The Role of Mechatronics in Crop Product Traceability

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1 Introduction

Today crop production worldwide has to be realised on continuously decreasing agricultural used areas combined with an increasing world population. Starvation on one hand and affluence on the other hand are dominating our daily life. Engineering is delivering higher and higher performances and new technologies are changing traditional production processes. The community often meets this developments with sceptical, because agricultural production became a strange unknown thing to the people:

- milk comes from the super market, if milk has a connection to the cow it is because of TV advertising for chocolate with the colourful (violet) cow.
- The well protected environment is required by all people, agriculture is the primary enemy of the environment.
- Crises like BSE and Foot and Mouth Disease support the consumer in his distrust against agriculture – agriculture means environmental pollution and profit.
- The work in the garden, with flowers and pets, loved by almost all people, leads to a self-overestimation – everyone becomes a specialist in agriculture.

Against this background the community has given agriculture the role of the “bad boy” – agriculture has become a looser. Agriculture itself has forgotten its results and advances in production, in the protection of animals and in environmental protection. In many cases agriculture is very sceptic against technical developments and progress and is therefore missing new chances.

2. Overview on precision crop farming

2.1 Intelligent technologies

New intelligent technologies in agriculture are leaded by the utilisation of information technologies. “Mechatronics”, the combination of mechanics and electronics together with

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hydraulics makes intelligent components available which can be connected using electronic communication. This connection can be limited to the internal communication of a machine or an implement where it increases the performance of the machine significantly and/or where it makes the control much more easier. But the electronic communication can also connect tractors with implements or implements with other implements if standardised communication system like LBS / ISOBUS (fig. 1) are used.

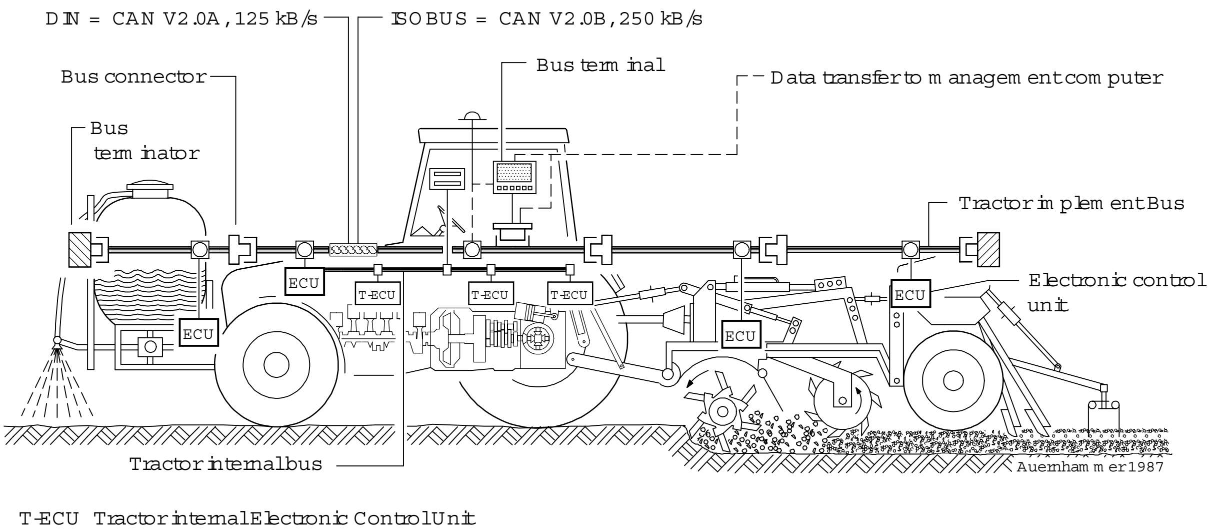


Figure 1: Structure of LBS / ISOBUS

If positioning services like GPS NAVSTAR, GLONASS or Europe's future Galileo will be integrated, than the way for automated information acquisition and information use by location and time can start.

2.2 Precision Farming

Intelligent technology in combination with "position and time" is much more than dividing fields into management zones. Precision farming is positioned within the structure of precision agriculture (fig. 2).

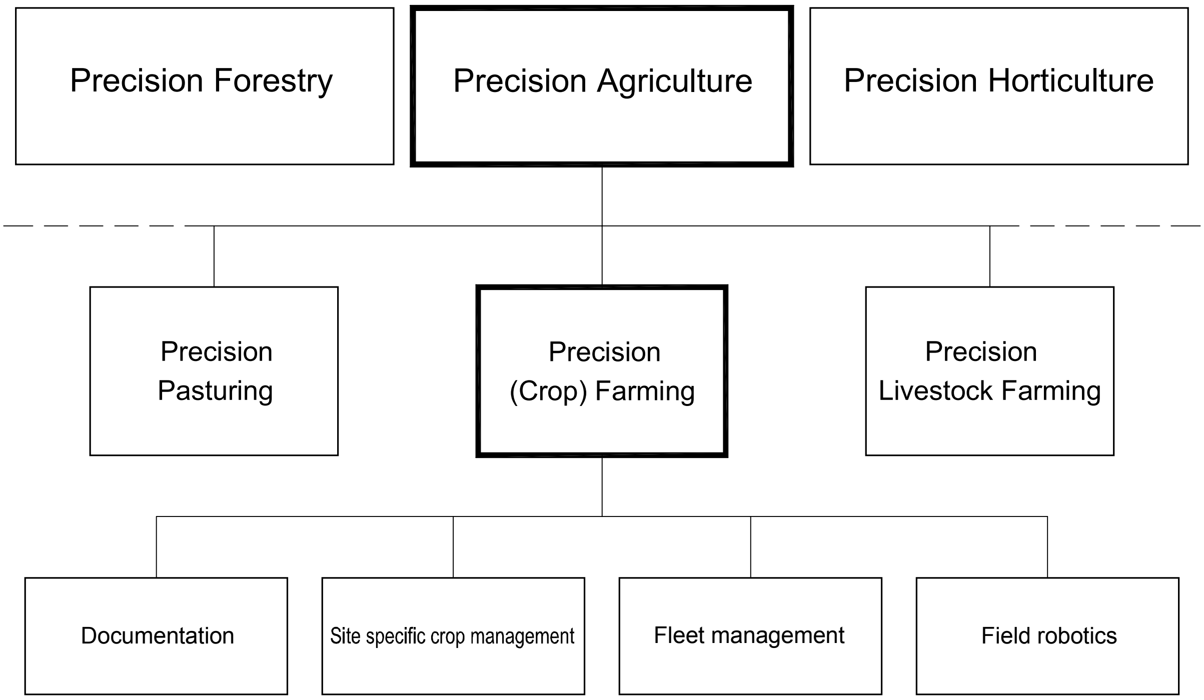


Figure 2: Precision agriculture

Within this structure also precision forestry, precision horticulture and precise landscape management are located.

Within precision agriculture precision (crop) farming and precision livestock farming are well known. Both are completed by precision pasturing or grassland management.

Precision (crop) farming also can be differentiated. It starts with information acquisition, continues with site specific farming and ends with machinery management and organisation and the field robots (fig. 3).

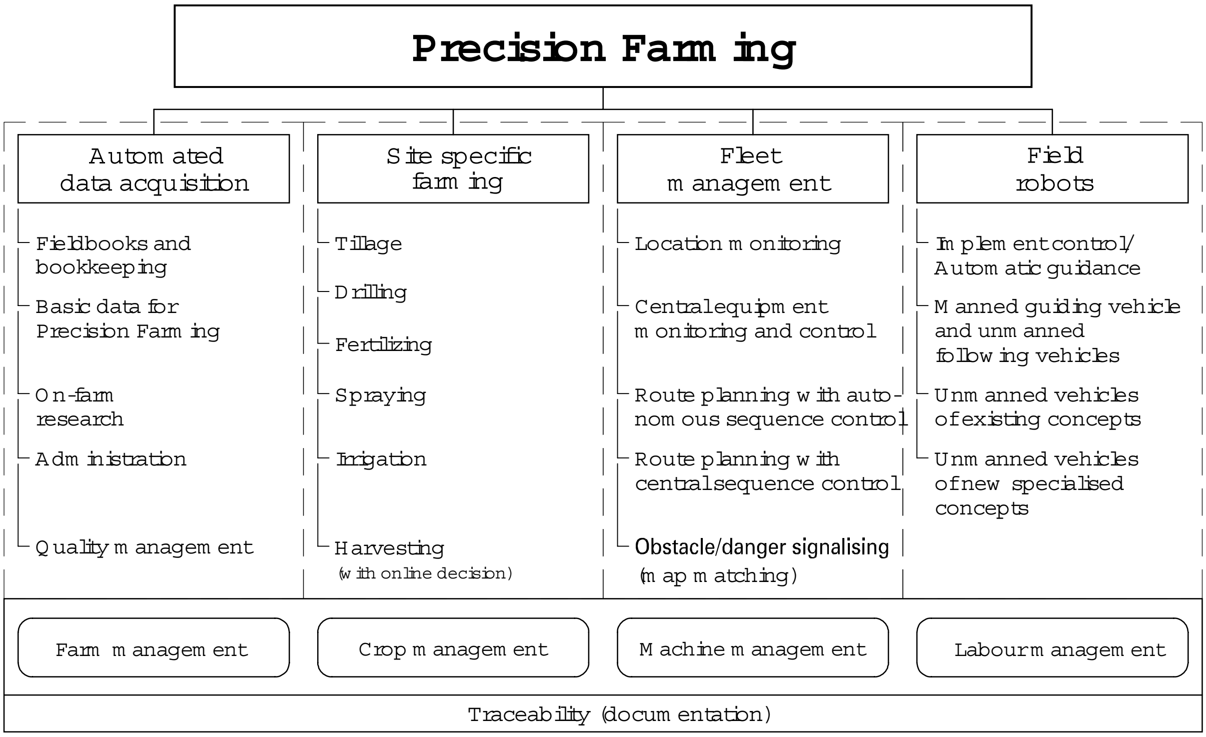


Figure 3: Applications of Precision Farming

3. Applications of mechatronics

Key examples should illustrate the new possibilities and show their realisation.

3.1 Automated data acquisition

By the use of sensors intelligent technology is able to collect information autonomously. In combination with position and time electronic data acquisition makes the documentation of production processes possible. If all machines and implements involved in the production process can be electronically identified the automation of the data acquisition can be realised. Agricultural production traceability is on the way (fig. 4).

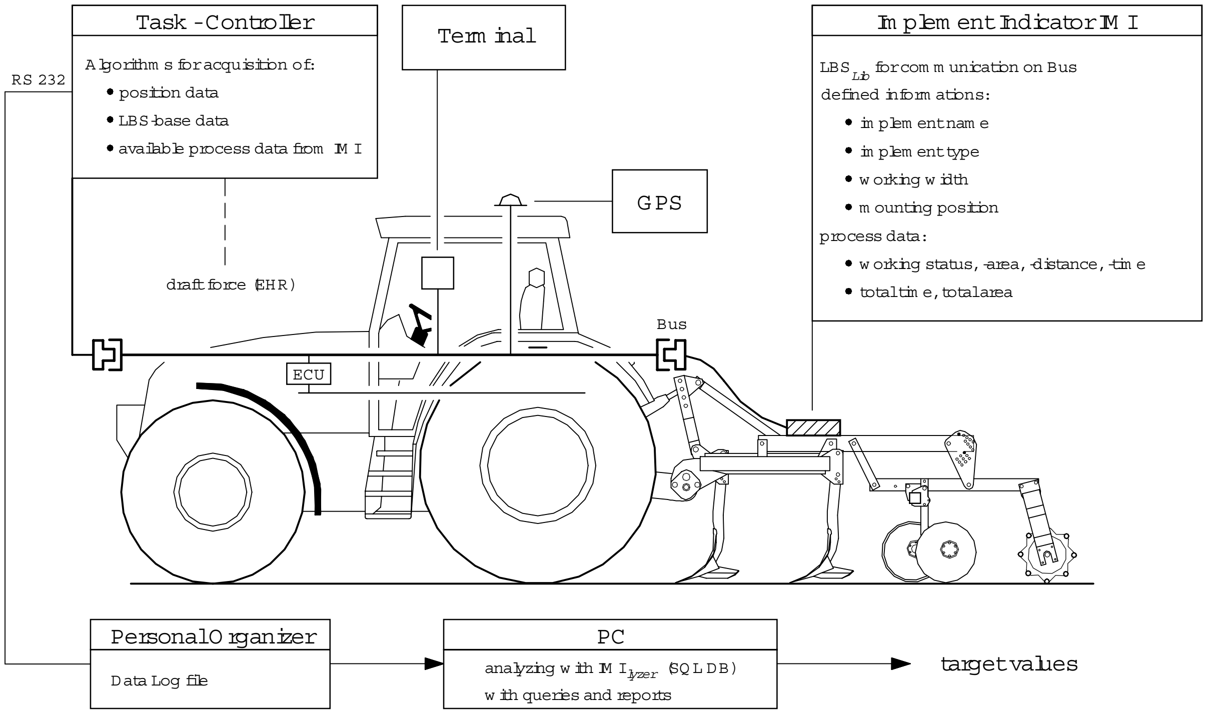


Figure 4: Automated process data acquisition with LBS, GPS and the implement indicator IMI

3.2 Site-specific crop management

Site-specific crop management needs fields, which can be divided into zones and is therefore limited to farming structures with large fields. In this regions precision farming has started and has already become an established farming system in many areas of Europe and the US.

3.2.1 Site-specific farming

In areas with large fields (large scale farming) site-specific plant production takes the heterogeneities within a field into account following three different strategies (fig. 5).

- Following the **mapping approach** the level of the basic fertilization (not nitrogen), seeding and planting densities are deduced from multiple local yield data and/or systematic (geo-referenced) soil sampling.
- **Sensor systems** (real time approach) register the actual situation of the plant development (biomass) in the field or the growth of the weeds. Based on defined algorithms of the target yield (biomass) the amount of nitrogen fertilizer is calculated and on-line directly distributed.
- Finally **both systems can be combined** (Real-time approach with map-overlay) . With this combined strategy the application of too much nitrogen can be prevented, especially if caused by unusual plant development nitrogen fertilizer amounts are calculated from the sensor signals, which do not compare to the long-term yield structure.

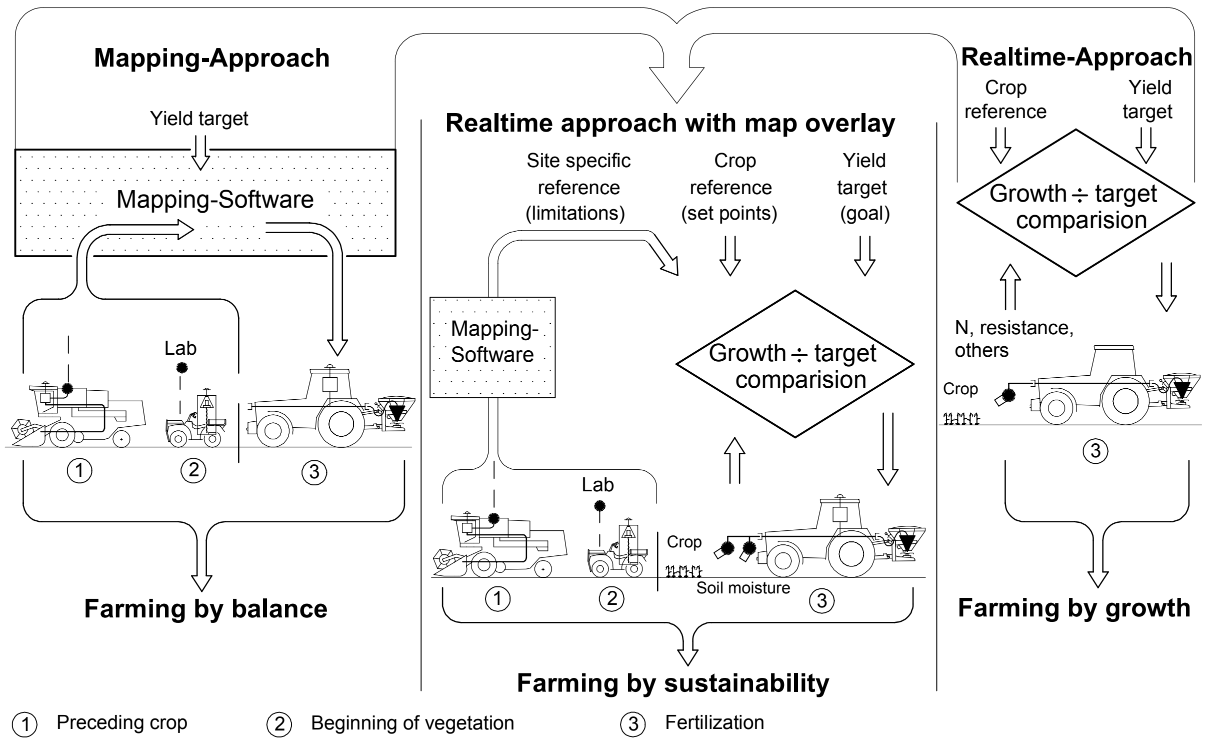
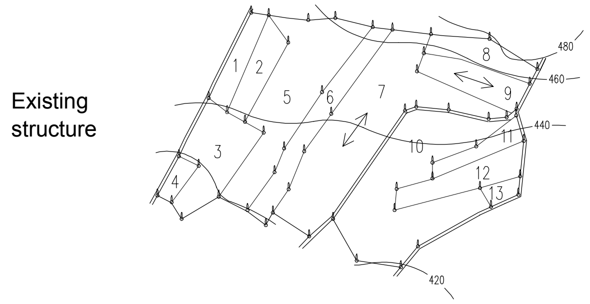


Figure 5: Strategies of site specific plant production

All these strategies require larger fields with the possibility of a virtual separation of management zones with similar yield potentials, similar soil types, similar weed population or similar irrigation requirements.

3.2.2 Transborder farming

Farms with small fields (small-scale farming systems) can only participate to this technology if there is a very strong heterogeneity within their fields and if they have special precision farming technology available for small fields which is - compared to enterprises with larger fields – much more expensive. But with existing site specific farming technology the system can also turned around – the existing small fields are used and treated as the management zones of a larger virtual unit. Creating larger units (transborder farming) will introduce a "virtual land consolidation". On this fields site specific farming can be realised following different aims and strategies (fig.6).



		WW	WG	WR
Farmer	A	12	5	1
"	B	4; 6	10	9
"	C	8	3	13
"	D	2	11	7

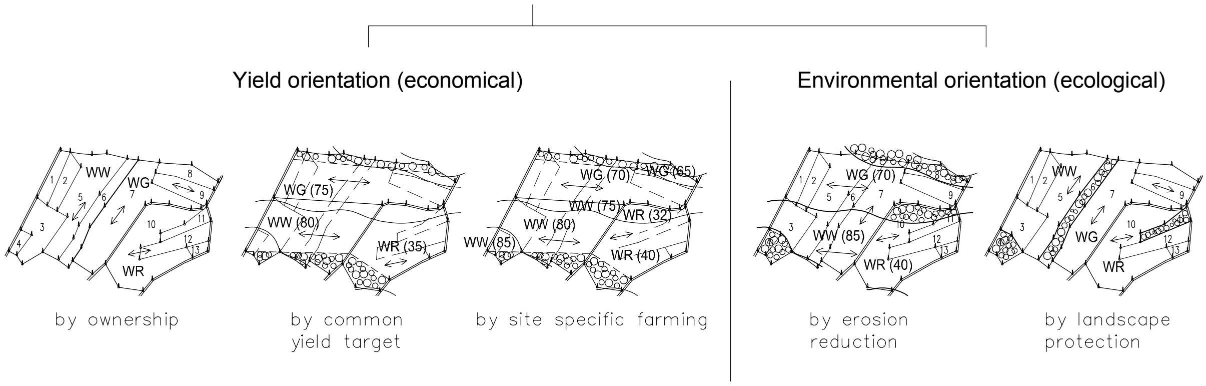


Figure 6: Transborder farming in a “virtual land consolidation”

3.3 Fleet management

Together with position and time the machine internal information can be used not only for economic decisions, but also for the central management of the machine organisation and utilisation. For that purpose the information transfer from the mobile equipment to a central coordination headquarter and/or vice versa is needed. For use in the headquarter, the locations of the machine action with all fields has to be made available in geographic data. Machinery co-operatives (e.g. sugar beet harvesting co-operatives like shown in figure 7), machinery rings and contractors would be able to
calculate and plan the machinery demand to

- make the needed machines available at the right place just in time
- control the performance continuously
- react on upcoming or possible capacity shortage
- optimise the machinery adjustment using telemetric-service
- initiate necessary service or repair measures from the headquarter

by using fleet management systems.

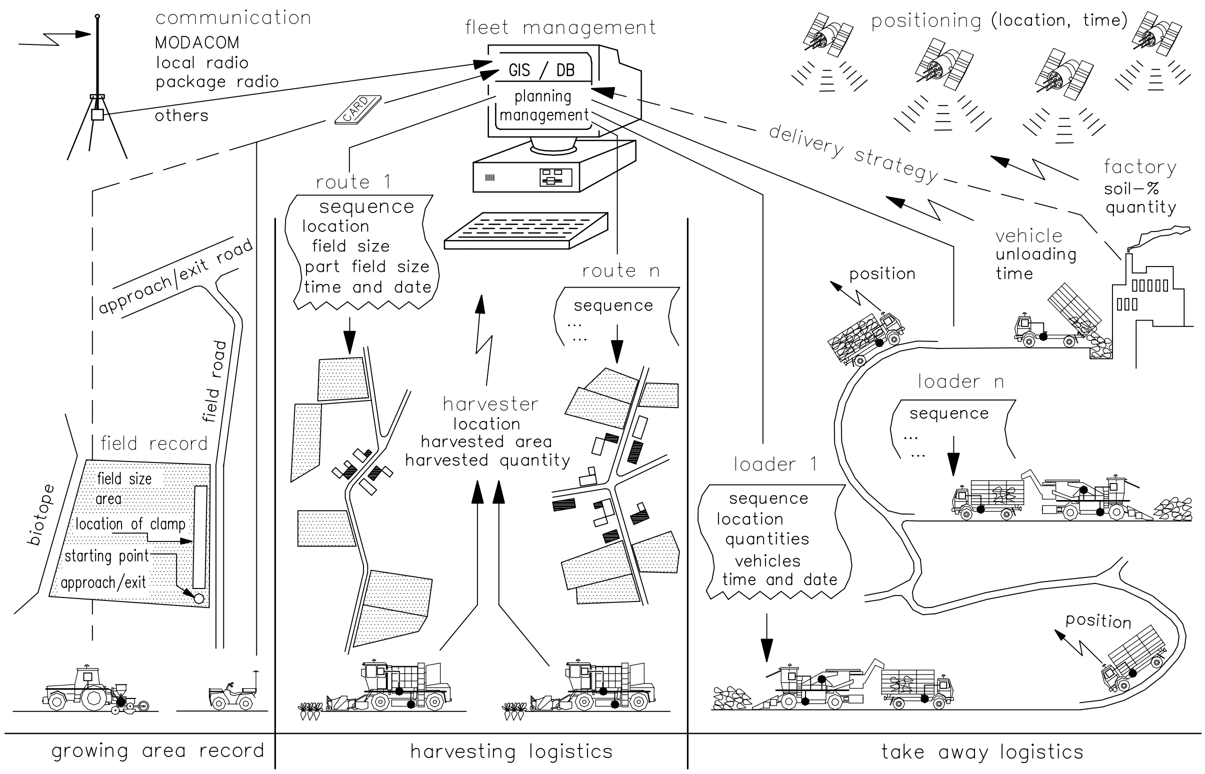


Figure 7: Fleet management system for sugar beet harvesting and transport by machinery co-operative

3.4 Guidance and field robotics

At least the extensive machine internal information together with position and time and a geographic planning of the sequence of events makes the automated guidance of vehicles without any human driver possible (fig. 8).

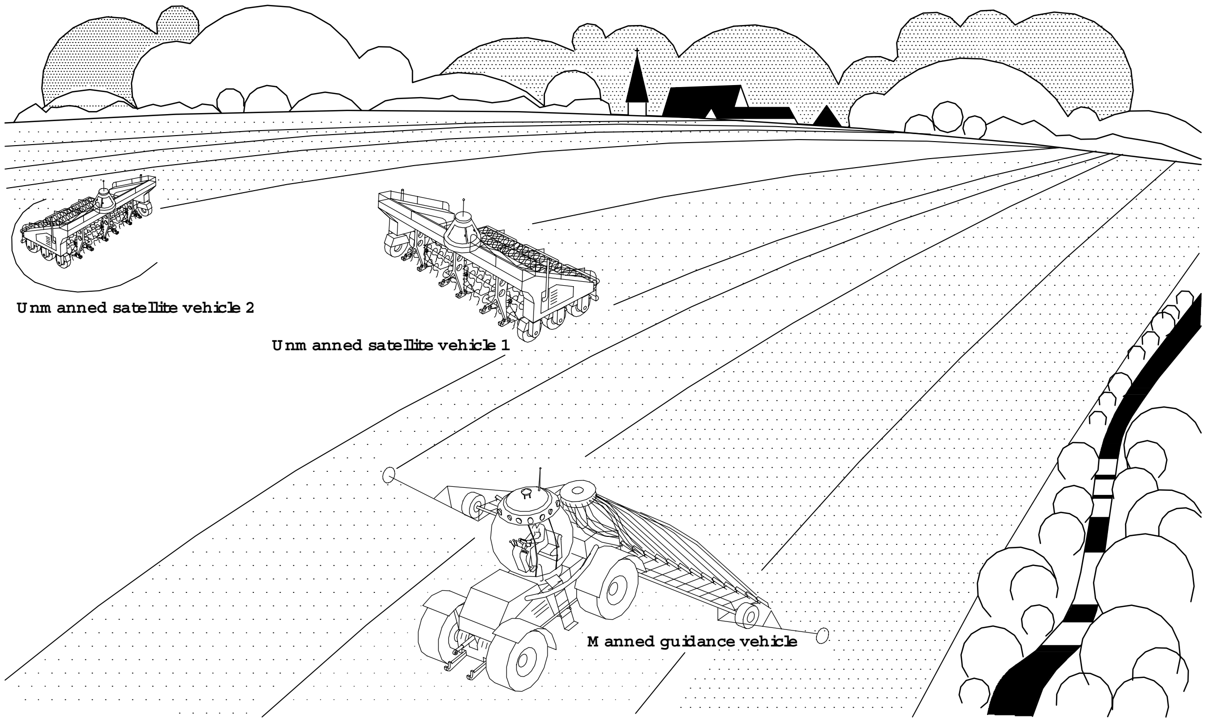


Figure 8: Autonomous vehicle guidance in a master slave system

Developed step by step starting with

- automated machine or implement guidance with human control on board
- combinations of manned guidance vehicles and unmanned following vehicles (master slave principle)
- unmanned autonomous guided self propelled machines based on existing concepts / constructions can be realised. But at the end there has to be developed a new type of specialised unmanned autonomous guided vehicle for multi purpose field works. With such a new conception the trend towards bigger and larger and heavier machines in agriculture might be stopped and with a "herd of robots" it could become possible

on one hand to preserve and to farm small scale agriculture like in Japan

and

- on the other hand to minimise the huge demand for seasonal workforce in large and highly specialised farms like in parts of the USA, GB and Eastern Germany (vegetable production).

Therefore there is a real need for an active and efficient research and development in the area of field robotics with a lot of possibilities and requirements not yet mentioned.

4. Traceability

With the availability of machine internal sensors, actuators, positioning and timing with GPS and the use of electronic communication all technical parameters and activities in processes of the field processes can be automatically collected, stored and processed. In combination with manually collected information a new type of information pool will be available. It spreads across the agricultural production processes on the fields, the farm management, further processing and storage units up to the distribution and the retailer systems.

Information in this context means traceability (fig. 9) with interfaces in the production chain from one process to the following one and with interfaces to the
- administration → taxes, control and subsidies
- society → confidence (transparent production)

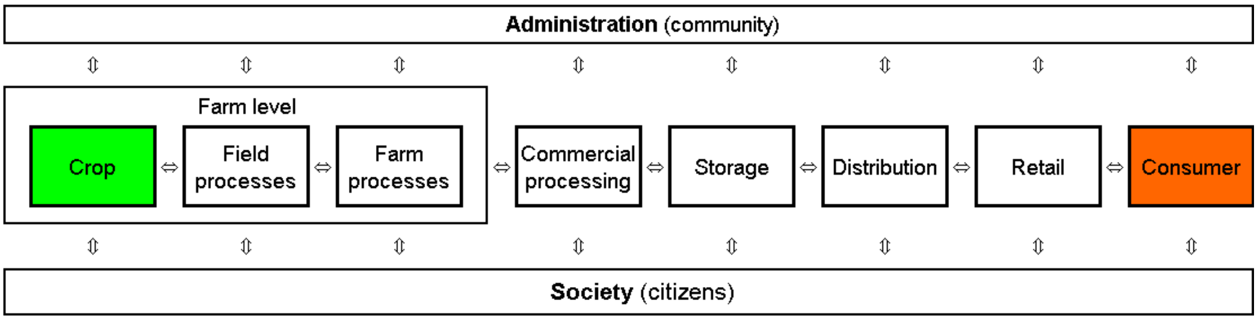


Figure 9: Traceability in the production chain

Though the real information requirements within the product chain have not been defined until now. The information demand is varying very wide. Regarding the three main steps in figure 9 the following information groups with sub-information seem to be important:

Farm level (Farmer)
- Field location, field size, crop, treatment, yield expectation, yield, ingredients
- Nutrition application, nutrition balance

Commerce/Trade (Succeeding processes)
- Mass/volume, origin, route of transport, time of transport, occurrence during transport
- Processes, ingredients, classification

Consumer
- Farming type, farmstead, region, time of production, field operations
- Applications, fuel consumption, working conditions, soil stress / working distance/ha
- Ingredients, water content, quality rate/class

The farmer will be able to deliver different information parts to the consumer depending on his participation in the production and to take over the necessary responsibility in parts or in total (fig. 10).

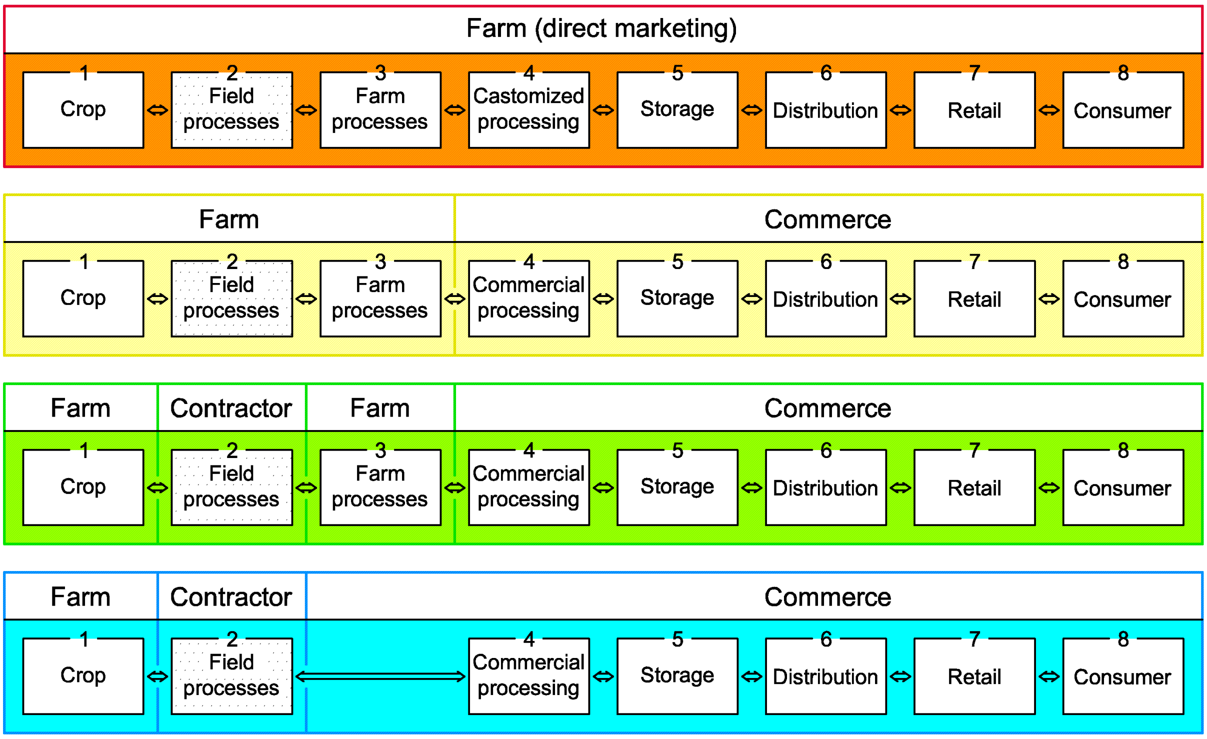


Figure 10: Information responsibility in the crop product chain

Starting with the total responsibility of the farmer it decreases with increasing transfer of the processing and treating more and more. At the same time the influence of the farmer on the product is reduced:

Farmer-only (direct marketing) chain:
- Customized products are the demands of the consumers
- Responsibility only by the farmer

Farmer – commerce chain:
- No influence on the end product by the farmer
- Main responsibility by the farmer

Farmer – contractor – commerce chain:
- No influence on the end product by the farmer
- Contractual influence to the contractor
- Main responsibility by the farmer

Contractor – commerce chain:
- No influence on the end product by the farmer
- Contractual influence to the contractor
- Main responsibility by the contractor

Also the shown information chain includes additional information of supplementary products (fig. 11).

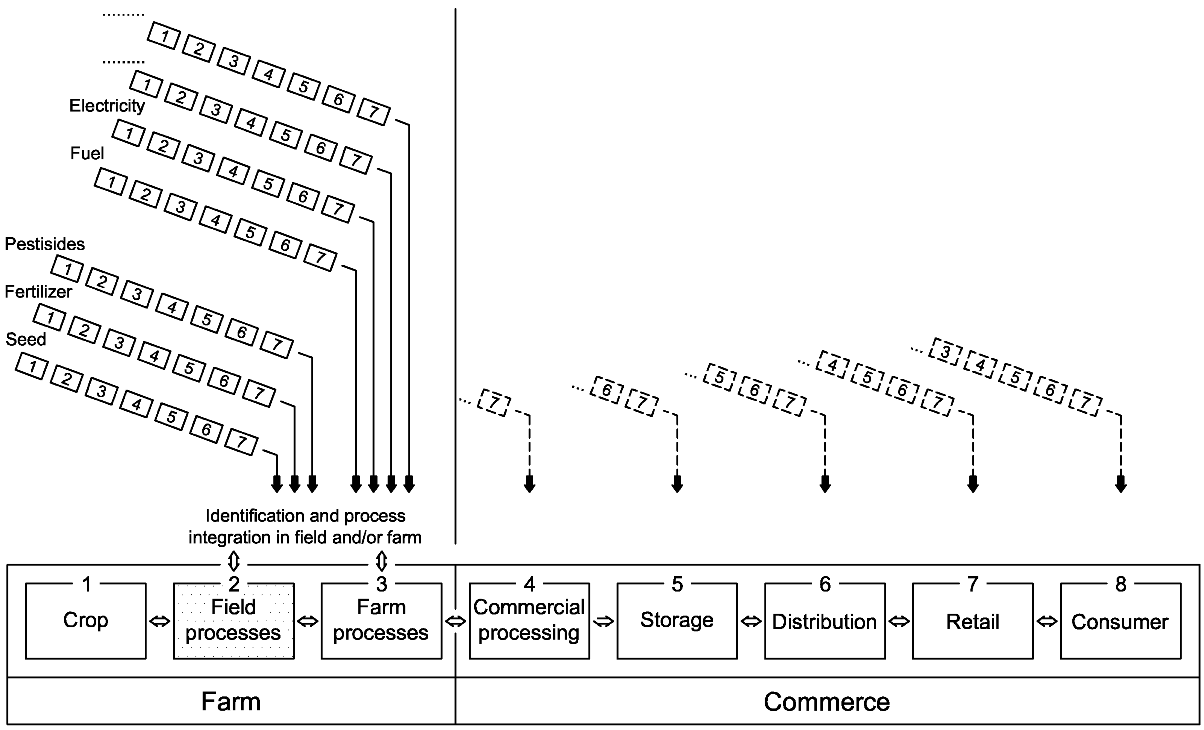


Figure 11: Product chain with supplementary products in the food production

Regarding this products the farmer respectively the processing chain play the role of the consumer. This shows the complexity of a continuous and complete documentation because also the means of production have their own “side information”. Therefore for the farmer clear and comprehensible (realisable) interfaces have to be created. They must be applied to his production and to his farm management.

From the situation of a farmer (farm level) traceability includes (fig. 12)

- signalling from crop, soil, environment
- information gathering
- information processing
- information integration into the farm management
- information supply to/from the trade (hand over and take over)

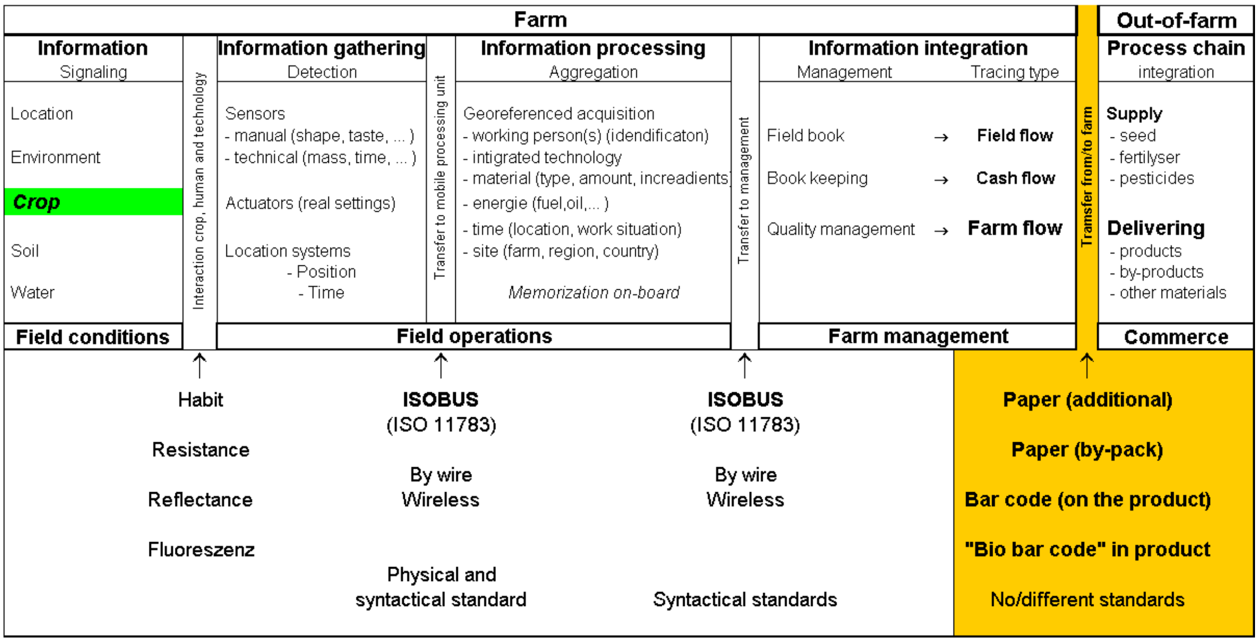


Figure 12: Information flow on the farm level

The role of mechatronics therefore means all activities in this processes and steps of farm work. Mechatronics on the farm level should

- be prepared to sense signals
- use sensors for crop and field processes
- use controllers and actuators
- establish a through-going information flow and information management
- guarantee the information flow and information quality

4.1 Efficient sensors

Traceability includes the complete and comprehensive documentation of

- the process with its typical figures
- the product
- the unequivocal temporal and local assignment of the collected data and the changes within the process.

In a modern technology many sensors are available today. Problems occur with the unequivocal mass and weight detection (harvesting and application).

At a very early stage of development are the possibilities of the detection of quality and ingredients under "real-time / on-line" conditions in the field (tab. 1).

Parameter	Range [%]	R^2	SECV [%]	Factors
Water	57,4 – 68,6	0,774	1,39	13
Amylomaize	28,0 – 41,2	0,608	1,62	13
Enzyme soluble matter	63,8 – 75,9	0,449	1,69	16
Crude fibre	12,4 – 21,4	0,423	1,39	13
Crude protein	6,5 – 8,9	0,706	0,28	12
Slag	3,5 – 4,8	0,303	0,25	11
ME [MJ/kg]	10,0 – 11,5	0,348	0,23	9
NEL [MJ/kg]	5,9 – 7,0	0,360	0,17	9

Table 1: NIR-real-time sensing for quality detection

Here a new wide field for future developments is opened which is expecting to much of single institutions or manufacturers. Therefore integrated projects should be established to investigate and examine the different possibilities and solutions. In connection to this "standardised calibration routines" have to be defined and there improvement and modification have to be tested with newest information technologies. Indispensable are "sample extraction units / sampling automation units" with the possibility to store samples for a longer time for the documentation of the actual status.

In addition such systems need also additional information from the point of the consumers. These are objective possibilities to detect

- form, shape, size
- colour
- consistency
- and others.

4.2 Distributed controllers

The usually used sensors are components within a control unit together with actuators, integrated control strategies and an interface to other controllers (nodes). The sensor information therefore normally is only one sub information of the controller and must be processed in combination with other information to the target information. Already today dedicated controllers are able to detect with its sensors a wide variety of information and create and document well known as well as new process parameters in the assignment to position and time (fig. 13).

date	start time	end time	field	tractor	implement	procedure
2001.04.30	19:45 pm	20:30 pm	TH01	MB-trac	spreader	fertilising

used time in field				
total	*working*	*turning*	*standing*	*time / field*
0.59 h	61 %	23 %	16 %	0.10 h/ha

driven distance in field			
total	*working*	*turning*	*distance / field*
4.11 km	81 %	19 %	0.71 km/ha

working speed		**PTO speed at work**	
mean	*stddev.*	*mean*	*stddev.*
9.26 km/h	2.27 km/h	450 RPM	61 RPM

cultivated area	**applicated volume / weight**		
sum	*sum*	*mean*	*stddev*
4.75 ha	915.6 kg	203.4 kg/ha	34.9 kg/ha

Figure 13: Parameters from automatic data acquisition in field work

More sophisticated networks of controllers need in both, the mobile as well as in the stationary technology additional and new functions e.g.:

Extended Task Controller: Besides the organisation and the control of tasks provided by the farm management (normally by application cards and so on) this controller should be able to collect and create required field parameters for traceability depending on the specific needs of the farmer under his specific conditions. Starting from a basic-data-set of total working time, total amount of used/harvested material and total consumption of diesel more and more detailed information should be provided.

Field tracing controller: Detailed field data have to include the position and the time information from GPS/Galileo. The provided records may again include a basic-data-set and/or a more extended one for geographic data processing. Its resolution in recording may be defined by different criteria like:

- time stamp based (e.g. once per second)
- occasion based (e.g. by changing on parameter in the whole process like application rate, working depth and so on)
- distance based (e.g. every 10 m).

In-field controller: As more and more information during field processes may be obtained on-the-go, a specific in-field-controller may integrate this information into task order data from the management. Its function and organisation may be explained by the following example:

Today the needed nitrogen in top dressing is calculated from a given yield target and the real-time sensor signals showing the actual growth stage. Oversupply on spots with historical low yields and/or low fertiliser uptake depending on available soil water create avoidable pollutions of ground water and inefficient use of nitrogen. In this case a more sophisticated controller with an included knowledge base could optimise both and only such a controller would be able to generate a traceable in-field information.

4.3 Standardised communication

Today these requirements could be fulfilled if the worldwide acting agricultural equipment manufacturers would be willing to take over the standardised electronic communication by ISO 11783 (ISOBUS) as an international realisation of the German standard LBS by DIN 9684. To realise this

- all interfaces have only to follow this standard
- controllers for all technologies have to be available
- test installations for the standards have to be available.

Because of the high number of manufacturers and because of the company specific interests this ideals seems not to be able to reach. A reason for this is also that every standard as smallest common denominator includes not all needed contents and beside this some contents are still not clearly defined. In this realisation into the code of silicon this leads to unavoidable incompatibilities with

- very long development cycles
- extensive and continuing tests on conformity
- frustrated users because of remaining incompatibilities with not detectable reasons in a complex system

Because of this only the use of a standard code like it is realised in a “open source project” (fig. 14) is able to deliver the needed acceleration in the development with fast error detection and solving. If not incompatible “open systems” or more or less “closed systems of the global player” will dominate the market of tomorrow.

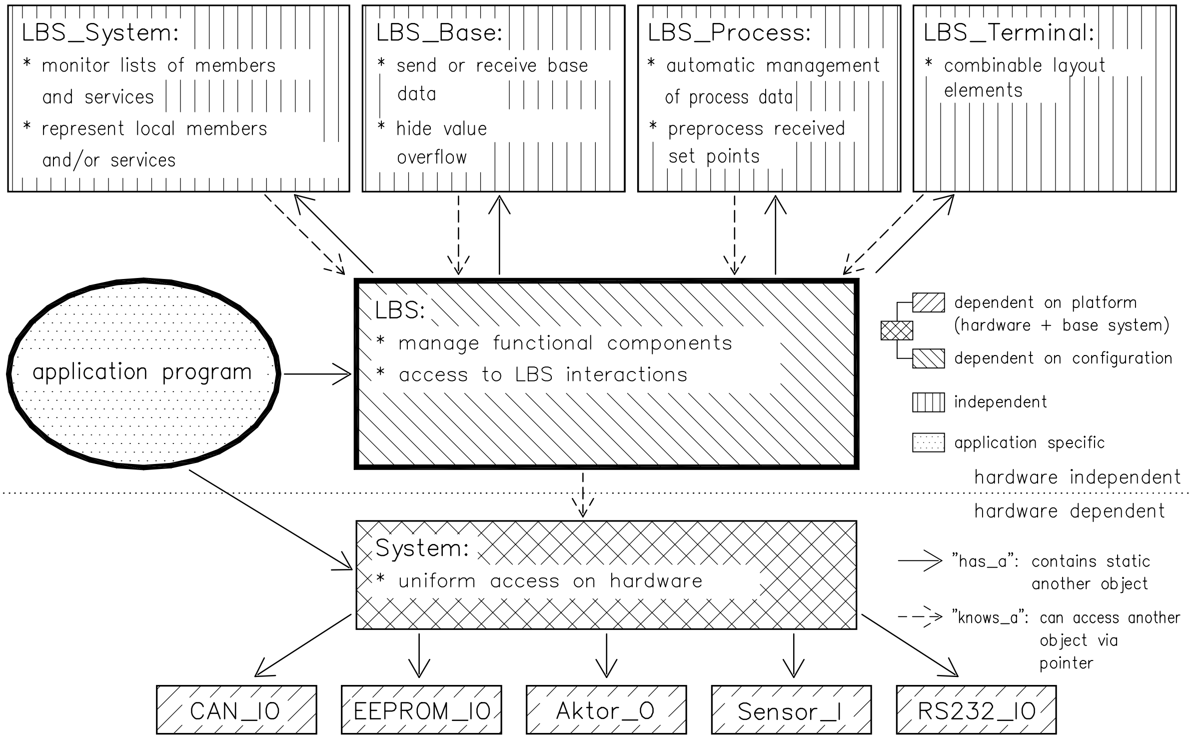


Figure 14: Open source model LBS_{lib}

4.4 Integrated security / safety

Traceability needs an overall information security. To reach this aim much more efforts are needed as mentioned and planned until today (mind crises like BSE, FMD, Nitrofen). Manual possibilities to manipulate the system are the week points. Therefore more and more automation has to be used (fig. 15).

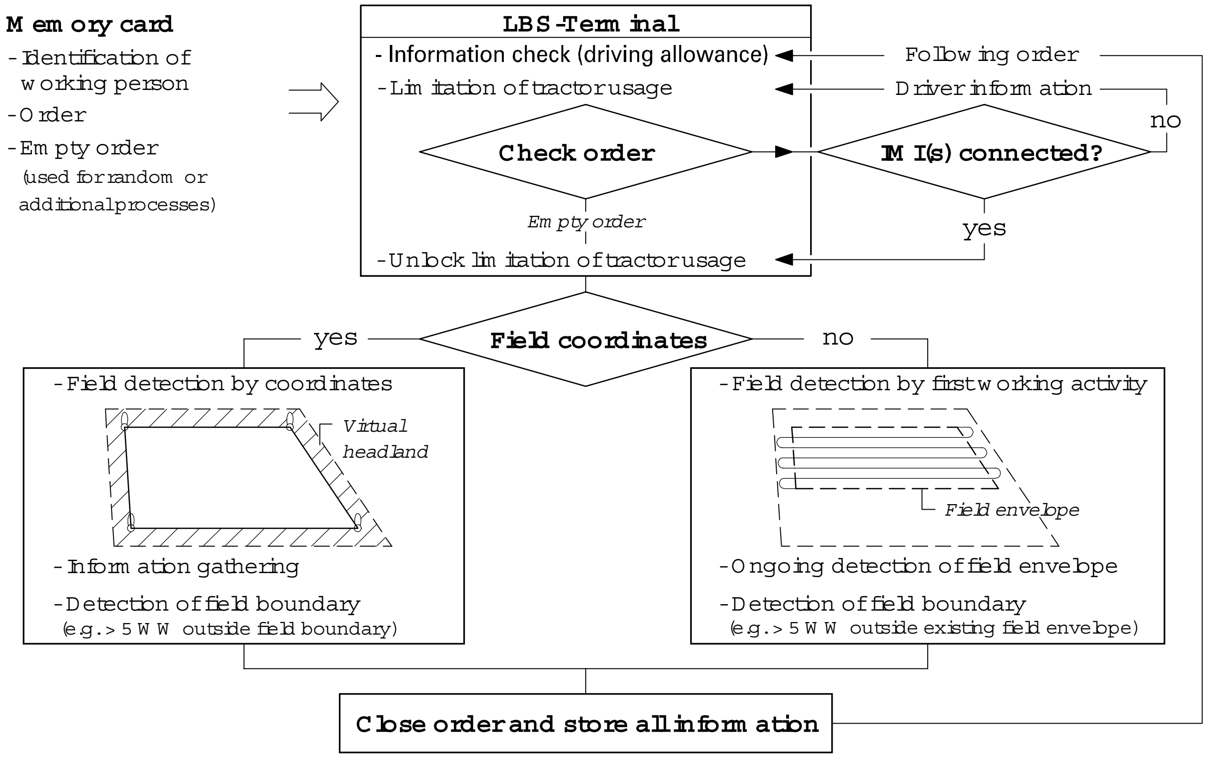


Figure 15: Safety concepts for the automated process data acquisition

Only by using these procedures it can be guarantied that traceability

- makes a general information security possible
- manual manipulation can be avoided
- on farm security is possible
- pass the control of the administration
- earns and stabilise the confidence of the community

5. Conclusions

From these selected criteria of mechatronics and traceability the following conclusions may be drawn:

- Agricultural machinery is becoming more and more intelligent. Position detection with GPS (or Europe's Galileo after 2008) will become a basic component as well as a standardised electronic communication based on LBS / ISOBUS and a high number of different sensors on tractors, implements and self propelled machines.

- Precision Farming seems to be the farming strategy and practise of the future. Within Precision farming applications automated data acquisition will have the highest priority. It will be followed by site specific crop production and fleet management. As a final development autonomously guided vehicles will be introduced into agriculture.

- Product traceability needs information gathering, processing, integration in the farm management and information supply to/from the trade/commerce. and documentation.

- Within mobile agricultural equipment GPS and the standardised communication by ISO 11783 opens ideal possibilities for traceability.

- Sensors available today sense a wide variety of process parameters. There is a big demand for the detection of the product quality, the ingredients and additional parameters defined by the consumers.

Traceability exceeds all existing security concepts. Manual input allows manipulation. Automation may be the adequate answer.
Comprehensive traceability concepts are possible in crop production. But they exceed the capabilities and possibilities of many institutions and agricultural equipment manufacturers. Only in multidisciplinary integrated projects a minimum standard can be reached fast and certainly which than can be further developed in many directions.

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