

Computer integrated agriculture: an essential element in agricultural chains

DR.IR. D. GOENSE

*Department of Agricultural Engineering and Physics
Wageningen Agricultural University
Bomenweg 4 "Agrotechnion"
6703 HD Wageningen
The Netherlands*

Abstract

Consumers attach great importance to safe and clean products. This requires market oriented production in which quality, environment and animal welfare are considered. New integrated tools in management to fulfil these requirements require more information and a better information flow between different production phases. The objective is to develop a competitive modular and open IT system for the new generation of management tools in agriculture. This will be achieved by adapting knowledge, concepts and solutions from Computer Integrated Manufacturing (CIM) technology.

To realise such a system the CIA project is carried out in which the main business processes in agriculture are defined, an architecture is designed and information is described in a detailed information model. An inventory is made of communication technologies, and a selection will be made for the different levels of communication in the agricultural production system. The developed models, definitions and protocols are submitted to international standardisation bodies.

This paper describes an architecture for the agricultural production control in the primary sector. The architecture is based on different levels of architectural generalization as described in the CIM-OSA concept. As such the generic parts are applicable in all branches of agriculture. In this paper especially the control of production processes will be highlighted. The most important objects associated with production control that are relevant for data exchange between the different production levels and production organisations will be discussed.

An important aspect of the integrating infrastructure is the communication technology. The possibilities for application of the Manufacturing Message Specification (MMS), the application layer used in the MAP standard, on the process control level in agriculture is investigated.

Introduction

Consumers attach nowadays great importance to safe and clean products. They are not only concerned on composition and possible residues, but they consider also the method

by which is produced. Production methods must be save for the environment and animals should be kept on a sound way.

This requires that the outlet to the consumer can control and eventually prove that the stated production methods are followed.

The cost of production must be competitive in a open international market. This last aspect requires optimal adjustment of production between the different organisations within a production chain.

This requires market oriented production in which quality, environment, animal welfare and cost are considered. New integrated tools for management are developed to fulfil these requirements. They are able to optimize the level of product input based on more objectives, like profit, labour saving, environmental protection, etc. Production control will be focused on achieving a well specified quality of produce. These management tools require more information and a better information flow between different production phases.

The CIA project

A European research project is started within the ESPRIT III CIME programme with the objective to develop a competitive modular and open IT system for the new generation of management tools in agriculture. This project "Computer Integrated Agriculture" is carried out by the Danish Agricultural Advisory Centre and Land-Data from Germany, both producers of agricultural software, three manufacturers of process computers; LH-Agro specialised in control equipment for crop production and Skiol-Datamix and Skov specialised in control equipment for pig production. All three come from Denmark. The Agro Telematic Centre and the Department of Agricultural engineering and -Physics of the Wageningen Agricultural University are the partners from the Netherlands in this project.

The development of an open IT system will be achieved by adapting knowledge, concepts and solutions from Computer Integrated Manufacturing (CIM) technology as it is under development now in the industry. To realise such a system the CIA project is carried out in different phases for analyses, design and selection of technology. These are;

- definition of the main business processes in agriculture production,
- design of an architecture,
- description of information in a detailed information model
- inventory of communication technologies and
- election of technology for the different levels of communication.

Implementation will be realised by;

- communication interfaces for on-farm and external communication,
- a system wide data base,
- a farm application manager for crop and pig production,
- a plot manager for crop production and
- integrated production control.

An important aspect of the project is the validation.

The developed models, definitions and protocols are submitted to international standardisation bodies, particularly ISO/TC23/SC19 that deals with agricultural electronics on farm equipment and installations.

The scope of the project is limited to crop and pig production, but the chosen and developed technology is intended to be valid for all agricultural branches.

Architectural framework

A reference architecture is to be provided for the agricultural production sector that must fulfil the following requirements.

- The models must reflect enterprise decision making, the organization, the business processes, the activities, information interchange and material flows.
- The models must be flexible to reflect a changing environment and it must be possible to build implementations on an evolutionary manner.
- The models should guide the user in a wide variety of production branches.
- The models must assure system consistency.
- The models must support a system wide information interchange.

These requirements can be fulfilled by adopting the architectural framework as described in the CIM-OSA approach. Central in the CIM-OSA is a three dimensional description of the whole framework;

- the architectural levels,

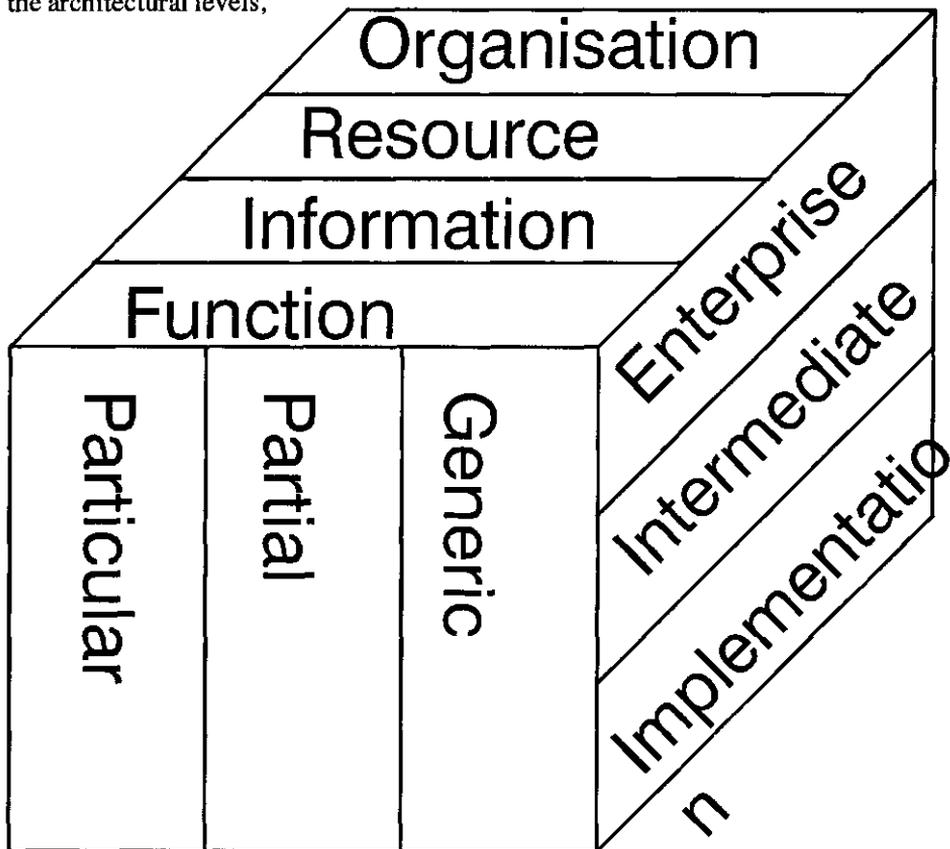


Figure 1. The CIM-OSA Architectural Framework

- the modelling levels and
- the CIM-OSA views. (*Fig. 1*)

Architectural levels.

The architecture has three levels of genericity; the Generic Level, the Partial Level and the Particular Level.

- The Generic Level is a reference catalogue of generic building blocks (for components, constraint rules, terms, service functions and protocols), which are not specific for a particular production sector.
- The Partial Level creates a particular architecture for a particular category of production enterprises.
- For the creation of the Particular Level Architecture Instances both the Generic and the Partial constructs are used.

Modelling levels.

Three levels are distinguished in modelling; the Enterprise-, Intermediate- and Implementation Modelling Level.

- The Enterprise Modelling Level contains a number of fundamental business aspects which are expressed in views. It includes the requirement definitions.
- The Intermediate Modelling Level considers all enterprise constraints (business and system capability related) and provides a globally optimised set of enterprise requirements.
- In the Implementation Modelling Level contains system descriptions (Component Specification)

CIM-OSA views.

The distinguished views are the Function, the Information, the Resource and the Information View

- The Function view describes a set of hierarchically structured business processes.
- The Information view gathers all information defined and contained in the enterprise.
- The Resource view contains relevant information on resources.
- The Organisation View describes the different responsibilities in the enterprise.

The approach followed by the consortium.

It was from the beginning onwards felt that an object oriented approach would be the appropriate one to follow in this project. Much of the arguments in favour of a object oriented technology such as modularity, reusability, extendibility and reliability (Meyer, 1988) are applicable for the project. However at the start of the project there were practical reasons not to follow object orientation consistently. Some of them were;

- lack of experience with an object oriented technology by most of the partners,
- no proven wide accepted methodology for object oriented analyses and
- because of above mentioned reason no case tools to document object oriented analyses.

It was decided that the technique of structured analyses following Yourdon (1989) would be used in the analyses phase of the project to describe business processes and enterprise

activities. Entity relationship diagrams following Chen (1976) are used for description of the information. Eventually an object oriented methodology would be used in the design phase and following implementation. This would be based on the structured analyses methodology. Later it was decided not to follow the object oriented methodology for the system wide data base to be set up by the German partner. The reality is that a medium sized enterprise can't base his most important tool, the data base, on a new, not proven technology as object oriented data-bases. An object oriented design and implementation is also not used on the lowest process control level in crop production, where cheap micro controllers are required for economical reasons.

Farm management software will be designed and implemented following an object oriented approach. This approach will also be used by the Department of Agricultural Engineering and Physics for an experimental set up of a process control system in crop production. In such an experimental set up cost aspects for commercialisation are not considered. Object orientation will be used in stationary process control up to a certain level in the hierarchy, as will be discussed under the MMS communication system.

The CIM-OSA architectural framework is regularly used as a reference for the work in the CIA project. It is referred to as a concept, but at the starting time of the project hardly any implementation technology was made available.

The CIA information model

A number of organisations, enterprises and manufacturers of components and software are involved in Computer Integrated Agriculture. To be able to develop an open system there must be a common representation of the "world" they are working in. Such a common description is made in the CIA project by formulation of an information model.

It is the intention of the consortium to describe one information model that is valid for primary agricultural production in Europe.

Branch organisations to promote information technology in agriculture in the Netherlands started to build branch specific information models for the primary production sectors. (Siplu, Situ, Siva, Sivak, Taurus) One of the problems faced with these models when used as a starting point for the work in the CIA project was that notwithstanding all used the same methodology (Information Engineering), they show differences in describing functions and information which they have in common. In Germany and Denmark mixed farms are more common than in the Netherlands and software houses are less branch specific. General enterprise activities as maintenance of durable equipment, personal administration and bookkeeping must be uniform. For a software house it is efficient to treat activities as stock keeping uniform for all branches of agriculture.

Information model as base for standards.

The CIA information model will be used as a bases for international standardisation of communication in agriculture. For communication on the different levels in the agricultural chain there must be a common model that is shared between the partners that interchange information. Information exchange can take place on different levels of model instantiation (*Fig 2*)

Communication on the industry (production branch) level is of interest for comparison of enterprise performance.

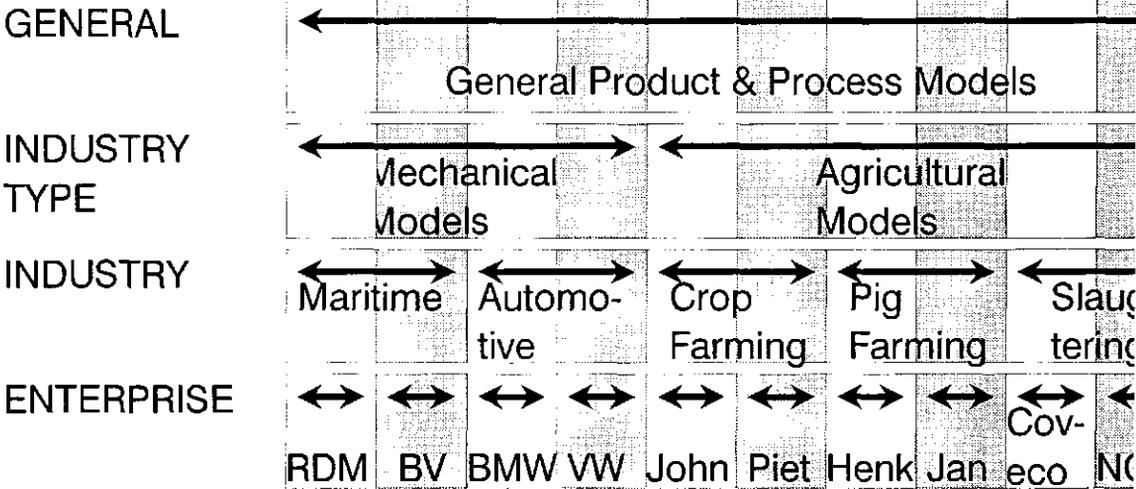


Figure 2. Layers of model sharing

Figure 2 shows that pig farmers and Slaughterhouses need at least a common agricultural model to exchange data, but as soon as transporters, which are also active in other industry types, are involved there is a need for more general models. Aspects of process control and measurements will also need general models when process controllers and intelligent sensors are involved. They are not manufactured for a particular industry type.

Description of Business processes.

Business processes describe that what is required to achieve a particular enterprise objective. It can be expanded in a hierarchy of business processes and a Business process cluster of lower level process activities (Enterprise Activities) required to carry out the tasks. (CIM-OSA). As such Business processes are comparable with the Functions in Information Engineering (Martin 1989)

The business processes for Computer Integrated Agriculture are described as processes in the top of the hierarchical structure of the Data Flow Diagrams.

Whether on the top of the hierarchy a division must be made between production sectors like crop production, pig production, dairy production and contracting, or between functions in the control concept like strategic-, tactical-, operational-planning, execution and evaluation took some time for discussion.

Because the Business Process "Scheduling" has to deal with activities from different sectors in a mixed farm enterprise the choice ultimately came to a division based on a general control concept.

Here a similarity can be found with the structured description of processes in an agricultural production chain. Here also an early division can be made in functions connected to the different production organisations or in the management control functions of the chain as a whole.

*Object model.**The need for a common object model.*

It is possible that manufacturers agree on standard communication techniques for data exchange between the different levels from sensor to farm controller. In these standards the functionality of ISO-OSI layer 1 through 7 will be covered, and information expressed in abstract objects like variables and files are exchanged.

In computer integrated agriculture it are the applications that must be integrated. Characteristics of the produce like an animal for slaughtering, a box of beef, a lot of ornamental plants, a lot of potatoes or a bag of frozen French fries must be passed to the other organisation which is responsible for further processing or resale. The Device Controllers, the Tool Controllers or the Intelligent Sensors calculate or measure the characteristics of the Product/Produce during primary production or processing. These controllers also measure the Specifications such as process data and used products during the operations on the produce itself or on the objects like animals and crop area's where the produce will be harvested from.

Different organisations within an agricultural production chain might have their own specific object model to describe the relevant objects in their enterprise, but for communication in an integrated agricultural production chain there must be a common description of the objects on which information is exchanged.

Within each enterprise there is equipment, computers and software from different vendors that is used to plan, realize and control the production. These vendors sell on many different enterprises. Especially in the primary agricultural production sector these resources include the application programs for production control. For communication between the resources of different manufacturers there is also a need for a common object description.

Objects in primary farm production

There is a clear distinction made between the management of resources like workers and equipment and the control of processes with their specifications in the description of the objects in primary agricultural production.

Operation

To produce crops, raise animals and maintain equipment there are *Operations* performed on *Account Objects* like *Cultivation*, *Animal Group*, *Animal*, *Equipment* and *Building*. The operation describes the change in the condition of the object that must be (or is) realized following a *Specification*. Such a Specification might either be an amount of product that should be used or is harvested (*Consumption Yield*) and/or includes *Process Data* such as for instance a working depth or a milling grade and it can eventually also exist of *Measuring Data*. (Figure 3) Specification reflects the object as a whole. For smaller units within objects like animal groups and fields there are special measures.

The Operation has a status variable which indicates whether the operation is;

- An optional operation, Which indicates that the operation can be carried out in a certain time period following a particular specification. It is up to the production planner and scheduler to choose between optional operations to realize a particular production function.

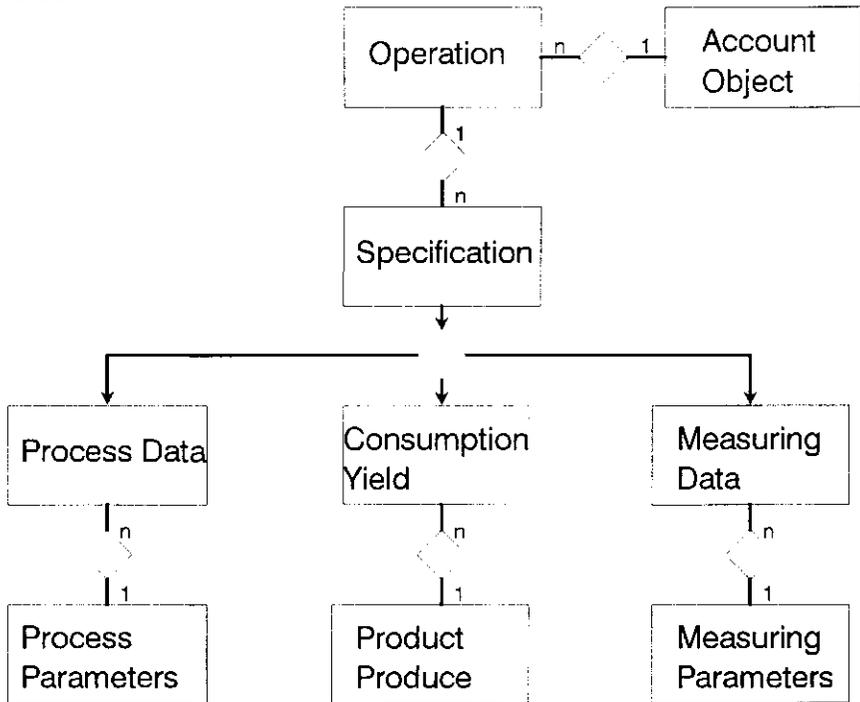


Figure 3. ERD Diagram: Operation

- A planned operation as the result of the scheduler to be carried out within a certain time period.
- An Operation in execution.
- An interrupted operation when the work is partly finished and has to be continued.
- a realized operation which is finished.
- a terminated operation which is partly finished and will not be continued.

Job and Task

Resources as workers, powered vehicles, implements and installations are required to realise the work. An operation following a specific specification can be carried out by different working methods, i.e. how it is organised. Sometimes operations depend on each other as is the case with harvesting, transport and loading a storage. Sometimes it can be executed in parallel or separately, like for example harrowing and planting. It is up to the scheduler to choose the way in which the work will be organised in respect of availability of the resources.

All the resources working organisationally together to realise one or more operations on the same object form a gang and execute a *Job*.

Resources that are physically linked together form a work-set and execute a *Task*. Such a task can exist out of more operations like harrowing and planting executed at the same time in crop production and milking and concentrate feeding executed at the same time in

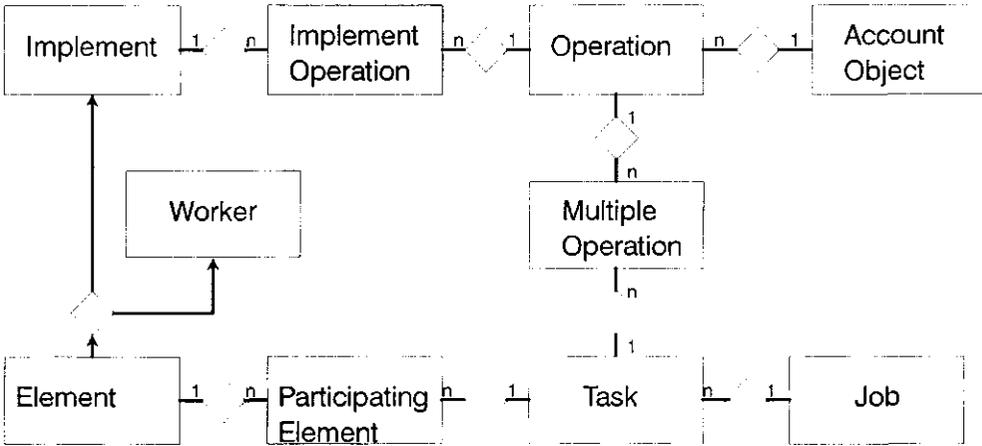


Figure 4. ERD diagram: Task-Job

dairy farming. On this manner a Job exists of one or more Tasks and both can have the status; planned, in execution, interrupted, realised or terminated. (Fig. 4)

The information collected on Tasks and eventually Jobs is restricted to management data, such as Participating Element that specifies the time that a resource was active in task and for equipment the time of eventual breakdowns. On a task also the time can be measured in more or less detail, depending on the requirements of the specific enterprise.

In a lot of cases there will be one operation for each Task and one Task for each Job, so the need for a distinction between Operation, Task and Job will not always be felt and therefore not found in present day agricultural software.

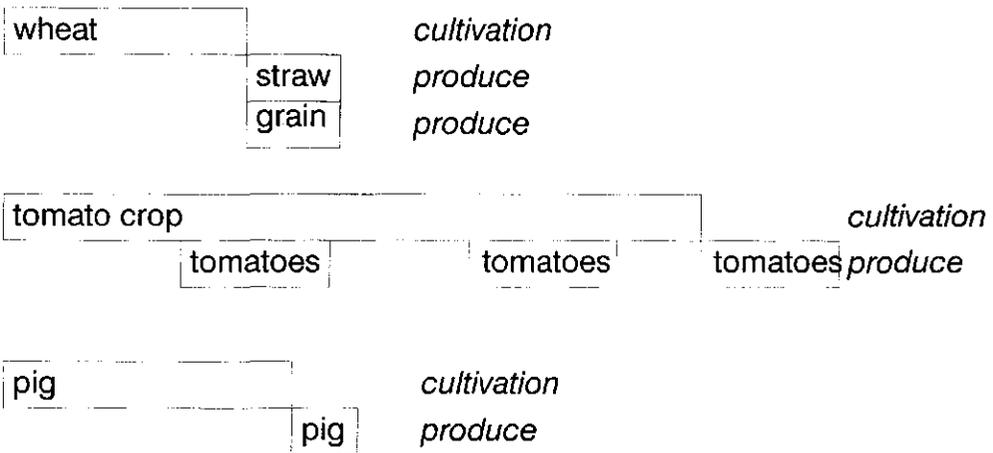


Figure 5. The conversion of Cultivation to Produce

Cultivation and Product/Produce.

The most important objects in agricultural chains are the Products used in a production process and Produce as the result of it. A division is made between the object that is used for bringing forward a Produce, the Cultivation, and the Produce itself.

Wheat growing on a particular field is a cultivation that can bring forward two produces; the straw and the grain. A cultivation of tomato plants results periodically in a batch of tomatoes as produce. With ornamental plants or pigs the same physical object of plant or pig is converted from Cultivation to Produce at the time of collection for delivery. Potatoes are a produce that at a certain time will be a product used as input for a next cultivation. (In the model there is no distinction between product and produce) (Fig. 5)

Registration of the process parameters, amounts of products applied and status data can take place on a Cultivation during operations, which might be pure measurements. Because operations as cooling sorting and disinfecting can also be performed on the produce itself there are also registrations on the produce.

An operation as sorting has one product as input and two or more products as output, while in animal production a new product will be produced by milling and mixing two or more products.

Small units.

Operations are executed on objects like fields and animal groups, but more and more a differentiation in the specification is required for smaller areas within a field or individual animals within a group. Positioning systems and identification systems make this feasible. The specification for each to distinguish unit is given as an absolute or relative value of the referred Specification for the whole object.

In an agricultural chain it might be of interest to the whole chain to keep smaller units of produce separated and individually treated. With animals and produce stored in containers this should not be to much of an effort, but in crop production where present harvesting, transport and storage equipment is based on treatment of the whole field this will require high additional investments.

The farmer and the following logistic part of the chain can only be encouraged to do these investments when the price of the produce is a non-linear function of a to distinguish characteristic of the produce.

Architecture for farming.

The proposed production architecture is described for crop production and its specific aspects. The architecture is however also applicable for animal production.

The farm controller is on top of the hierarchy and incorporates processes as operational crop/animal/contract planning and scheduling. The job controller is responsible for control of all the resources that work organizationally together and the task controller is responsible for the resources that work physically together in realising one or more operations. The device controller is responsible for the coordination within the device that on itself can be divided in different tools like flow control valves and booms which have their own closed loop control. On the lowest level intelligent sensors and actuators will be used. (Fig. 6)

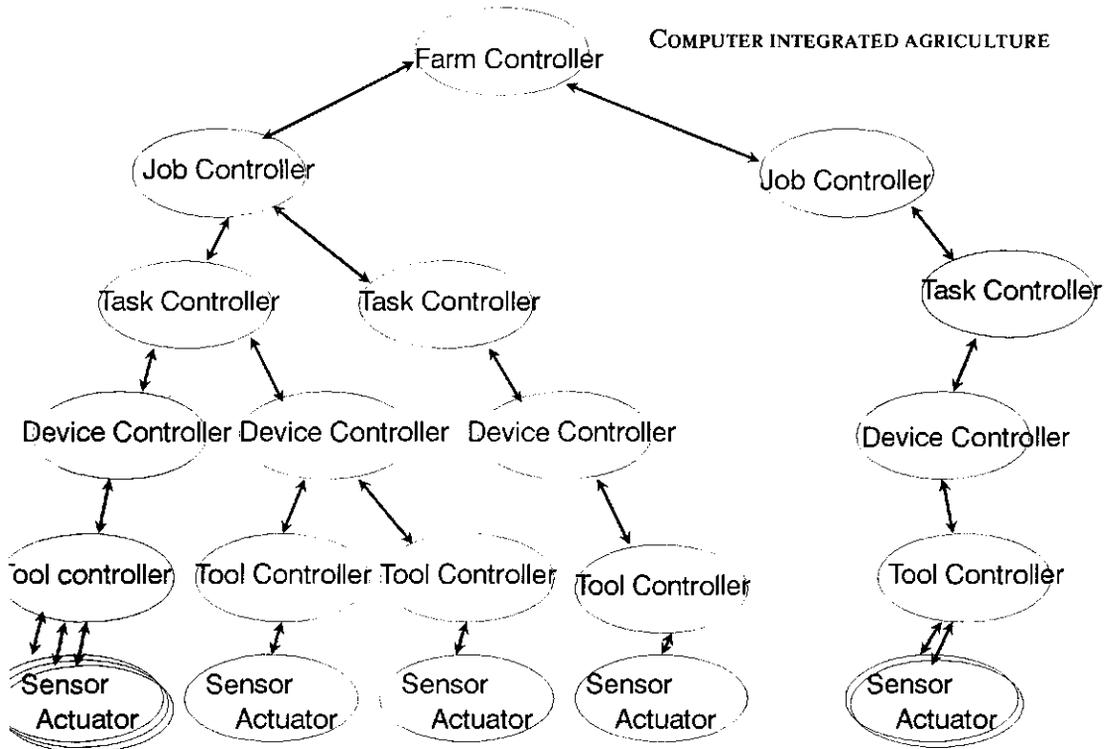


Figure 6. A controll architecture in primary farm production

Communication.

The controllers mentioned in chapter 5 are functional units which can be implemented on different platforms and platform types. The lines drafted in figure 6 represent information flows that need to be communicated. In an open environment with different manufacturers this communication has to be standardized, even when they are located in the same computer system. The techniques that are appropriate will be determined by the physical distribution, the data volume and eventual real time aspects.

The Job Controller in arable farming can be located at the home base and than it can be located in the same computer system as the Farm Controller, but it might also be possible that it is located in the same computer system as the task controller on one of the work-sets in the field. In dairy farming or horticulture it can be located more near to the work place. In that case a communication link is required between those two systems.

Present standardisation activities.

ISO/TC23/SC19, the subcommittee on farm electronics developed the Agricultural Data Interchange Syntax (ADIS) as a protocol for information interchange between Management information Systems (Farm Controller) and the process computers (remote Job Controller and Task Controller). This protocol specifies the format of an ASCII file by which messages are interchanged. The content of a message is specified in a so-called D-line by a listing of data dictionary numbers out of a application specific data dictionary. The values are given in one or more subsequent V-lines.

WG1 (mobile applications) and WG2 (stationary applications) of mentioned subcommittee are formulating data dictionaries for their respective applications.

Within WG1 standards are drafted for communication between mobile process computers on farm equipment. This standard will be compatible with the ISO standard for Truck and Bus and uses the CAN protocol. Messages for the agricultural application have still to be specified. The CIA information model will be used as a basis for the data dictionaries.

Manufacturing message system, MMS.

The communication technology is an important aspect of the integrating infrastructure. The possibilities for application of the Manufacturing Message System (MMS) on the process control level in agriculture is investigated.

MMS, that is part of the application layer used in the MAP standard, has the objective to control and monitor remote applications by means of loading programs, starting and stopping programs, reading and writing variables, etc.

MMS uses the concept of the virtual manufacturing device VMD, which describes the external behaviour of a device and contains a representation in the form of objects of the resources and the functionality of the device.

Objects used to describe such a system are: variable, domain, program invocation, event, semaphore, journal. A number of appropriate services are defined for these objects such as read, write, download, etc.

A sprayer described as VMD.

An agricultural sprayer can be described by a list of terms as nozzle, open/close section, mixing bin, pump, control valve, product, folding section, water bin, chemical bin, etc.

How such an agricultural sprayer can be described as a virtual manufacturing device is shown in *figure 7*.

The device has a number of VMD specific variables, such as NumberOfProductBins, NumberOfFlowControlSections which are specific for an agricultural sprayer. Apart from the specific variables it has the generic VMD variables such as Name, Status, ListOfCapabilities.

A program invocation object represents a program that realises particular functions of the VMD. In a sprayer there can be programs to control the height and balance of the spraying boom, a program that controls the product application, and one that deals with cleaning of the equipment at the end of a task.

Within the VMD a number of domains are specified which describe specific data structures for an application. They can be seen as objects used within the VMD and have their domain specific variables.

Events represent an occurrence that is the sign to start a specific action. By starting such actions the VMD can come in different states like Power Up, Transport, Idle, Ready, Operating, Filling.

There can be different classes of sprayers. Some sprayers require that placing in/out transport is done manual, other can do that automatic. Some sprayers are able to dose different products simultaneously, others are not. This is specified in the list of capabilities and there is a correspondence between capabilities and the domains, program invocations, variables and services that must be present in the VMD.

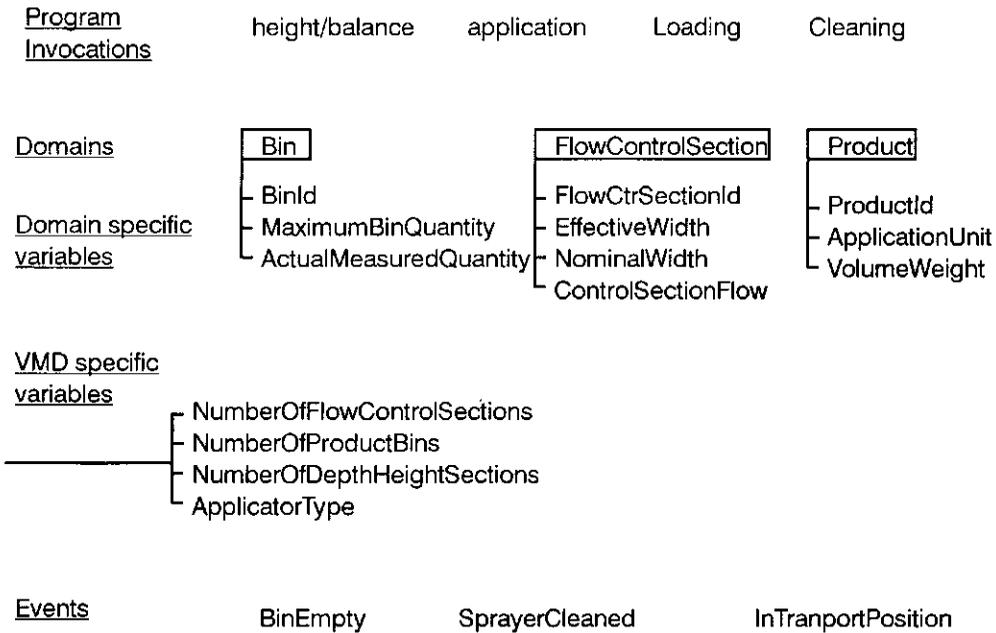


Figure 7. An agricultural sprayer described as a Virtual Manufacturing Device

MMS in agriculture.

The main reason to use MMS in agriculture is because it provides a standard method to communicate with devices which is independent of the location of the device and eventual applied communication technology. This means that an application process can “talk” with an other application process by means of MMS primitives, without even knowing whether the other process is located in the same computer platform or located on an other one and must be reached by a communication protocol. The big advantage is that it is a ISO standard applied in the production industry and that MMS compatible tools and software will be available.

The original place of MMS in the MAP communication system will not be acceptable in agriculture because of the large overhead in the for MAP defined OSI layers 1-6. It is possible to use the principle of MMS with a simpler communication protocol and this is also done in the industry.

It must be investigated to which extend MMS can be applied in real time control loops. The software overhead of MMS in combination with the applied low priced hardware in agriculture will have its limitations.

Experiments will be carried out with a mobile application, but stationary applications in agriculture might be more appropriate.

Communication in agricultural chains.

Often the impression is given that communication between enterprises in an agricultural chain is through the computer system that handle the management of the enterprises. Central computer systems can eventually have a role in this communication.

In the future also computer systems that are lower in the hierarchy will have to communicate. An example is the board computer of a truck that is hauling milk and communicates directly with the cooling system on the farm to pass actual data on the milk. An other example is the controller of a manure injection system that directly gets his data on manure composition from the truck that delivers.

This means that apart from technical standards for such communication also the data which is used near to the process level in the different enterprises must be uniformly defined.

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