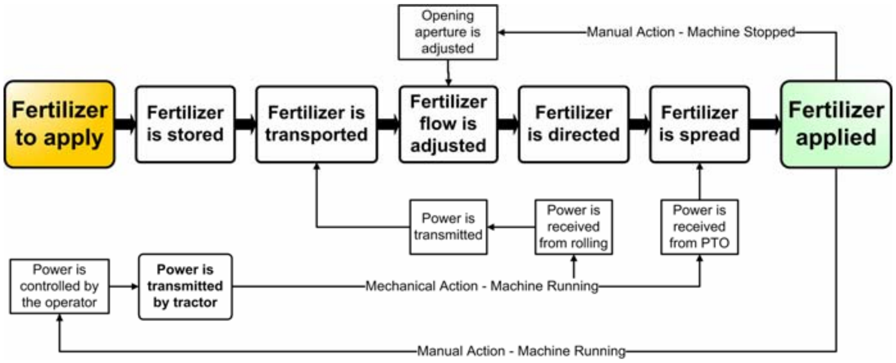

Figure 4. Operation event chain for the trailed fertilizer spreader.

This result allowed to further abstract the purpose definition of the machine, namely the overall function statement. In order to assess which elements participated in the operation, a dynamic observation was done during field machine usage. The machine is supposed to have its fertilizer flow calibrated before operation in field conditions. These functions are omitted in this stage because of the main objective of establishing the event chain of the agricultural operation. It is worth noting that it displays the partial operations in the same way as in the technical process definition as stated by Hubka and Eder (1992). It also exhibits the main controlling actions which are exerted upon the technical process of displacing the fertilizer up to the spreading organs, which effectively launch fertilizer particles onto soil. Those actions will be important for consolidating the function structure definition, as it will be explained.

3.2. Overall function statement

The in-field dynamic observations, at the structure of the Agricultural Machinery Testing Nucleus (NEMA) in the Federal University of Santa Maria, led to the declaration of external elements to the technical system. Those are: the operator, which acts from the power source during operation, but could adjust the equipment; the work area, defined by the swath where the fertilizer is spread upon; the power source, which provides the power for operating the machine; and the fertilizer itself, which is carried and transported till being spread onto the crop. The overall function statement exhibited in the Figure 5 is valid for a machine which applies solid fertilizer on soil within a fixed application rate.

System control, power take-off (PTO) shaft rotation and drawbar pull are provided by the power source; the fertilizer is responsible by the stored fertilizer and fertilizer mass inputs; the work swath receives applied fertilizer and kinetic energy within fertilizer particle speed; the environment is to receive lost fertilizer, lost energy (heat, power, etc.) and soil compaction; and the operator interacts with the system by controlling the power source while the coupled machinery is running and setting up the machine while it is stopped. Taking into account the concept and the organization of precision agriculture systems, an overall function could be inferred also for the case of variable-rate fertilizer application, as shown in the Figure 6.

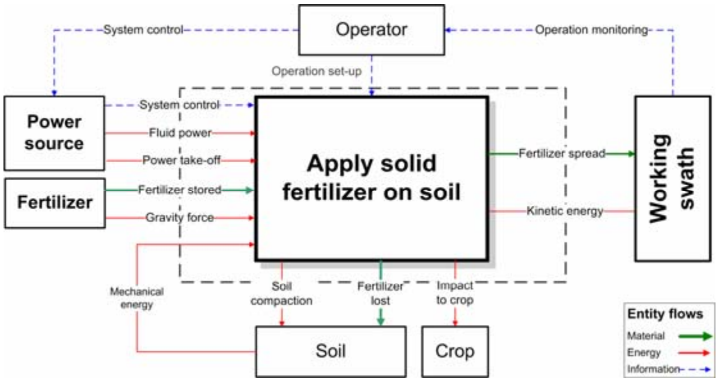

Figure 5. Overall function statement for the trailed fertilizer spreader – fixed application rate.

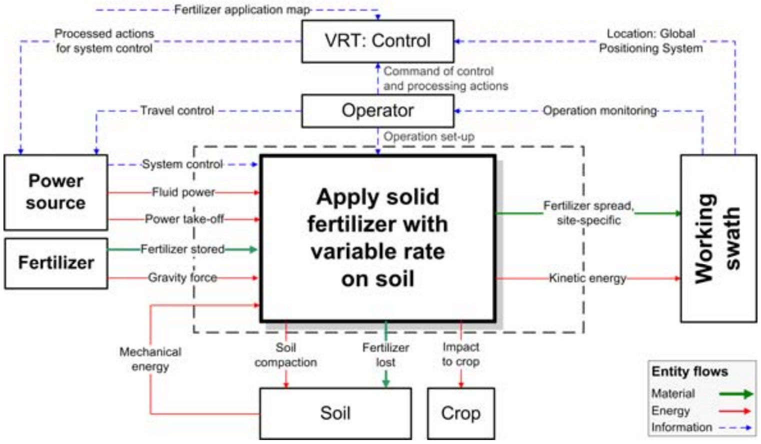

Figure 6. Overall function statement for the trailed fertilizer spreader – variable application rate.

This interpretation exhibits the presence of an information system, commanded by the operator and fed with global positioning coordinates and application map prescriptions, which does on-board adjustments during the operation.

The heuristics of visually stating the overall function is explained: the elements providing inputs for the system are positioned in the left; the elements which are supposed to effectively receive system outputs are positioned in the right; up in the middle, the operator element is presented in order to represent its control under the process; and the environment, which receives unintended physical effects from the system, in the bottom of the diagram. This one seems to reconstitute the approach used by Dos Reis (2003) for declaring his overall function statement in the design of a precision flow meter for small seeds. This heuristics is followed on through the process of deriving the elementary functions for the spreader. It can be stated that the explicit presentation of this heuristic may consolidate its role in defining a systematic framework for declaring the global function. As it can be observed both on Figure 5 and Figure 6, the overall function statement declares the elements the system interacts with and how those interactions occur.

This overall statement is to be broken down into sub-functions until the elementary level is reached. This process, according to Pahl & Beitz (1996), is done with the following objectives in mind: the determination of sub functions; and their combination of those into a simple and unambiguous function structure.

4. FUNCTION STRUCTURE SYSTEMATICS

4.1. Deployment systematics

The first phase of this process is done with the aid of the established operation event chain, shown in the Figure 4. It illustrates how the agricultural operation of fertilizer application is accomplished since the hopper is filled until the fertilizer is spread onto the working swath. This sequence is entitled to compose the main functional chain, whose line of action is to be positioned in the vertical center of the functional structure, as exhibited in the Figure 7.

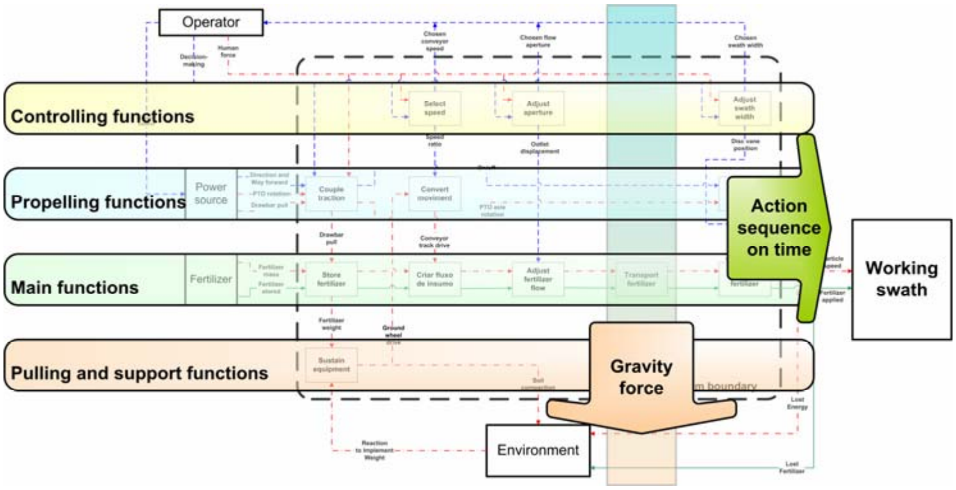

Figure 7. Approach for deriving partial and elementary functions.

Also in this picture, a first systematic arrangement was done in the diagram. The fertilizer processing functions constitute the main action chain in the function structure. The mass/weight supporting functions were positioned below the main action chain, as well as they transmit the entire weight of machine and fertilizer onto soil and receive the pulling power from the power source. The auxiliary functions with the role of transmitting PTO power were positioned on top of the main function chain. The controlling functions, most of them requiring the operator intervention, were positioned on top of the function structure, next to the upper system boundary. The horizontal flow on the function structure takes into account the sequence of actions which shall be done by the machine in order to accomplish the overall function. It was accomplished in this study that the main action chain was organized in a horizontal line even when declaring the elementary functions and their integration modules.

The approach on deriving the elementary functions is also depicted in the Figure 7. This heuristic takes into account the gravity flow, which conventionally occurs from upside down onto land, as the agricultural machinery is supposed to function on top of the crop terrain and its weight exerts a force whose effect influences heavily in crop productivity, which is the soil compaction. This is an undesired effect to be avoided as possible, with the purpose of lowering the interference of soil internal resistance in plant growth and productivity.

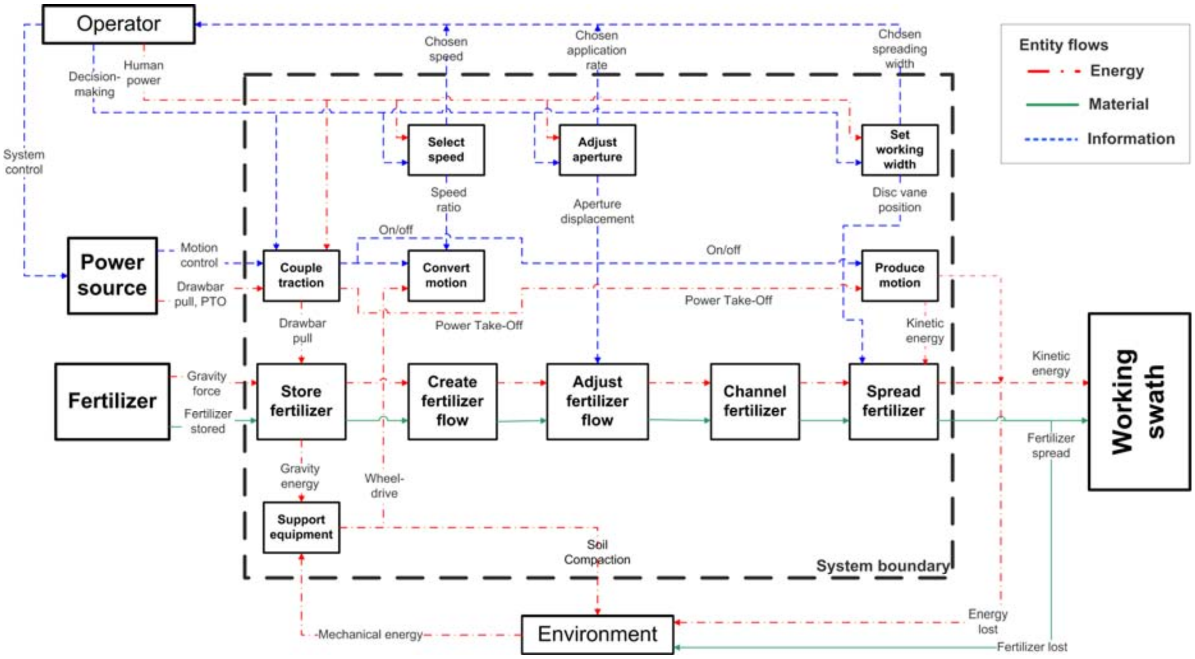

Figure 8. Partially derived, intermediate, function structure for the trailed fertilizer spreader – fixed application rate.

The elementary function structure accomplished in this study is slightly different from the partially derived, intermediate, function structure depicted in Figure 8, because of the more thorough understanding which was acquired on the real entity flows which characterized the operation of the equipment. The proper establishment of elementary functions and their entity flows is critical for the unambiguous understanding of the function structure in explaining how the equipment currently works.

4.2. Elementary functions

The part catalogs supplied by the manufacturer had a valuable contribution in helping to establish the way elementary functions were deployed. This allowed accomplishing a level of understanding the product which encompasses: knowing how it operates; knowing how the principles work; and, how it is assembled. The fundamental physical actions which constitute elementary functions could also be inferred. Thereafter, functions which were not deployed in the intermediate stage were then considered. These include other human interaction functions: the machine calibration functions as they exert an important role on establishing the extent of action from the machine components from the main action chain; and, the hopper access ladder, for verifying how much fertilizer is stored inside.

The other auxiliary functions were also deployed with physical processes in mind. The triple transfer case for spreading the fertilizer, as example – see “produce movement” function in the Figure 8 –, was analyzed into three elementary functions: receive power, transfer power and deliver spreading speed. See their representation in Figure 9.

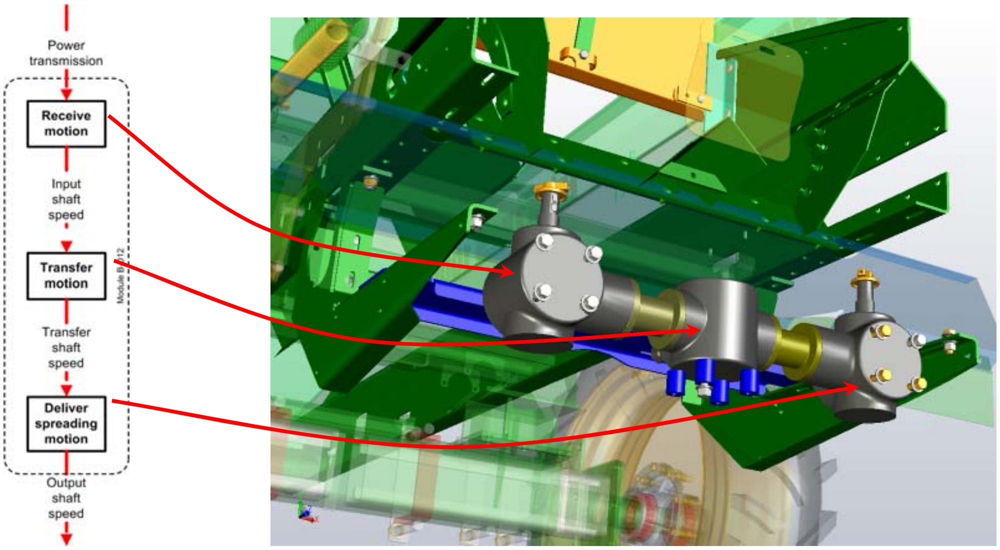

Figure 9. Elementary functions for delivery of spreading speed and their organs.

The entire function structure with all elementary function chains for the case of fixed application rate has been developed within this level. Two distinctive auxiliary power flows deserve attention.

The first power flow (C-chain, Figure 11) comes through the drawbar pull exerted by the power source (the agricultural tractor) when moving on through the crop field. This power is delivered through the coupling elements and the front-end bar, and its shocks are then absorbed by elements in connection to both front-end bar and implement structure (support fertilizer load function). This structure is then coupled to double sliding semi-axles (adjust supporting width) whose external ends can be connected also, as option, to spreading height positioning organs. The axle end bearings, connected to the implement wheels, transmit this power flow to the soil/tire interaction. This power flow is further redirected to provide for fertilizer conveyor operation through the contact of the rolling wheel with an auxiliary wheel which transmits power in torque form through a set of shafts and joints. This torque is converted inside a gearbox in order to exert a desirable traction effect in the conveyor belt, as explained by the representation of the function module exhibited in Figure 10. The picture also exhibits the functioning states near the entity flows, which mean the possibility of manual intervention for their control (see arrows).

This kind of representation, which displays sets of elementary functions inside modules, made easier to explore the functioning states of the system based upon the respective entity flows inside each module, see also Figure 9, and augmented the function structure utility by providing resources for doing safety and reliability analyses. The second power flow (see A-chain, Figure 11) comes through the tractor PTO shaft speed, which is transmitted onto the triple transfer case and then provides enough speed for the disc vanes to spread fertilizer particles onto the working swath. This power flow may serve also as spare in case of failure of the ground-wheel transmission.

Other energy flow which has not been detailed in the representations, but plays an important role in establishing the actual configuration of the machine is the fertilizer weight, which is direct result from the gravity. This one is transmitted from the fertilizer storing functions onto the fertilizer flow ones and then transmitted to the supporting functions, which deliver the load to the terrain in form of soil compaction.

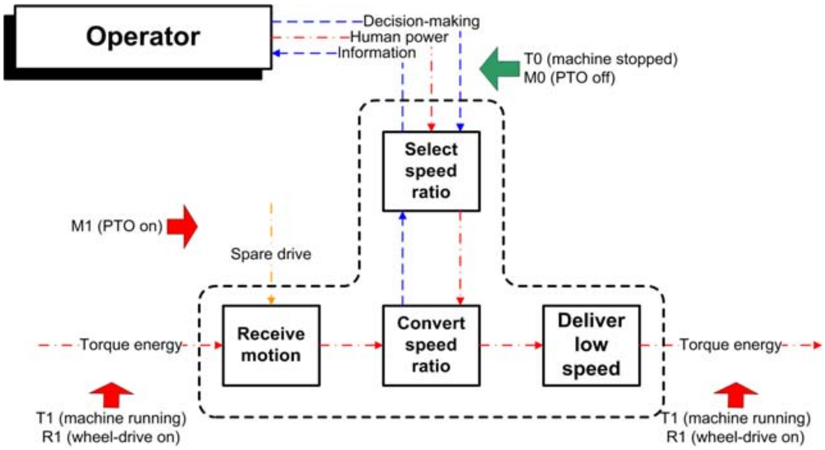

Figure 10. Transfer/reduction case module representation into elementary functions and operation modes.

The fertilizer flow (central chain, Figure 11) has been enough detailed in the operation event chain and in the intermediate partial function structure, and is informed through the main action chain. The heuristic approach used in representing the elementary level function structure was done by two means. First, the area inside the system boundary has been considered like inside a two-dimensional matrix, whose columns imply the sequence of action among system functions and lines imply the delivery progress of auxiliary entity flows into the main action chain and/or the transmission of weight through the supporting functions to the crop terrain. Second, the main action chain is represented in the vertical center of the structure and its graphic elements are a little bit emphasized, with the purpose of establishing a strong reference when reaching high complexity in its representation.

Other adjustment functions were included in the elementary function structure were: the machine height adjustment fro top-dressing application upon well-grown crops; and the axle width adjustment for row-crop setting, which is to be done properly depending on the existence of row-crop spaces in order to avoid plant damages. The remaining elementary functions were derived from using an approach on deriving physical actions performed by the machine during its operation from its component structure. The main action chain, derived from the operation event chain was also developed in order to declare the additional physical actions which are performed by the machine in order to accomplish the overall function statement.

The X, Y, and Z-chains (Figure 11) represent the controlling functions of the equipment. While they were supposed to be placed in the superior portion of the structure, they had to be displaced in the representation because of their interfaces with power and main flow chains (A, B, and C). In order to solve such problem, the inputs and outputs were all declared for each function chain, according to the approach used by Stone at al. (2000). The elementary function terminology was defined to provide an adequate understanding of their actions for product engineering purposes.

5. INSIGHTS AND CONCLUSION

When dealing with an existing product, the deployment of its function structure could lead to a better understanding on how its components and modules should be assembled. This is stated by Pahl and Beitz (1996), which in addition suggest that the deployment of the function structure allows a clearer definition of current machine subsystems and even newly developed ones. These affirmations can be assessed as true in this case. The thorough study of equipment actions and their principles is synthesized in a unitary representation of the actions involved in the actual mode of action of the machine. Despite the inherent complexity of such representation, it brings valuable information which may define the difference between success or failure in designing. Some specific training of design practitioners into the subject of function structuring would leverage the knowledge gap from the current level to a better understanding.

Such was accomplished by this research work and the results are therefore exhibited. First, a better knowledge on which functions and respective organs would be the critical ones for the proper functioning of the machine. The transfer/reduction case which provides shaft rotation for the traction of the conveyor belt track may be considered as the most critical component for the performance of the overall function. The entity flows and elementary functions of the developed function structure can constitute an important basis for the development of a FMEA (failure mode and effect analysis) procedure on which consequences might be foreseen on the machine performance if the transfer case fails.

Second, there is possibility of establishing operation modes in each entity flow within the entire function structure. If there are two incoming entity flows to a certain function, one from PTO shaft and other from human action, the functioning of one of them would be prevented in order to preserve human safety in machine usage.

The modes of action would be established depending on the adjustment possibilities of the entire system and the intended functioning states, according to operating needs of the analyzed function. An example is depicted in the Figure 10. The definition of operating modes is to be applied upon each entity flow, which has to be identified from its source onto its application chain. In the example, the ground wheel-drive (energy flow) applies onto the elementary functions which are constituted by the power-transmitting organs inside the transfer case. As the gearbox is not synchronized, its speed ratio can not be changed unless the power transmission is off. So, it can be established, which entity flows can operate and which can not operate. The third important insight is that interventions might be done in the manufacturing and production system which currently makes the machine available to market.

The bill-of-materials, which establishes how the machine is to be assembled, can be changed in order to take into account the module divisions that can be inferred from the establishment of the function structure, This would create better conditions for concept flexibility, in two main aspects: upgrading, in which the product owner/operator perceives a need in improving its operation capacity by adding modules with higher specifications; and, retrofitting, in which the customer foresees a service advantage by adding specific equipment for application management at variable rate.

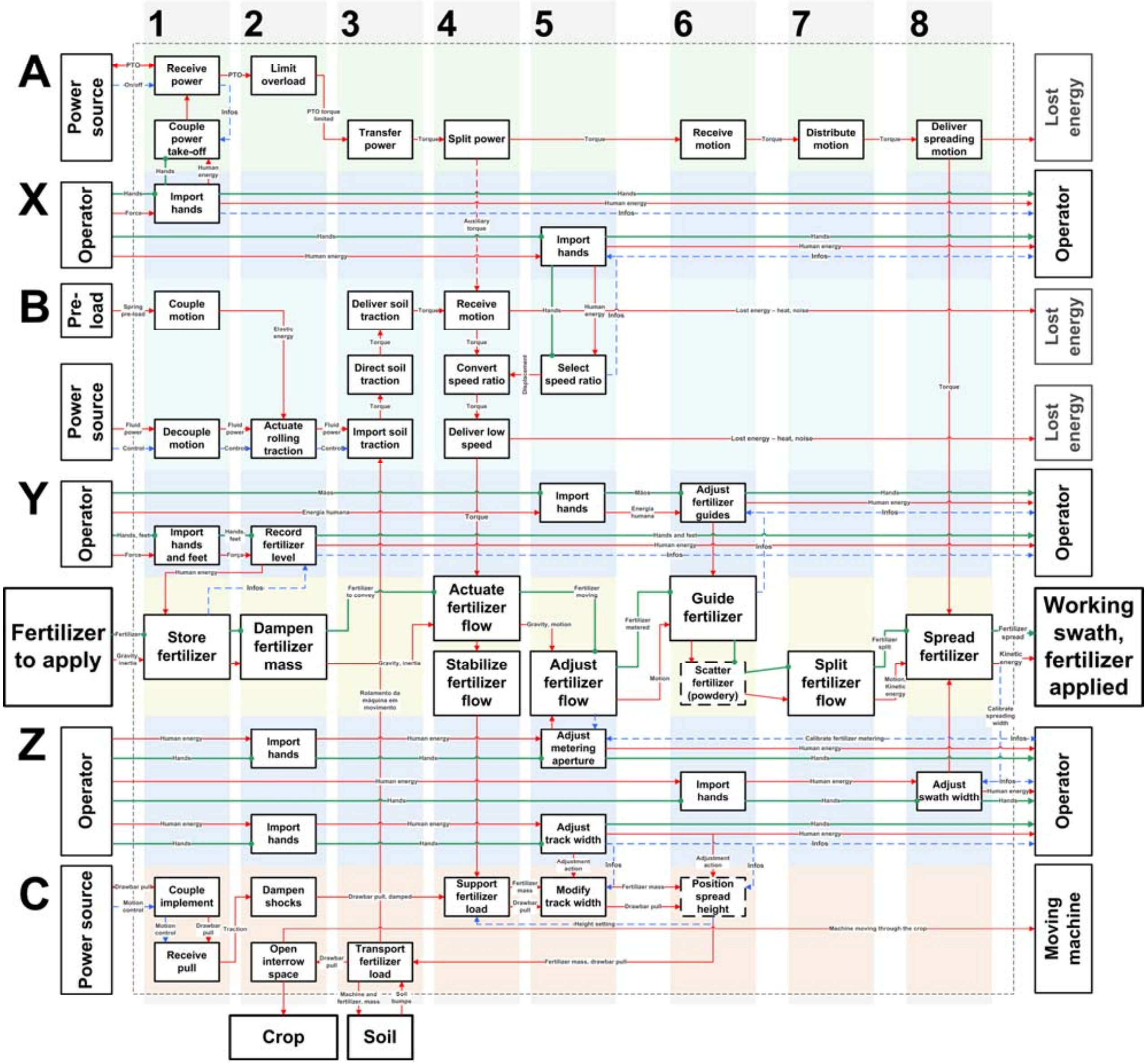

Figure 11. Elementary function structure for the trailed fertilizer spreader – fixed application rate.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE