An introduction to the reference model for the agricultural machinery development process

Leonardo Nabaes Romano
Federal University of Santa Maria
romano@smail.ufsm.br

Nelson Back
Federal University of Santa Catarina
back@emc.ufsc.br

André Ogliari
Federal University of Santa Catarina
ogliari@emc.ufsc.br

Vinícius Kaster Marini
Federal University of Santa Maria
marinivk@gmail.com

Abstract: The majority of Brazilian industrial companies operating in the agricultural machinery sector use an informal product development process. This is most apparent in small and medium sized companies, whose products are usually developed based on adaptations of existing, previously commercialized, solutions. This paper proposes a Reference Model for the Agricultural Machinery Development Process (RM-AMDP), designed to clarify the existing knowledge of this process, thereby shedding light on and formalizing this practice. The reference model comprises the phases of project planning, product design and manufacturing planning, pilot production, product launch on the market, validation of agricultural machinery and project closure. Each of these phases is composed of activities for which the input data required for their execution and their deliverables are modeled. Three other dimensions of the process are also detailed: the knowledge domain, the mechanisms used and the controls. This model can be applied for teaching engineering students and as a basis for companies to improve their product development processes.
Keywords: engineering design, project management, product development process, reference model, agricultural machinery

1. Introduction

Nowadays, there is a growth of research activities on the subject of product development process (PDP) in a variety of industrial branches,e.g., automotive, aerospace, plastics, civil construction, agricultural machinery, food products, among others (ROZENFELD, 1997; VALERI et al., 2000; ARAÚJO et al., 2001; DARÉ, 2001; ROMANO, F. V., 2003; ROMANO, L. N., 2003; PENSO, 2003; SANTOS, 2004). Thus, these efforts produce specific contributions to the improvement of the PDP for each specific sector. Because of its complexity and by the very particular characteristics of each industrial segment, there are several subjects which may be studied and thus improved. It is interesting that, often, accomplished studies in a particular branch can have the same needs and purposes of studies in other, totally odd, branches. In these cases, it may be stated that the knowledge interchange and sharing can help in establishing directives and solutions which may meet the particular aspects of each sector. For any branch of knowledge, a common phase in the improvement effort is the modeling and assessment of current development processes, with the purpose of knowing and describing the way they are undertaken in practice (ARAÚJO et al., 2001). Thus, it is the process modeling that permeates the research processes of this nature, even in different industrial sectors.

Process modeling may be defined as the set of activities to be followed and executed to create one or more models of a process in general, composed by its domain universe, to meet the purposes of representation, communication, analysis, synthesis, decision-making or control (VERNADAT, 1996). According to the same author, it supports a better understanding and an uniform representation of processes, it helps in the planning of new areas and the resulting model can be used for controlling and monitoring the daily process operations.

It is widely known the way by which the PDP is undertaken in a great number of industrial companies of the

Brazilian agricultural machinery sector. This occurs more often in small and medium-sized companies, which do not use systematic processes for the product development, making it easy to quote examples where this process is practiced with the only support of the experience knowledge of the main responsible for the project (ROMANO et al., 2001), exposing the company to a set of risks which may affect its competitive ability.

Even inside the companies which undertake the process with a certain degree of formality, more often in the large companies, there are problems, among others, in the starting phases of the product design process. For instance, the lack of application of design methods which help in conceptual generation, that causes difficulties in meeting the real market needs – the Brazilian market only is widely diversified – which directly affect the field performance of those machines. Thus, it can be assumed that the industrial sector corporate culture values only the product and not the process by which it is developed.

As result, the development of new products – new machine concepts – is undertaken in some cases only by technology transfer agreements with foreign companies, it is, the selling of Brazilian-manufactured, foreign-designed products. With rare exceptions, the PDP in the agricultural machinery industrial sector is based in the definition of the market need and in the custom adaptation of existing agricultural machine concepts, resulting in the market launch of very similar products. The direct consequence of this situation is that the companies lose opportunities to improve their knowledge about the current products, because they lack to consider the systematic approach for the PDP which determines more formalism.

Thus, a new paradigm shall be established, which determines that the development process is to be more important than the product itself. In this case, it is unbearable for the companies to ignore the manner, it is, the processes by which the products are developed. They need to evaluate the PDP as practiced (WHEELWRIGHT & CLARK, 1992; ARAÚJO et al., 2001; VALERI et al., 2000).

With such purpose, the evaluation systematic of the agricultural machinery development process (ES-AMDP) proposed by ROMANO et al. (2005) helps in diagnosing the PDP practiced inside the companies. This reveals, by specific criteria, the strong and weak points of the process, undertaken either by an informal manner or formal, helping in planning a migration path for an improved PDP, supported by a reference model and in conformance with the company established business objectives and goals (Figure 1).

Inside this context, this article presents the Reference Model for the Agricultural Machinery Development Process (RM-AMDP).

2. Reference models

A reference model, as defined by VERNADAT (1996), is a partial model (or not) that can be used as baseline for development and evaluation of particular models. A critical characteristic of a reference model is the building of a holistic vision of the process, about its activities, resources, organization and its information flow, as about its inter-relationships. This characteristic generates an idea of uniqueness and integration about the process. Besides,

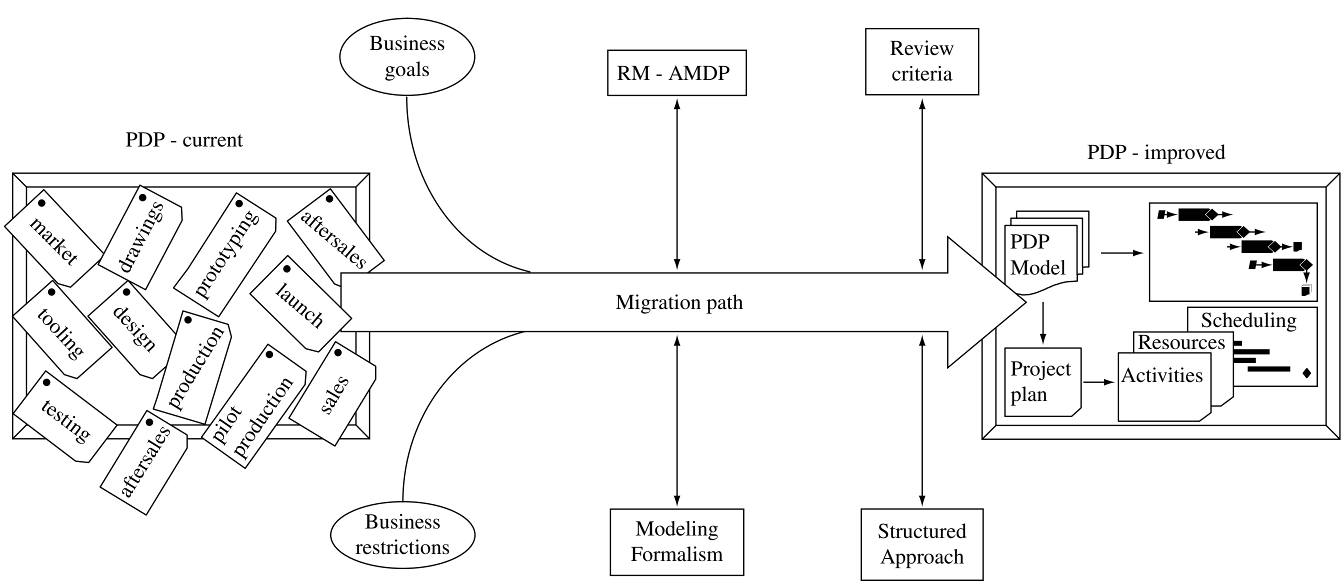

Figure 1. Migration path for PDP improvement (adapted from VERNADAT, 1996).

the reference model development allows the understanding of product life-cycle information, as well as the integrated usage of auxiliary design and management methods and techniques, establishing a detailed and integrated work perception.

2.1. Reference model structuring: graphic and verbal representation

As the purpose of reference models is to make explicit the process knowledge, the elaboration of a reference model for the AMDP demanded the development of a representation structure able to meet the following requirements:

- A representation based upon a process vision, in conformance with the strategic plan of business and products within the organization;
- The overall perception of the PDP, through the cohesion in graphic and verbal representation;
- Process subdivision in phases and macro-phases;
- Indication of the logic sequence of activities;
- Presentation of what shall be done throughout the process, it is, the activities and tasks, supported by concurrent engineering principles and by project management process directives;
- Indication of the involved knowledge domains in the execution of each task;
- Definition of the information needed about activity execution, presented in the way of forms, methods, tools, resources, etc;
- Definition of phase exit evaluations, and their desired deliverables;
- Implementation of improvements to the reference model (new phases, activities, etc.); and
- Employment of easily accessible and ready-to-use computer-based tools.

As start, a graphic representation of the reference model has been developed, shown in the Figure 2. The "process" is represented by a unique pentagon, subdivided in "n" irregular pentagons, representing the process macro-phases, which are further decomposed in "n" phases. The number of macro-phases and phases changes along with the studied process. In each phase exit, there are rhomboids representing the evaluation points about the phase deliverables and their desired outputs.

From graphic representation, the reference model structure was established upon a spreadsheet format composed by "n" sheets, each representing a phase of the AMDP. Each phase is described through seven elements: inputs, activities, tasks, knowledge domains, mechanisms, controls and outputs. The element layout in the spreadsheet is shown in the Figure 3.

In each spreadsheet line the activities and tasks which represent the work to be done are described. Inputs, mechanisms, controls and outputs are the basic modeled dimensions that describe each task, following reference model following the recommendation given by the IDEF0 methodology (NIST, 1993).

The described tasks in the reference model are classified by knowledge domains, whose purpose is to help for identification of needed personnel and abilities for task execution. In the majority of cases the knowledge domains are related to the functional departments of an organization. Due to the multidisciplinary nature of the PDP, tasks may be linked to more than one knowledge domain in some cases, it is, they may involve personnel from several organization areas, either contributing to the task itself or taking group decisions.

One of the resources that can be used upon the spreadsheet reference model structure is the usage of filters to the description elements in each phase (inputs, activities, tasks, knowledge domains, mechanisms, controls and outputs), allowing to locate a specific information subset of the whole model and work with it. The advantages of this resource can be observed when a named domain is filtered, allowing the visualization of all related tasks throughout

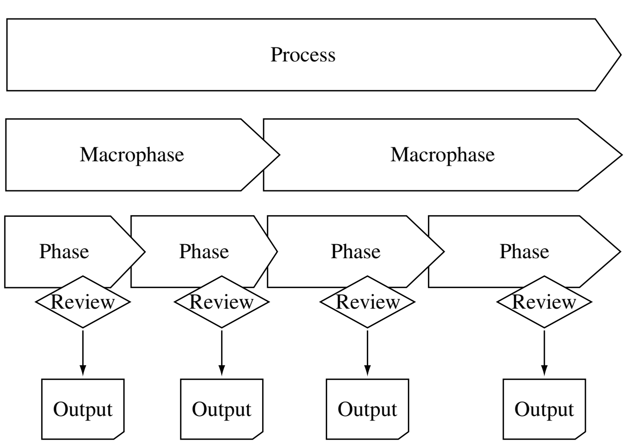

Figure 2. Graphic representation of the reference model.

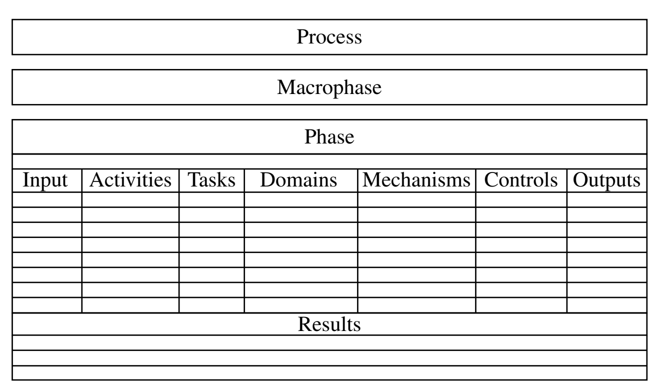

Figure 3. Element layout in the spreadsheet.

the process. Other example is the identification of usage of a named mechanism or control, for assessment of model consistence.

2.2. Contributions from the structure for representation of reference models

This representation structure grants improvement studies and changes in the PDP, by the overall visualization, with the purpose of establishing an adequate environment and a work methodology to support its execution. Among other contributions, the following may be stated: leveling of the understanding degree about the process across the several company areas; personnel selection, training and adaptation to the process; sharing of deliverable-defined common goals among the team members.

With focus on the process management the project manager has, by the several possible visualization arrangements generated by information filtering in the electronic spreadsheets, adequate conditions to establish the procedures needed for the PDP conduction, not depending on the project typology in which refers to the integration, scope, time, costs, quality, to the human resources, communications, risks, supplies, as does recommend the NBR ISO 10006 standard (ABNT, 2000). In addition, this kind of representation permits easy and fast content updates, and manuals, flow diagrams, presentations, etc. can be produced from it for the project management process, easing the planning, communication, training, analysis, synthesis, decision-making and project control.

In which it takes account the concurrent engineering principles, the reference model representation structure for the PDP allows a visible concurrent process, by the definition of activities that may be executed in parallel, e. g., the product design and the manufacturing plan, among others, easing the accomplishment of a good project for manufacturability and logistic support.

3. Reference model for the agricultural machinery development process

The Reference Model for the Agricultural Machinery Development Process (RM-AMDP) has been developed with the purpose of clarifying the knowledge on the PDP, providing support for the process understanding and practice. Thus, the RM-AMDP can be used either in professional formation and/or in the updating of product development professionals, as baseline for the implementation of improvements in the PDP inside the companies. In other words, the RM-AMDP contributes to a more formal and systematic product development practice, integrated with other business processes, supply-chain involved agents and with final customers. In addition, it provides means for new product innovation and development inside the companies' facilities.

3.1. RM-AMDP presentation

The RM-AMDP is decomposed into three macro-phases:

- Planning – corresponds to the project planning phase. It encompasses the elaboration of the agricultural machine project plan, which is the main phase output;
- Designing – it involves the elaboration of the product design and the manufacturing plan, being decomposed in four phases, namely informational design, conceptual design, preliminary design and detailed design. The main results of each phase are, in respective order, the design specifications, the machine concept, the economic feasibility and the investment request; and
- Implementation – it includes the implementation of the manufacturing plan in the company production plant and the project closure; and is decomposed in three phases, namely, pilot production, launch and project validation. The main outputs of each phase encompass, in respective order, the product release, the initial production and the project closure.

The Figure 4 shows the graphic representation of the RM-AMDP, with the macro-phases decomposed into eight phases and the range of involved knowledge domains (KD), illustrating their partaking on through the AMDP phases from the start to the finish. At each phase exit the achieved result is reviewed, for authorizing the project progress into the following phase. The knowledge domains are defined as follows (domain name and acronym):

- Business Management (BM) – refers to the tasks whose nature involves decision-making from the management board;
- Project Management (PM) – refers to those tasks whose nature involves the initiating, the planning the executing, the controlling and the closing project processes;
- Marketing (MK) – identifies the tasks in which market survey, marketing planning, product advertising and product sales are involved;
- Product Design (PD) – encompasses the tasks which involve the product design development and its validation;
- Manufacturing Design (MD) – refers to those tasks whose nature involves the development of the manufacturing plan and its implementation;
- Supplies (SU) – refers to those tasks in which the supplies planning and control are done, as well as the supplier involvement on product design and manufacturing planning processes;
- Quality (QU) – refers to the tasks whose nature involves assuring the accomplishment of the product quality objectives;

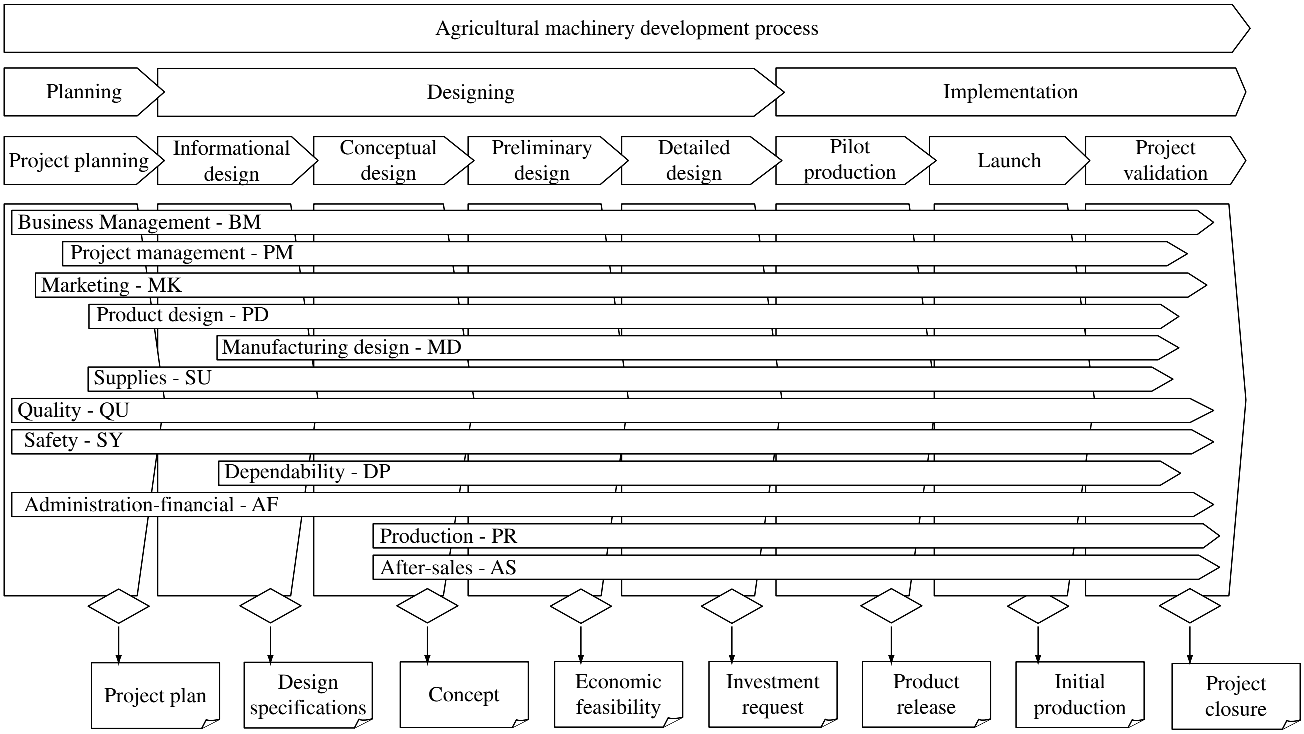

Figure 4. Graphic representation of the RM-AMDP (ROMANO, L. N., 2003).

- Safety (SY) – identifies the tasks which involve the safety review upon the product concept, final layout, prototype and its pilot production and initial production units;
- Dependability (DP) – encompasses the tasks which involve the accomplishment of the reliability and maintainability objectives, including the execution of tests and the preparation of the technical assistance logistics;
- Administration-Financial (AF) – refers to the tasks whose nature involves the solving of administrative, legal and financial issues;
- Production (PR) – identifies the tasks which involve implementation of the manufacturing plan and the product plant production; and
- After-sales (AS) – encompasses those tasks which consist in the implementation of corrective actions for the cases of failed and/or defective products.

As mentioned before, the activities and tasks were organized according to the logical sequence of events into electronic spreadsheets (Figure 5), providing for easy storage of information. Even though the activities are sequentially described, they can be concurrently developed, as long as the activity/document flow permits.

In each AMDP phase, the reading of spreadsheet elements is done by lines, from left to right. The Table 1 illustrates how the activities are described in the spreadsheet, considering the starting tasks of the agricultural machinery conceptual design.

The project management model used in the RM-AMDP comes from the PMBOK® (PMI, 2000). It is organized in five process groups as shows the Figure 6. The vectors represent the process and the document flows. The indicated process groups are connected, as the outputs of finishing processes become inputs of staring processes.

The process groups' activities superpose themselves each other, which provide interaction for all phases, characterizing the integrated nature of project management. The PMBOK® model establishes the project management directives in the process level as in the phase level (Figure 7).

As the representation structure is now known, the next section introduces the process itself through a synthesis of each of the eight phases encompassed by the reference model through its comprehensive approach as shown by the Table 2, number of activities and tasks by phase. As observed, the designing macro-phase is which defines the higher number of tasks.

3.2. Planning

The first AMDP macro-phase corresponds to the named phase, "project planning", as its activities are, in majority, related to the project management knowledge domain. This phase aims to make a detailed project planning, in conformity to the company business strategies and to the work organization throughout the AMDP. Figure 8 shows

Table 1. Electronic spreadsheet descriptive representation.

Phase 3 - AM Conceptual Design						
Inputs	**Activities**	**Tasks**	**Domains**	**Mechanisms**	**Controls**	**Outputs**
Phase exit approval form	To communicate the start of conceptual design phase	To communicate the AM design specifications approval to the product development team	PM	E-mail	Communications management plan	Communication of AM design specifications approval
		To call the product development team for 1st conceptual design phase meeting with the purpose of presenting the project plan	PM	E-mail	Product development team member list	Call for 1st meeting
Project plan	To update budget needs		PM, AF	Cash flow S chart	AM development budget	Cost estimates
Call for 1st meeting AM design specifications Update project plan Project Documentation System	To undertake team orientation and present the updated project plan	To present the updated project activities list	PM, all KD	Product development team meeting	Project activities list	Presented project plan
		To present the new product development team members	PM		Product development team member list	
		To present the updated development schedule	PM, all KD		Project development schedule	
		To clarify doubts, fine-tune project details and to close the meeting	PM, all KD		Project plan	
Project plan Cost estimates	To execute project plan activities	To provide resources for project plan execution	PM		AM development budget	Physical and financial resources
Marketing planning	To monitor market variations which may influence the AM 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 AM design-influencing factors	To establish the AM functional structure	To define the AM overall (purpose) function	PD	Oriented abstraction	AM design-influencing factors	Overall function
		To establish (deploy) AM 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 third-parties
		To analyze and select the suitable functional structure	PD	Decision matrix for selection	Design requirements	Functional structure

Source: ROMANO, L. N. (2003).

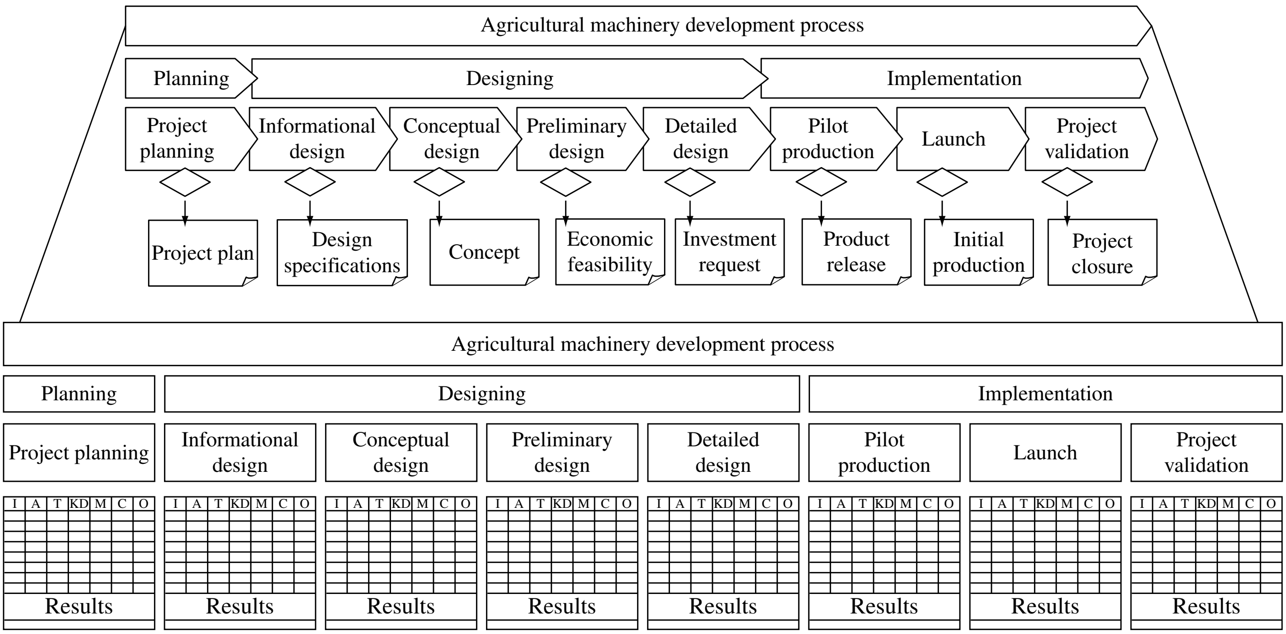

Figure 5. Descriptive representation of the RM-AMDP in electronic spreadsheets (ROMANO, L. N., 2003).

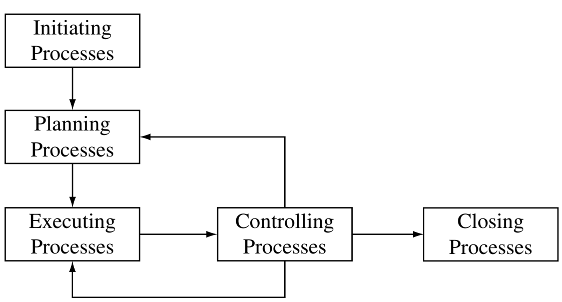

Figure 6. Project management processes (PMI, 2000).

the flow of elaborated activities and documents through the project phase execution.

The process is initiated with the marketing planning of the agricultural machine to be developed from the product strategy plan, which enables the writing of the project charter after its approval. This document formalizes the existence of the project inside the organization and names the project manager, whose main assignment is to elaborate and to implement the product design project plan.

With the issuing of the project charter, the project manager creates the Project Documentation System – PDS – in which the documents generated throughout the agricultural machine development process are registered and enclosed.

The PDS is composed by two parts, one that contains the project management documents and other, the technical ones. Among the project management activities, are included:

- Assessment of the parties involved in the project (direct and indirect clients, partners, project organization partakers, etc.);
- Elaboration of the communications management plan (directives for the project information control system);
- Establishment of the agricultural machine project scope statement – project justification, project restrictions, product description, project deliverables, project objectives and work-breakdown structure (WBS);
- Project risk assessment for the involved organization areas or departments, as criterion for defining the project management team, which may be formed by professionals from the ranked department with higher risk, getting higher team commitment in order to fulfill the project goals;
- Project management team definition; and
- Project plan elaboration – a formal document used to manage and control the execution of the agricultural machine development, which includes: activity list; physical resources list; organizational planning; product development team member list; activity sequencing; duration estimates; allocation of resources; schedule elaboration; cost estimating of physical resources; and, development budget.

In parallel to the elaboration of the project plan, the following management plans are also developed: procurement (procedures to be followed and executed by the team for buying goods and services needed for the product

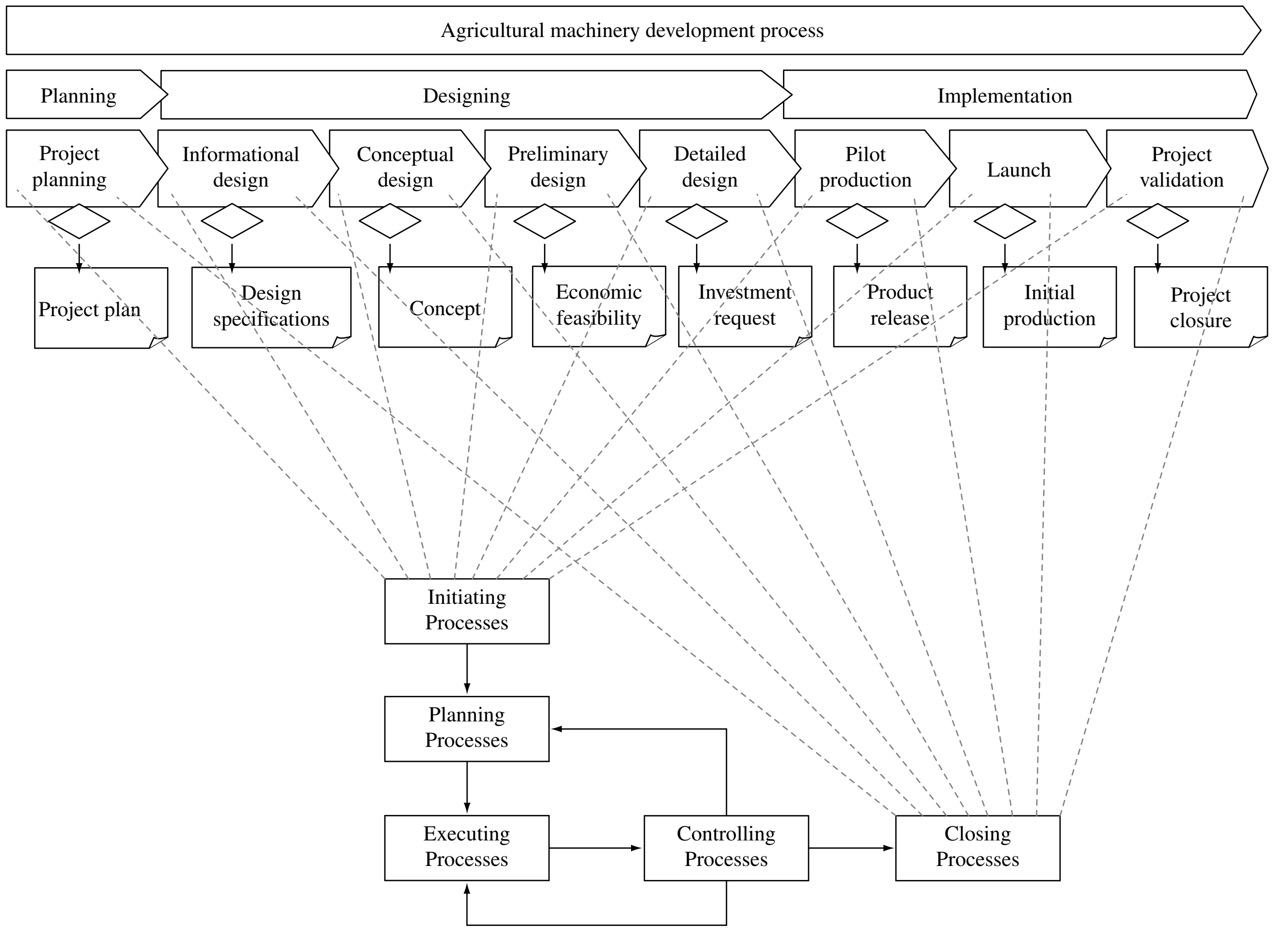

Figure 7. Project management directives in the process level and in the phase level.

Table 2. Number of activities and tasks by phase.

Macrophase	Phase	Activities	Tasks	Tasks' percent per phase	Tasks' percent per macro-phase
Planning	1. Project Planning	29	97	12,25	12,25
Designing	2. Informational Design	25	94	11,87	55,43
	3. Conceptual Design	20	61	7,70	
	4. Preliminary Design	24	117	14,77	
	5. Detail Design	34	167	21,09	
Implementation	6. Pilot Production	35	141	17,80	32,32
	7. Launch	21	69	8,71	
	8. Project Validation	17	46	5,81	
Total		205	792	100%	100%

development progress); and, quality (quality goals to be reached within the project development that may be related to the agricultural machine as well as to the development process itself). The intended safety goals for the agricultural machine are also established (warning signs in all accident-hazardous regions, physical protection for the moving parts, maximum noise level, etc.).

The best practices related to the undertaking of the phase tasks are registered as lessons learned, always before submitting the main phase result to approval. This activity is repeated systematically throughout the other phases of the process. Because of that, its presentation is omitted in the rest of the article. The closure of phase activities occurs when the agricultural machine project plan is submitted to

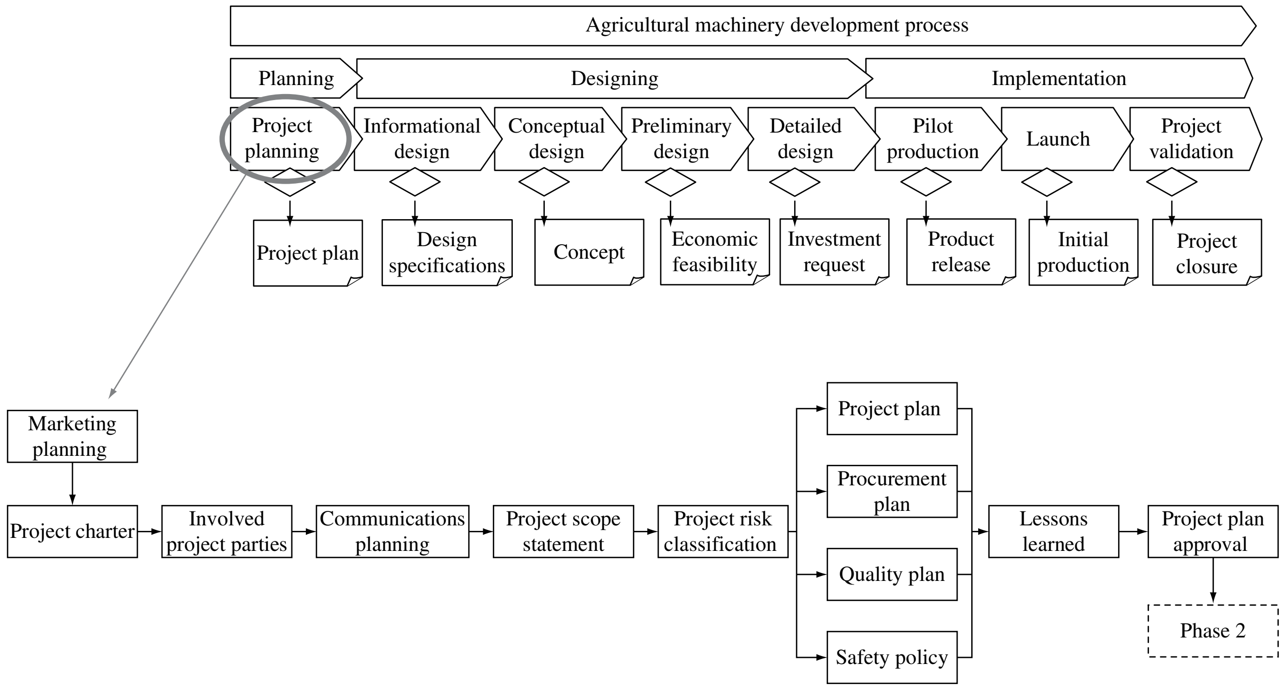

Figure 8. Flow of activities/documents of the project planning phase (ROMANO, L. N., 2003).

approval by the management board of the main organization in charge of project execution. This criterion authorizes the project progress onto the following phase. The commitment of the involved areas in the development process is obtained by the signature of each responsible member in the phase exit approval form.

3.3. Designing

3.3.1. Informational design phase

This phase aims the definition of the agricultural machine design specifications. The Figure 9 shows the main flow of activities/documents. The informational design phase is formally started by the first meeting of the product development team with the project management team, whose goal is to present the agricultural machine project plan. During the product development, meetings are appointed with diverse purposes. Examples given:

- Technical meetings – for discussion of technical subjects related to the product design and the manufacturing plan, involving product development team members and coordinated by the project leader;
- Management meetings – for discussion of subjects related to the project plan, involving project management team members, project leader and coordinated by the project manager; and
- Approval meetings – for decision-making about the approval of phase exit deliverables, involving management board members, project leader and project manager.

The project that begins to be executed is identified by an alphanumeric code, used by the team during its development to recognize it. This code labels all the documents related to the project.

The first technical activity is the definition of product design influencing factors, obtained by making analyses about diverse subjects: market-available agricultural machines, product endorsement technical standards for intended markets, safety factors, operator protection, customer defense, field and lab tests for prototypes and assembly line tests for the pilot production; performance factors related to functionality, reliability and maintainability; required agricultural machine characteristics resulting in project-specific knowledge (e.g. electronics, fluid power systems, etc.); agricultural operation to be executed and its involved agricultural and mechanical parameters. In order to assess such information, a survey is done on lab and field test data, simulations, case study and field evaluations, as well as operation and/or maintenance records of similar equipment.

The design influencing factors often take the form of measures, which can be classified by (DONALDSON, apud MIALHE, 1996):

- Physical specifications – general dimensions, mass distribution, torque, traction requirements, tank (fuel, grain, etc.) volumes, etc;
- Dynamic or time-depending characteristics – power, operation efficiency, service life, wear-resistance, fuel consumption, etc; and
- Economic characteristics – maintenance costs, repair procedures, refueling, etc.

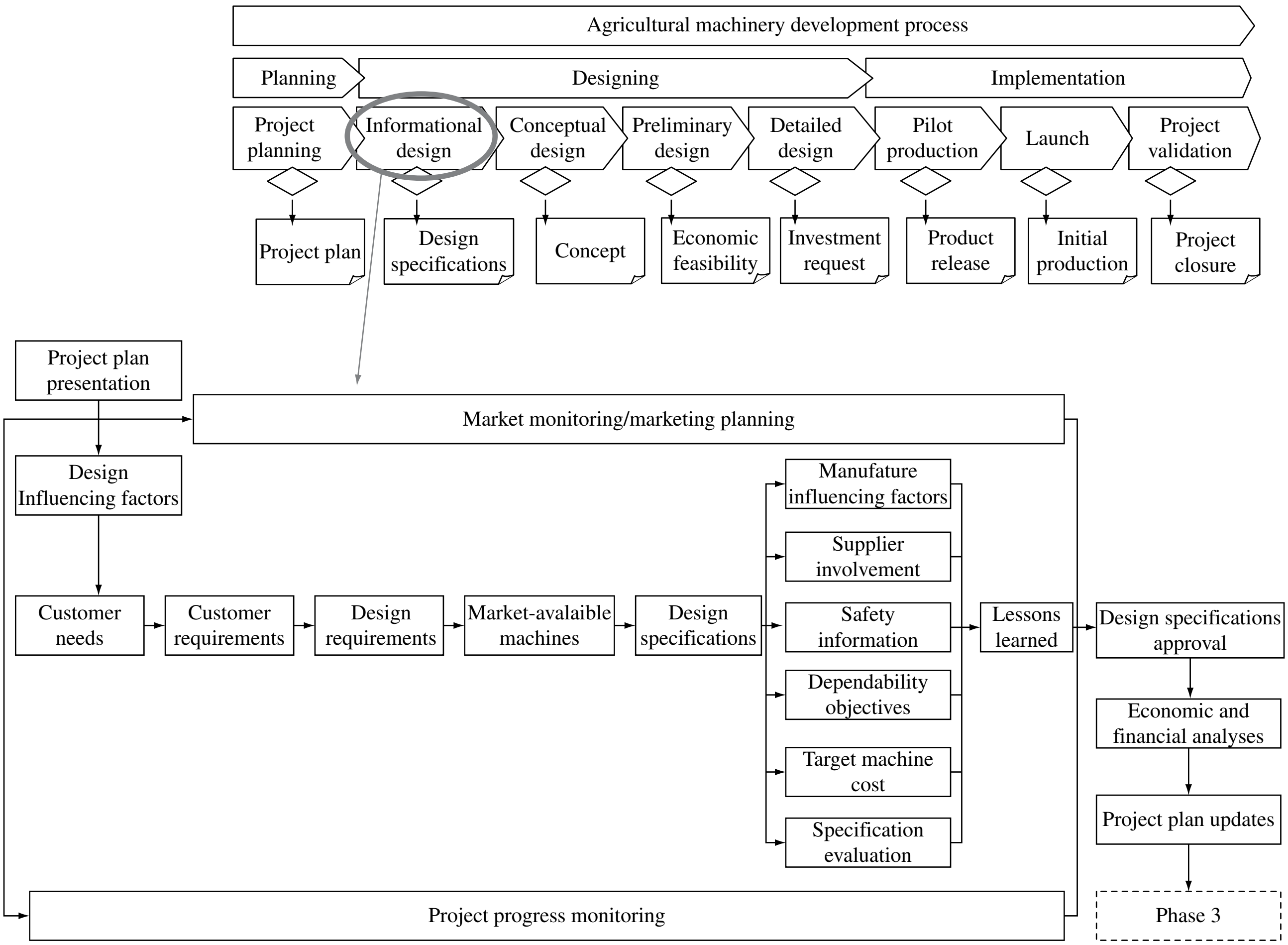

Figure 9. Flow of activities/documents of the informational design phase. (ROMANO, L. N., 2003).

Thus, the product design influencing factors give orientation for defining the design specifications in this phase, which transform into directives for the agricultural machine functional structure deployment in the conceptual design phase, as shows the Figure 10.

In parallel to the execution of activities to accomplish the establishment of agricultural machine design specifications, which extend till their submission to approval, the marketing planning (finished only in the detailed design phase) and the market monitoring continue in order to allow for identification of variations that may influence in settling the design specifications, main objective of this phase. The design specifications are established from the identification of customer needs and their deployment in customer requirements, going through their conversion into agricultural machine design requirements, considering different attributes: functional, ergonomic, safety, reliability, modularity, legal and aesthetic, among others. After that, the benchmark of market-available agricultural machinery proceeds, with the purpose of assessing the degree with which they meet the established customer and design requirements, and corresponding specifications.

The design requirements derive into design specifications, it is, the objectives which the agricultural machine has to meet (e.g. combine grain tank volume = 6,000 L; threshing cylinder diameter = 600 mm; cutter bar width = 5,400 mm). As possessing those specifications, are defined:

- Manufacturing plan influencing factors – for assessment of possible problems that may occur and existing restrictions in the current process or in the available manufacturing technology. This activity marks the start of the elaboration of the manufacturing plan, that is executed concurrently along the product design process;
- Third-part involvement strategy – through the identification of design specifications that affect machine parts to be developed by third-part companies;
- Safety information through the agricultural machine life-cycle – by the revision of the safety problem history, in order to review the accident and health injury hazards during machine operation;
- Dependability objectives – by the statement of reliability and maintainability objectives for the machine in development (e.g. it shall not fail on

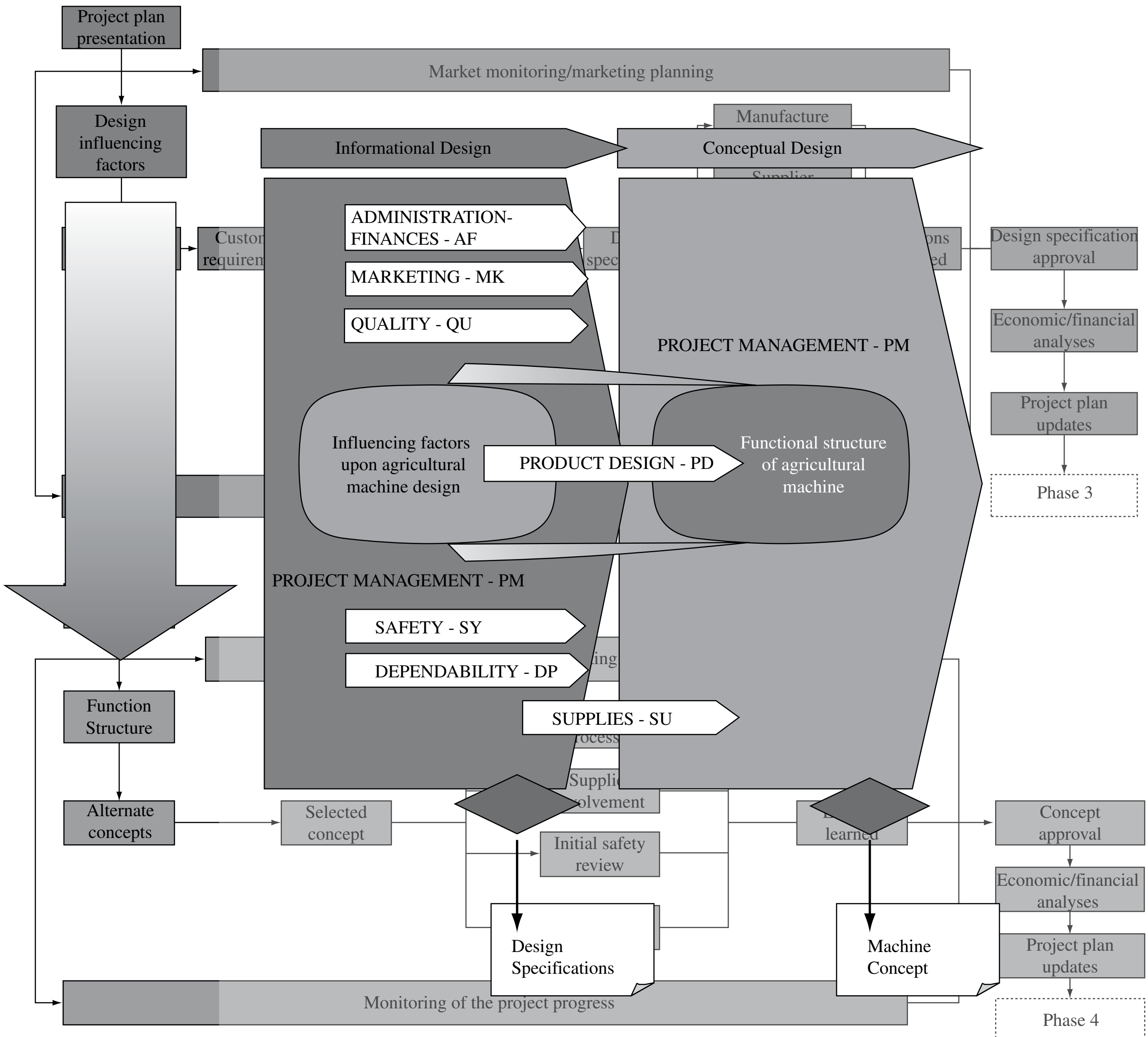

Figure 10. Dependence relationship between agricultural machine design influencing factors and its functional analysis (MARINI, 2005).

operating by 60 days at eight hours a day; service life of 10,000 hours; easily removing maintenance parts by the usage of usual tools; easy availability of spare parts, etc.);

- Agricultural machine target cost – the cost that the new product must meet to accomplish the established target revenues for the product life cycle; and
- Design specifications' review according to the project scope.

In parallel to the phase activities, the management team is responsible for the project monitoring (e.g. determination of cost and schedule deviations) and by the economic and financial analyses (project cash flow). The informational design phase is closed with the submission of the agricultural machine design specifications to the responsible management board for approval. This is the criterion that authorizes further progress of the project onto the following phase. In this second moment the project plan is updated in order to permit the sequence of the PDP.

3.3.2. Conceptual design phase

The achievement for this phase is the concept generation for the agricultural machine design (Figure 11), in order to accomplish the established design specifications. The phase is started with the orientation of the product development team, with respect to the project plan updates. This activity

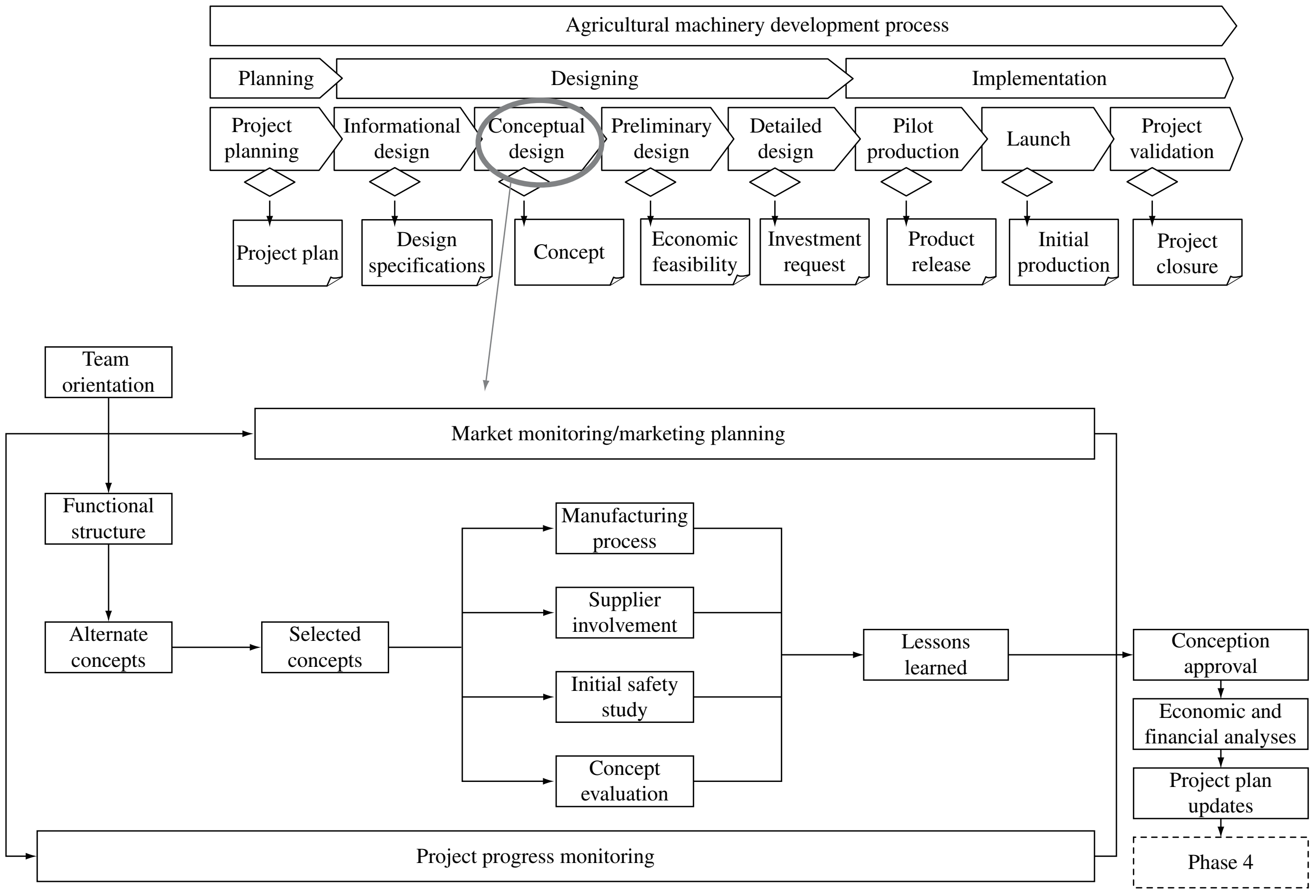

Figure 11. Flow of activities/documents of the conceptual design phase (ROMANO, L. N., 2003).

is further repeated in the start of next phases, thus needing not further comments.

In order to succeed in its main deliverable, the conceptual design phase encompasses the execution of diverse tasks, which intend, in the first moment, to establish the agricultural machinery functional structure with the consideration of the design influencing factors, according to the illustration shown in Figure 10, along with the agricultural machine design specifications. This activity is based in a top-down approach and involves the definition of the agricultural task overall function and its sub-functions – partial, auxiliary and elementary functions, and the determination of energy, material and information flows as well (PAHL & BEITZ, 1996).

Depending on the type of project in development (e.g. original products), the resulting functional structure may suggest the establishment of modified structure variants, provided that they should be developed to allow a more thorough knowledge on the agricultural machine functions by the development team. From the comparative analysis of the alternate functional structures according to technical and economic criteria from the project scope, the best functional layout is chosen. The selected functional structure shall thoroughly describe all functions along with their flow dimensions (energy, material and information), and identify the sub-functions that are going to be developed by third-part suppliers.

According to the selected functional structure, alternate agricultural machine concepts are developed through the use of solution principles generated for the elementary functions (bottom-up approach). Product models are generated from them (physical or virtual) whose allow detailed analyses on their functionality and also make possible to determine initial cost estimates for each concept.

For the generation of the solution principles, several methods are employed for helping the creative development of new concepts (e.g. TRIZ, morphological matrix, brainstorming, technical systems analysis, etc.). The concept choice is made through the comparative analysis among the generated concepts, taking into account: the design specifications; the agricultural machine target cost; the development risks (from product design and manufacture planning – complexity, deadline, cost, third-part involvement, etc.); the quality and safety and dependability objectives.

The chosen concept shall describe its characteristics, thus defining the agricultural machine conception. All knowledge domains are involved in this task.

It may occur in some projects, depending on the situation, the selection of more than one concept, preventing the determination of the best one. In this case, the final concept definition occurs after the development of the respective layouts for each concept.

The study of different concept layouts gives evidence to new information which grants the final concept selection. In extreme situations, where not even the concept layout studies bring enough information for decision-making, the need for construction of prototypes for functional tests (detailed design) may occur.

Thus, in such cases, an agreement shall be reached among the involved areas for the phase transition to the preliminary design, postponing the machine concept approval or, in the most extreme cases, the phase transition to the detailed design shall be done by agreement, further postponing the approval of the economic feasibility.

From the agricultural machine concept, the studies for identifying the possibly used manufacturing processes are undertaken (new or known, internal or external to the main project organization).

Concurrently, the deadlines and accountabilities are defined along with the suppliers for the development of the specified functions in the functional structure, and then agreements are established between the parties.

The purpose of establishing contracts in such moment, even conditioned by the conception approval, is to assure that the planned schedule for preliminary design and detailed design phases is to be accomplished, as the conditions of secrecy and industrial property are defined. In addition, an initial safety study shall be done about the chosen concept as also an agricultural machine concept review, according to the project scope criteria.

Closing the phase activities, the agricultural machine conception is submitted to the management board for decision-making about the further project progress into the next phase.

3.3.3. Preliminary design phase

The main objective for this phase is to determine the economic feasibility of the agricultural machine project. To accomplish such result, all details from the chosen concept shall be drawn, it is, all its forming elements shall be made particular. The Figure 12 illustrates the main flow of activities/documents in the preliminary design phase.

In this phase, the number of models to be developed is determined by taking the intended markets in consideration, and this decision presents a strong relationship with the alternate layout study for the product. Still referring to the marketing knowledge domain, the impact of the defined models on the market-available products must be analyzed, as such as their preliminary sales price. Because of the number of models and intended markets, the development of the product launch strategy is started, according to the strategies of product, market and technology within the organization.

In order to establish the final machine layout, the process is always started from an initial proposal, called initial layout. Its delineation is done from the analysis of the design specifications, and involves the following activities:

- Identification of the design specifications that define the form requirements and determine the main product dimensions and the considered requirements in the layout development, such as, materials, safety, ergonomics, manufacturing, etc;
- Elaboration of a schematic diagram of the machine construction elements, it is, of product parts represented by chosen solution principles, by existing elements and/or non-determined functions;
- Grouping of construction elements in modules, obeying to the limits defined by the design requirements;
- Layout and form definition for the construction elements of each module, for definition of their main dimensions;
- Identification of interactions and interfaces among the construction elements and/or modules, for establishing adequate solutions for them; and
- Analysis of main interactions among construction elements, corresponding to the generation of non-desirable, disturbing, effects (e.g. vibration, noise, heat, etc.) of an element upon another, that doesn't cause functional compromises, as well as the secondary interactions, it is, those generated by the raising of the non-desirable effect levels, which provoke machine failures or functional compromises.

During the initial layout definition, along with the definition of externally-provided components, the supplier involvement grows with the establishment of the desired specifications.

About the initial layout, the alternate layout development is recommended with the objective of making a detailed study about the possibilities in order to obtain the best arrangement of the corresponding machine component modules, with the purpose of meeting the number of specified models for the intended market. The involved tasks in this activity include:

- To draw alternate layout sketches;
- To demonstrate characteristics and benefits for each alternate layout;
- To review patents and considerations of safety and legal aspects of the alternate layouts;
- To estimate the cost of the generated layouts;

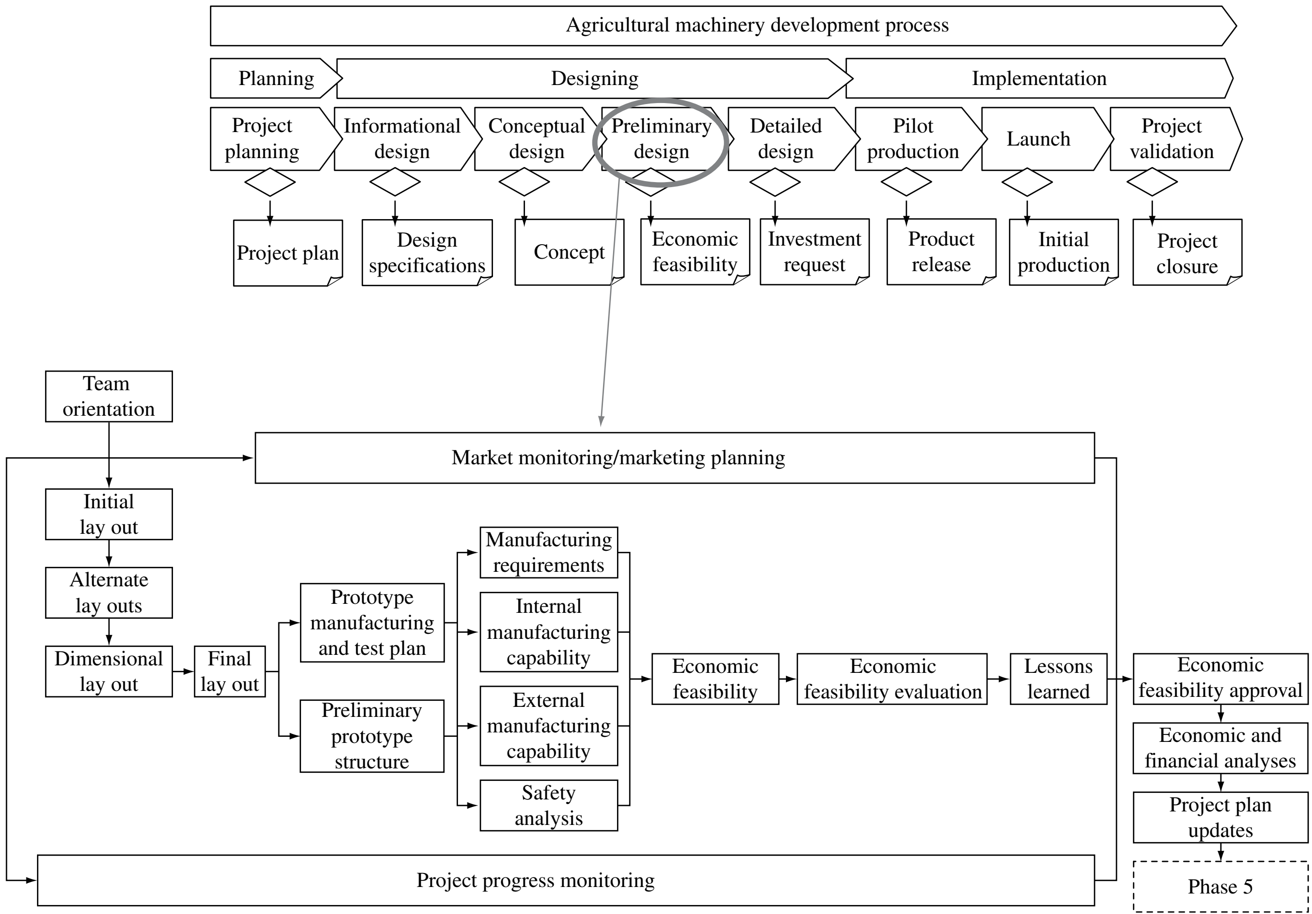

Figure 12. Flow of activities/documents of the preliminary design phase (ROMANO, L. N., 2003).

- To review the generated layouts (by marketing, technical and economic criteria); and
- To select layouts with the purpose of meeting the number of models defined in the marketing plan.

The dimensional layout development, by its turn, involves the refinement of the alternate layouts in order to allows a more thorough evaluation and the consequent election of the most adequate layout for the agricultural machine. Thus, each alternate layout is optimized and the weak points are eliminated. The same happens with the critical points that are identified and analyzed. The main component dimensions are established, as well as the kinds of material and manufacturing processes. For each studied layout, drawings are elaborated with the main dimensions so the mock-ups (digital or physical) can be produced with the purposes of being reviewed during clinic events with customers and verifying the conformity with the market needs. The transformed information until that moment of the development process allows to estimate the costs of each dimensional layout, of tooling and other resources needed for its production.

The selection of the dimensional layout which better meets the market demands is done by the comparative evaluation of each developed layout, taking as criteria the design requirements, the technical feasibility analysis of the product design and the manufacturing processes, the machine compatibility with tractor and/or implement, as well as the economic feasibility. The chosen dimensional layout is then fixed as the agricultural machine final layout.

In parallel to the dimensional layout selection, the project scope must be reviewed, because the chosen layout may have any construction element (component or module) that might cause changes in other elements, outside the initial project scope. In this case, the team must assess the impact upon the project plan activities, as new elements now make part of the project scope. About the selected dimensional layout, the machine model components are then defined, and the optional items and accessories that are going to be offered, meeting the marketing definitions about the intended market launch models.

Once reviewed, the final layout is fixed and the style and form definitions are improved, at the same time that the drawings are then completed. The product general data are concurrently generated, which include: the component and final layout drawings; the bill of materials, including existing and new components, externally developed or provided or made inside the company itself; the preliminary cost of components and modules; the machine technical specifications; and, the patent request report if it is to be the case. About the last item, it shall be analyzed if the developed concept and its layout are eligible for an invention patent request. In positive case, and if it is to be the interest of the organization, the patent request process may be started, observing the implications upon the agricultural machine project plan.

Established the final layout, the process goes further to the manufacturing plan development and the prototype testing. In this activity, the prototype manufacturing and assembly schedules are defined, as well as the prototype testing schedule. With the elaboration of the prototype manufacturing and test plan, its request is issued. The prototype construction happens only in the next phase (detailed design), if the economic feasibility has been approved by the management board. The preliminary prototype structure is elaborated at the same time, which includes all the components and modules that compose the agricultural machine, and must be enclosed with the prototype manufacturing and test plan. As the preliminary component cost is already available, the prototype cost is then estimated. This estimate is going to be compared afterwards with the real cost of the assembled prototype.

From this point, the prototype manufacturing requirements are defined, the internal and external manufacturing ability is evaluated and the final layout safety analysis is done.

Afterwards, the machine economic feasibility is determined, because the prototype preliminary cost, the manufacturing preliminary cost, the investment request for prototype construction, the advertising and market launch costs, and the product development budget are already available. The economic feasibility of the agricultural machine is determined by considering the planned yearly sales volume and the preliminary sales price of each unit.

Before the economic feasibility approval, it is evaluated in which it meets the business strategy plan of the company. In closure to the preliminary design phase activities, the agricultural machine economic feasibility is then submitted to approval, what makes of it the authorization criterion for phase exit and entering the next project phase. The economic and financial analyses are then done and the project plan is updated.

3.3.4. Detail design phase

The last designing phase intends to accomplish the prototype construction and approval, to finish off the marketing planning, to finish the component specifications (conclude the product design process), to detail and finish the manufacturing plan and to prepare the investment request for starting the pilot production phase. The Figure 13 shows the activity/document flow for this phase.

Some important aspects are considered in the marketing planning during this phase. One of them is the probable product launch date and the agricultural schedule for the intended market. This means to say that, e.g., the launch of an agricultural machine intended for seeding summer crops is meant to precede the time when the summer crops are sown. The same happens with the schedule of agricultural machinery expositions, which are the main showrooms for the launch of new products. The customer clinics with prototypes or pilot production units can be planned to evaluate the product according to the customer needs. The elaboration of a training plan for the sales people, customer assistance and dealers may be started, foreseeing the quantity of machines to be produced by the pilot production for meeting its demand in the next phase.

From the request of prototype construction and of the needed financial resources, the manufacturing and assembly schedule is updated along with the planning of the component manufacturing in the prototyping sector and in the production line, as well as, the third-part produced components are identified and request for production warehousing. The prototype is then built according to the manufacturing plan, the component drawings and the final layout drawings. The assembly must be done conforming to the preliminary prototype structure, and monitored by the product development team, who evaluates the project critical points.

All remarks must be recorded in the prototype assembly report, indicating corrective actions for problems or incompatibilities between the drawings and the assembly. During each prototype assembly and after, the report must be identified with the project code and the name of the responsible person, e.g., the project technical leader. The built prototype is then presented and evaluated in a meeting with the product development team and the company management board, according to the design specifications and the product endorsement standards, if it is to be the case.

The next activity encompasses the execution of lab and field tests, and customer clinics. The kind of test to be done, described by the prototype manufacturing and test plan issued in the previous phase, depends on what is intended for evaluation and, because of that, each project may require different tests in order to meet its purposes. According to each case, the lab tests, field tests and customer clinics may or not be done concurrently.

The lab tests with the machine prototype and/or components have the purpose of providing technical support for the development team decision taking during the product

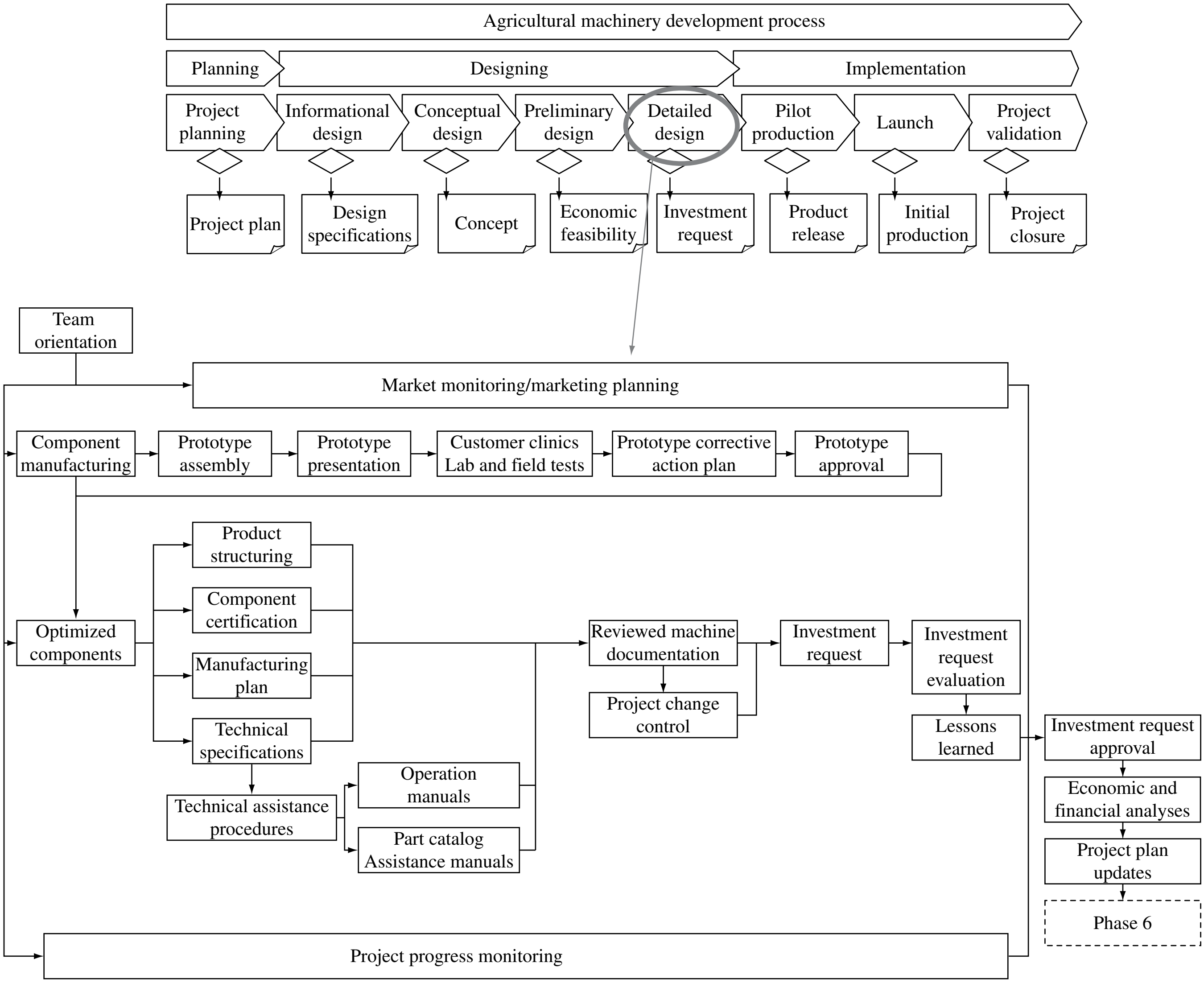

Figure 13. Flow of activities/documents of the detail design phase (ROMANO, L. N., 2003).

design, in any kind of project. For instance, when developing a roll over protective structure for tractors, the lab test will permit to verify if the proposed ROPS may be approved or not, it is, if its function is performed with a minimal resistance to withstand the test impact and offer a non-invasive deformation to the operator protection structure.

The machine prototype and/or components field tests may be considered mandatory, because their purpose is to evaluate the design technical specifications in terms of functionality, reliability and maintainability, providing information for product design consolidation. It is also done to compare similar and competitive products, to quantify the operational performance variations in real work conditions and to evaluate the component aspects in maintenance easiness, wear resistance and durability.

The customer clinics with prototypes and mock-ups are done in order to get information about the customer needs from clients, users, dealers, distribution companies, agricultural machinery manufacturers, research institutions, among others.

One of the analyses made during the tests has the purpose of verifying if the prototype meets the safety objectives. Other aims to verify if the prototype meets the dependability objectives and compare the obtained results with the market-available machines. If failures have occurred during those tests, analyses must be started in order to determine their causes and possible effects. A set of reports is obtained from the prototype testing tasks, which are analyzed to determine the necessity to change or to construct a new prototype, as well as, to undertake new tests. If needed, a prototype corrective action plan is elaborated and implemented in the sequence. After doing all tests, the corrective action implementation report is elaborated and emitted. This one, along with the prototype itself, is analyzed by the management board and the other members of the product development team, in order to verify if the product does meet the design specifications and to give the final approval.

Concurrently to the prototype construction/test/approval, the component specifications are progressively completed and the engineering document release schedule for production preparation is defined – component drawings, assembly drawings and component cost estimates, etc.

Soon after, the product structure (item number + item code + quantity + part name + material + source [manufactured/provided]) is complete, the components are certified, the manufacturing plan is detailed and the machine technical specifications are fixed. The main decisions to be taken about the detailing of the manufacturing plan involve:

- Physical production layout, manufacturing and assembly places and facilities, among others;
- Production machinery specifications and other needed resources for component manufacturing;
- Toolset design;
- Planning of production roadmaps;
- Definition of manufacturing and assembly procedure sets;
- Detailing of manufacturing cost estimates; and
- Issuing of the manufacturing plan.

From the consolidation of the machine technical specifications, the elaboration of technical support procedures is started. Results from this activity are the safety procedure instructions, the technical support procedures and the publication scheme (instruction manuals, part catalog and technical assistance manual).

The elaboration of product design and manufacturing plan is concluded along with the review of the generated documentation. Thus, it is an activity that can extend to the next phases of the process. The documentation review includes the approval of the component drawings and of the tool drawings by the responsible engineers, considering the component sample approval certificates. For each approved component, it is then managed by the design change control.

The investment request is then prepared from the conclusion of product design and manufacturing plan. The objective is now to emit the updated reports for the agricultural machine cost, the toolset cost, the product launch and advertising costs and the product development cost, as well as a detailed sales price review in relationship to the established target cost.

Before submitting the investment request to the management board approval, it is reviewed in a project management team meeting with the participation of the product development team. A critical analysis of the investment request is made taking the business strategic plan as criterion, and the investment budget is verified in relationship to the project plan budget. In the cases where the investment request budget is far beyond the planned values, all cost reports are thoroughly analyzed in order to search for critical points which determined the exceeding value. The same happens with the sales price formation, which is compared to the agricultural machine target cost. If necessary, the meeting may be divided in several parts. From considering all these information, the investment request is then reviewed. For any conclusion, the project management team must elaborate and issue a position for justifying the investment request, which is enclosed with it during the approval with the organization management board.

In order to close the detailed design phase activities, the investment request is submitted for approval, as this is the criterion that authorizes the project progress to the next phase. After approval, the financial resources for production preparation and market launch are then released and the cost and capital tracing is then implemented.

3.4. Implementation

3.4.1. Pilot production phase

The execution of this phase aims to prepare the agricultural machine production and to implement the marketing plan. The Figure 14 shows the activity/document flow. After the team orientation, several activities are done simultaneously to the marketing plan implementation, with the purpose of preparing the production for the agricultural machine assembly test (pilot production), the elaboration of the machine assembly documentation, the implementation of the manufacturing plan and the development of the production plan.

Some documents based upon the product structure shall be elaborated to guide the machine assembly through the production line, examples given:

- Base Assembly Board (BAB) – refers to the basic assembly of the standard model, without alternate and/or additional items;
- Variant Assembly Board (VAB) – refers to the assembly of alternate items in relationship to the standard model;
- Accessory Assembly Board (AAB) – refers to the assembly of additional items to the standard model; and
- Technical Specifications Board (TSB) – composed by diagrams, circuits, layouts, etc., from the diverse systems mounted upon the standard model.

The manufacturing plan implementation depends on the liberation release for toolset construction. In the cases when the toolset construction schedule compromises the machine market launch schedule, the liberation release may occur in the previous phase (detailed design), even if the

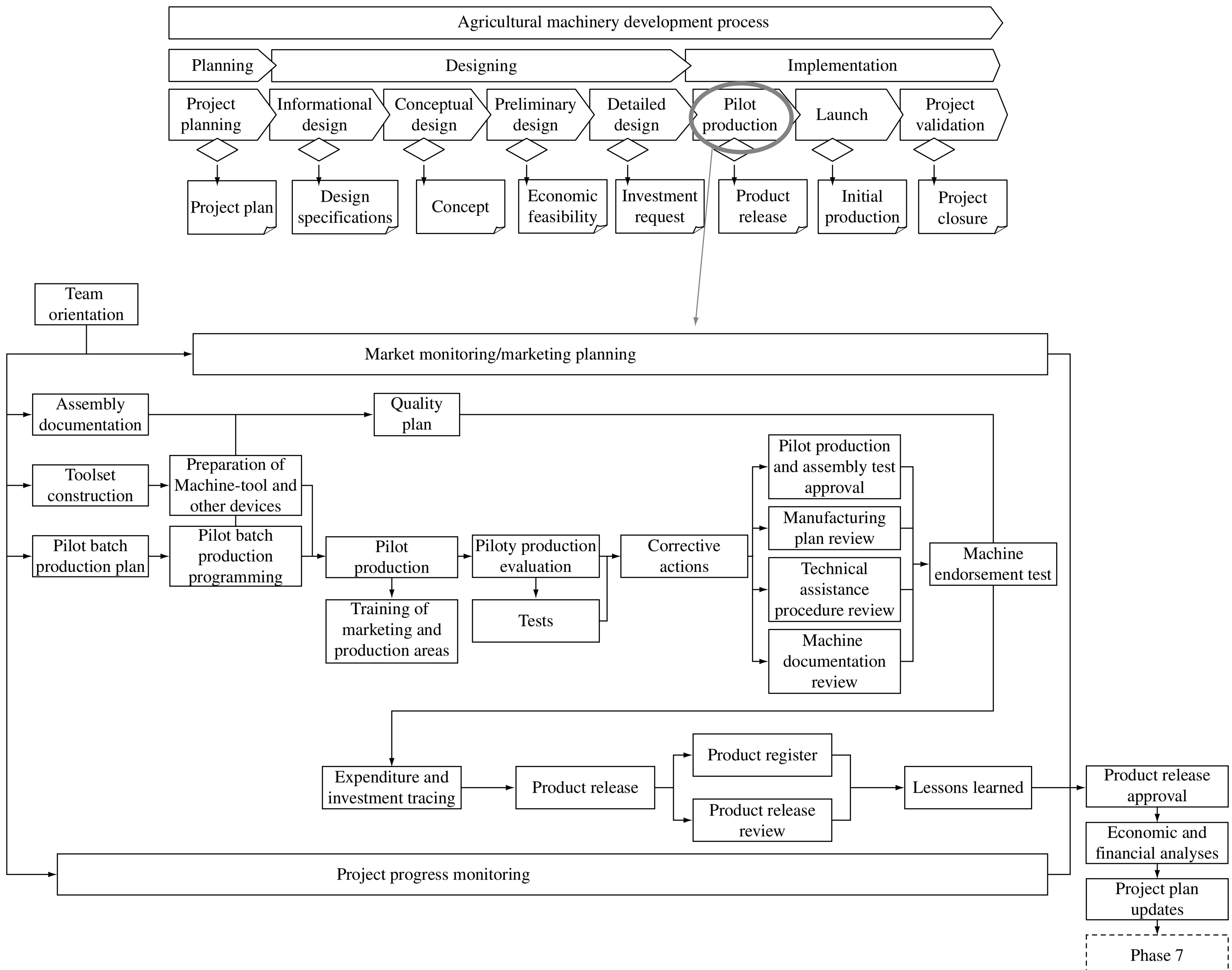

Figure 14. Flow of activities/documents of the pilot production phase (ROMANO, L. N., 2003).

investment request is yet to be approved, as long as such decision is entrusted by the management board. Because of that, thorough attention must be given to the implementation schedule of the manufacturing plan, though this activity involves several interveners, inside the organization and out, and it must be synchronized to the pilot production schedule. The following tasks of this activity involve the bid, reception, installation, test, and setup of the machine-tools and other necessary tools and devices for the production line implementation and the pilot production assembly. Normally this activity involve several changes in the plant layout, demanding a good cooperation and integration among the personnel from the product design, product manufacture, quality, supplies and production, without compromising the current operations inside the organization.

The development of the production plan involves, basically, the establishment of the pilot production schedule (which depends on the manufacturing plan implementation) and the definition of the quantity of machines to be produced. The pilot production for assembly test can then be programmed from the implementation of the manufacturing plan and the production plan development. Such activity involves specially the production and supplies areas.

The component request is issued along with the implementation of the pilot production schedule. The supplies and production personnel must control the component delivery schedules and the sample approval certificates, taking into consideration the fact that there may be components yet to be certificated. In this case, the product design, product manufacturing, quality and supplies areas shall trace these components, evaluating if they can be assembled even with a reproved sample approval certification. In the case of a consensus about the product assembly, the necessary corrective actions will have to be reported in order to provide for the definitive component approval.

During the pilot production, the assembly procedures are tested in order to evaluate product and process non-conformities, and also to train the personnel responsible for the assembly. The machines produced by the pilot production shall pass through an evaluation process, which involves the verification of non-conformities in relationship to then design established patterns. New tests with pilot production products may be needed, as well as the production of a second machine batch (before initial production which only occurs in the next phase) to confirm the implementation of corrective actions.

Thus, new lab and/or field tests or customer clinics with pilot production units may be undertaken. During their execution, the pilot production products are evaluated, if they meet the dependability objectives. The reliability growth must be observed and the final maintainability review must be done. The component failure analyses must be concluded in this phase, as well as the implementation of corrective actions upon the design. The dependability report of the pilot batch is issued, closing the activity. Concurrently, the pilot batch safety analysis is done, in order to assess the accomplishment of the established objectives.

The assembly test problems must be dealt with by the implementation of a corrective action plan, elaborated upon an implementation schedule that meets the development schedule objectives. The analysis of the report on the implementation of corrective actions and the assessment of the accomplishment of design specifications may influence the management board to approve the pilot production and the assembly test. The manufacturing plan is concluded and the corresponding cost is then updated.

The quality plan implementation is then monitored from the assembly test report, from the quality management plan and the pilot production products. It encompasses the process capability analysis and the current quality situation evaluation from the produced machines of the pilot production. Continuous production control methods are then established, as well as the product structure component certification is finished. The component sample approval certificates (CSAC) give the necessary condition for the adequate production scheduling, minimizing the risk of problems during the product component manufacturing and assembly. A new CSAC must be required for any component change.

The elaboration of technical assistance procedures is also accomplished in this phase. The safety procedure instructions in the agricultural machine transport, operation and maintenance are the revised and tested in pilot production units by personnel from safety, quality, after-sales and dependability areas. According to the specifications of each model, the operation manual, the technical assistance manual and the part catalog are emitted and used to execute the training plan for the sales and after-sales areas, as well as the dealer personnel, as determined by the marketing plan.

After the conclusion of the machine documentation review, it is emitted for elaboration of the product release document for full-scale production. As this procedure is done after then investment request approval, a major share of the resources is spent in the product design and manufacturing plan implementation. Thus, the investments and expenses of this macro-phase are thoroughly traced with the purpose of recursively updating the project cash flow.

When product endorsement tests and/or conformity certification tests are required, pilot production products are sent to test centers. The product endorsement, as stated here, has more focus on general safety questions, operator protection, customer defense, etc. The certification aims to declare the machine conformity to a certain analyzed criterion.

The product release is a formal document used to describe the characteristics of the machine which is being released for full-scale production and market launch. At the same time, the product specifications are registered with the FINAME and the company administrative-accounting system. The FINAME acronym stands for *Fund for Financing Machine and Industrial Equipment Acquisition*, is a program held by the Brazilian National Bank for Economic and Social Development (whose acronym is BNDES), and has among its purposes the financing, without value limitation, for acquisition of new BNDES-registered agricultural machines and implements, through authorized financial institutions. The FINAME registry must be done, because the majority of the agricultural machinery is acquired by customers (farmers – individuals or companies – and their cooperative organizations) through financing.

After that, the product release document is signed and the agricultural machine now formally exists as a product to be commercialized by the organization. The product release review validates the product according to the project scope criteria. A report from the project manager is enclosed with the document, which is then submitted to the management board for approval. According to the phase objective, the approval of product release is the criterion that authorizes further progress onto the agricultural machine market launch phase.

3.4.2. Launch phase

This phase aims to the agricultural machine market launch. The activity/document flow is shown in the Figure 15. The machine initial production batch is produced during the execution of this phase.

After the team orientation, with respect to the project plan updates and especially in relationship to the critical points of the launch phase, the marketing plan implementation proceeds with the emission of the advertising material for

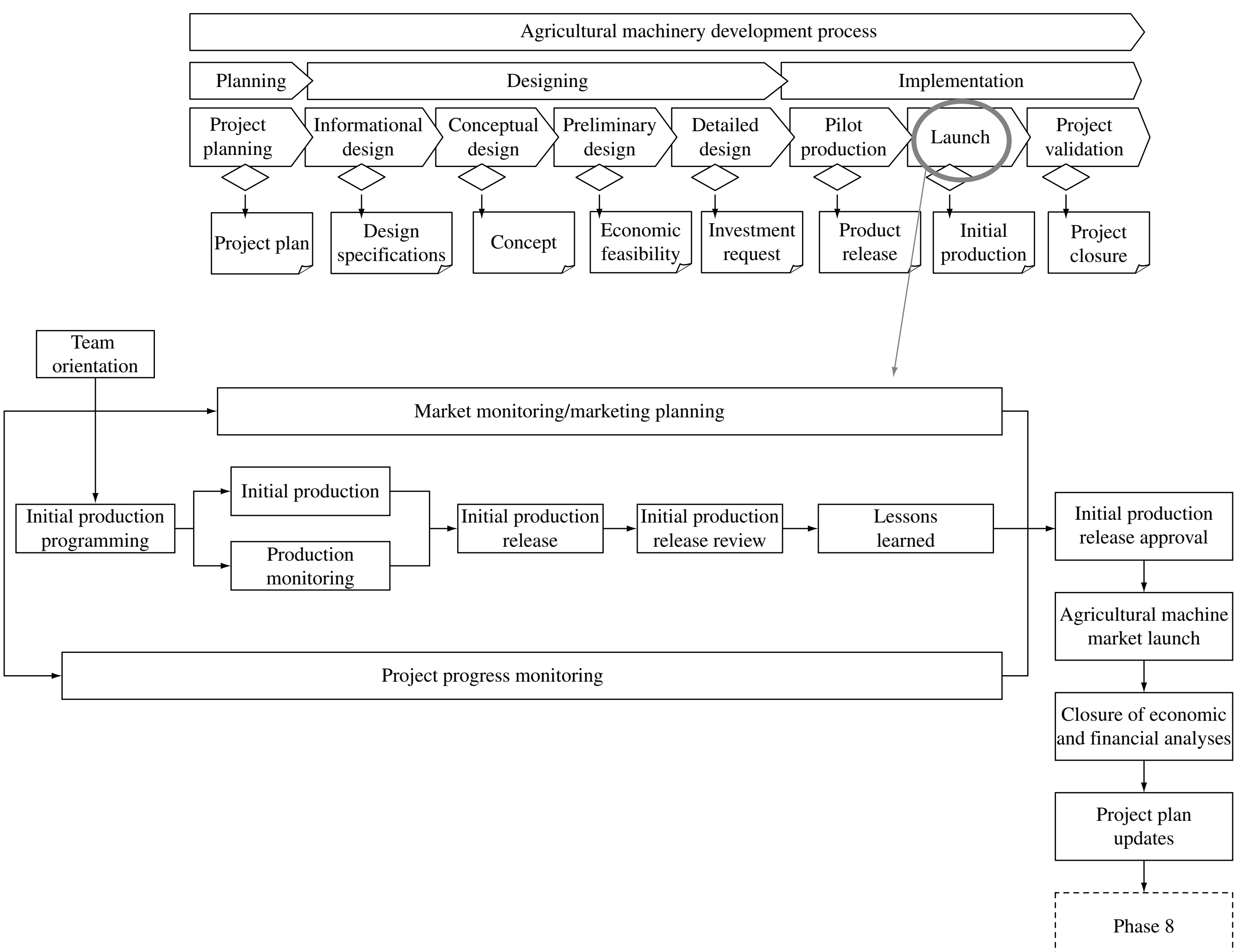

Figure 15. Flow of activities/documents of the launch phase (ROMANO, L. N., 2003).

the machine and the technical literature for commercial product advertising.

The literature for commercial product advertising encompasses the product catalogs, whose content underlines the technical characteristics of the machine (photos, functioning schemes, etc.). It is the delivered material for dealers for product advertising among the customers.

The production start date definition and the sales volume review for the definition of the machine production scale (quantity of machines to be produced) mark the start of initial product batch production preparation.

The activity proceeds with the final component approval review (CSAC) for full-scale production, with the elaboration of the component manufacturing implementation schedule, the initial product batch production programming and the product supporting toolset review.

Once started the plant and supplier production, the monitoring of produced machinery is done for verifying the occurrence of non-conformities.

Assembly audits are undertaken during the production, in order to gather the initial data about the behavior of the production process.

With production proceeding, the production, quality and supplies areas start the internal and external production leveling, in order to accomplish the planned production values. Along with it, the review of the continuous improvement process in supplier development progresses. The produced agricultural machines are evaluated in terms of non-conformities, which provide data for the emission of a quality report about the initial batch production.

The initial batch production is finished when the programmed production volume is achieved. Considering that it conforms to the established quality requirements (production report from the initial production batch), the agricultural machine initial production batch release is elaborated by the product design responsible personnel, and evaluated according to the project scope criteria. To finish the launch phase activities, the initial batch production release is submitted to approval by the company management board, being this one the criterion that authorizes further progress onto the following phase. After the agricultural machine initial production batch release approval, this event is communicated to the involved agents, as determined by the communications management plan.

The market launch of the agricultural machine is made, by the official presentation of the product to the customers, dealers, sellers, press, among others. The commercialization of the initial production batch is started, being monitored by the after-sales area.

The project economical and financial analyses are finished in this phase, and the project plan is updated to guide the activities of the last phase of the agricultural machine development process.

3.4.3. Project validation phase

This phase aims the agricultural machine validation with the customers and the project audit and validation with the direct project stakeholder, it is, the one who contracted the project. As this is the last phase of the project implementation and of the agricultural machine development process, it determines the project closure. The Figure 16 illustrates the activity/document flow through this phase. As in the other phases, the phase start is communicated to the involved personnel and, in the first meeting, the development team is guided with respect to the project plan updates and specially in relationship to the validation phase critical points. After the team orientation, activities are undertaken in relationship to the commercialization of machines and those involve:

- The implementation of the customer satisfaction assessment plan;
- The monitoring of the machinery performance;
- The monitoring of safety information in the machine usage/operation; and
- The monitoring of occurred accidents.

For the agricultural machine validation, the product design personnel define the reviewed items in the machines that have been sold, as well as the review criteria. The marketing personnel are responsible for the definition of the customers which will participate in the agricultural machine validation process, their respective crops, country region and responsible dealer for the customer assistance. As example, the following items and criteria may be important to be examined in the case of the project of an agricultural tractor with cab: the communication of technical information in the product delivery; the air conditioning system performance; cab ergonomics and comfort in terms of noise, vibration and insulation, seat, levers, pedals and hitch control; periodic maintenance; etc. Scores are to be assigned to the evaluated items, varying from zero (very bad) to ten (excellent), or other scale that well defines the customer and/or user opinion.

The validation is made upon the initial batch products, which were sold to customers. The customer opinion must be completely recorded during this phase, which will make part of the agricultural machine validation report.

The final evaluation of the machine validation is done in following. This consists in the analysis of the validation report which will point for each item the mean value according to the customer and/or user opinion. From such analysis results the definition of corrective actions for the identified problems, the definition of the implementation schedule and their implementation itself.

Furthermore, the continuous improvement planning is started, by the statement of objectives, examples given: machine cost reduction, product characteristics improvement, performance enhancement, among others.

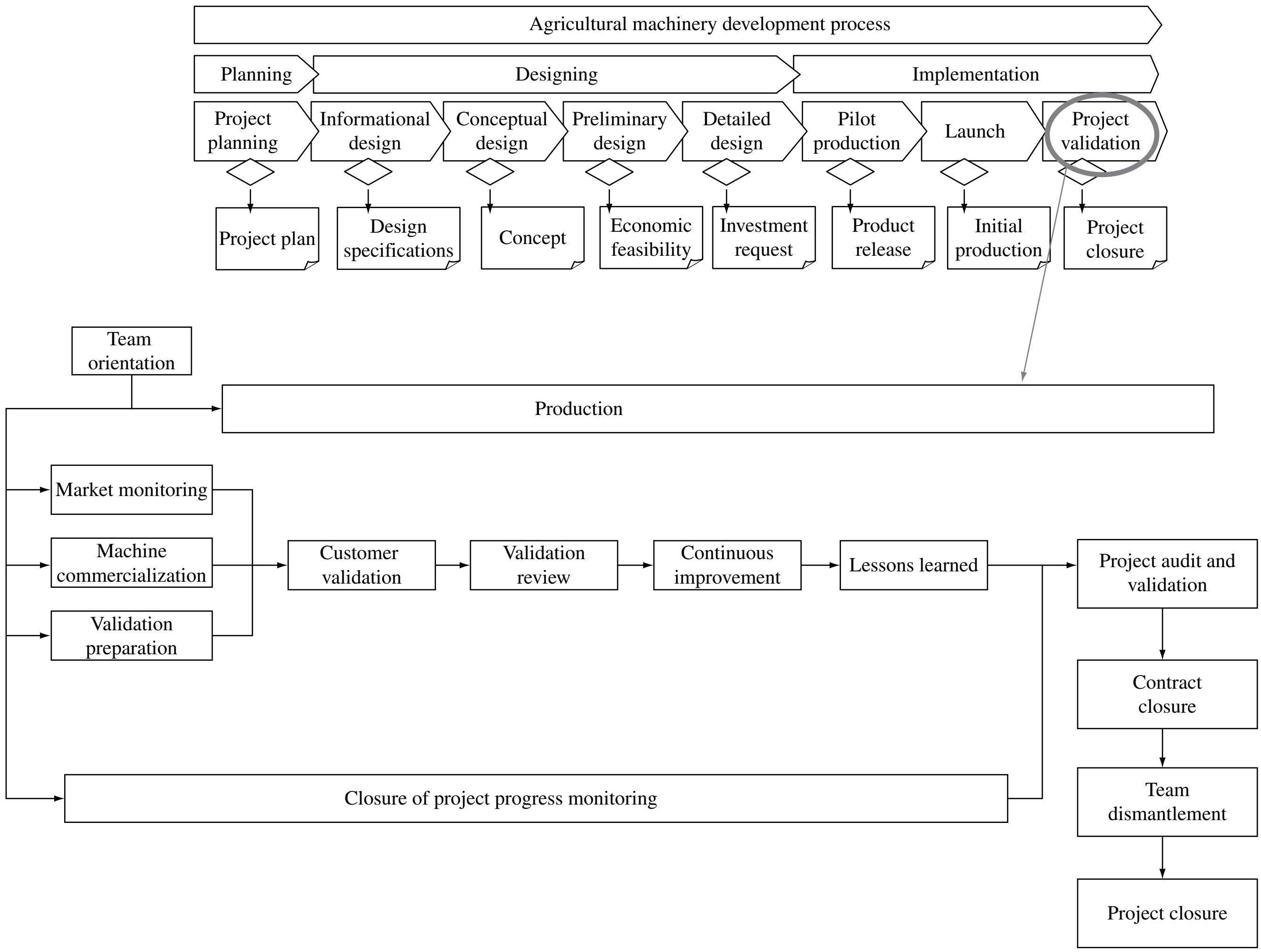

Figure 16. Flow of activities/documents of the project validation phase (ROMANO, L. N., 2003).

With the conclusion of the agricultural machine validation activities, the project progress monitoring is closed. The project management team emits the final project progress report.

The product development and project management teams can then discuss the project failures and record the lessons learned for application in further projects. The project results (machine validation report and project progress report) are submitted to audit and validation by the direct project client or the project sponsor. Examples of questions that may be answered in the project audit (VARGAS, 2000) are:

- Has the project met the planned objectives?;
- In negative case, which factors have contributed for the negative results?;
- What has been done in an adequate manner?;
- What could have been better done?;
- What are the recommendations for future projects?;
- What could have been made in a different way?; and
- What learning could be attained from the project?

As the project audit is finished, the document of formal project result acceptance is signed and the machine project validation is issued. In this moment, the pending contracts are closed, the project account reporting is done, and the product development team is dismantled as well as the project structure. The project documentation system is finished and archived. Finally, the agricultural machine development project is formally closed by the event communication to the involved agents.

4. Final comments

This work involves an experience on modeling the agricultural machinery development process, as the achieved result is based in a broad set of information originated of a thorough research in several knowledge areas. Thus, characterized by its multidisciplinary nature, the presented reference model itself constitutes a result, according to arguments that endorse the validity and importance of concurrent engineering integration and project management. Through the project management principles a structured result can be attained to provide the necessary support to the product development, and the concurrent engineering, the way to do the work among those several disciplines.

The developed form for the agricultural machinery development process (AMDP), meeting the principles defined by VERNADAT (1996) has contributed to the necessary degree of structuring and worked as an effective instrument for the organization of the involved knowledge, providing its detailed and integrated view.

Besides the easy and fast content update-ability and through the diverse possibilities on visualization arrangements, generated by the filtering of element information, the AMDP reference model promotes an infinity of resources to be used, either by the process comprehension itself, or by the elaboration of particular models, flow diagrams, procedures, manuals, presentations, etc., focused on the planning, communication, training, simulation, analysis, synthesis, decision-making and control of projects. Taking in consideration the lack of existing literature on the agricultural machine development process, it is believed that the RM-AMDP has a great potential for providing contribution for the clarification, teaching and learning of this process.

5. Acknowledgments

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Address for mailing

Leonardo Nabaes Romano – Federal University of Santa Maria, Mechanical Engineering Departament, Campus Universitário, Prédio 07, Sala 317, RS 509, km 09, Bairro Camobi, Santa Maria, Rio Grande do Sul, Brasil, 97105-900. e-mail: romano@smail.ufsm.br.

Nelson Back – Federal University of Santa Catarina, Mechanical Engineering Department, Nucleus of Integrated Product Development, Campus Trindade, Florianópolis, Santa Catarina, Brasil. e-mail: backnb@terra.com.br.

André Ogliari – Federal University of Santa Catarina, Mechanical Engineering Department, Nucleus of Integrated Product Development, Campus Trindade, Florianópolis, Santa Catarina, Brasil. e-mail: ogliari@emc.ufsc.br.

Vinícius Kaster Marini – Master degree student, Federal University of Santa Maria, Agricultural Engineering Post-Graduation Program. e-mail: marinivk@gmail.com.