# Automation in Crop Production

## - State-of-the-art und where to we go from here ?

Hermann
Auernhammer
Freising-Weihenstephan
Germany

*18th World Congress of CIGR*
*Section III Keynote*
*2014 Sep 16*
*Beijing*
*China*

# Don’t forget

**Anybody,**

**who is unfamiliar with the history,**

**is damned to repeat it !**

Georg Santayana: The Life of Reason, 1905

**And don’t forget,**

**there are about 30 million of tractors in use worldwide**

**compared with a very small number of self propelled harvesters, sprayers and spreaders (may be a total of 1.5 Mio.) !**

Herrmann 2001, DLM Hohenheim (Germany)

# Agenda

1. A very true saying from yesterday and figures of today

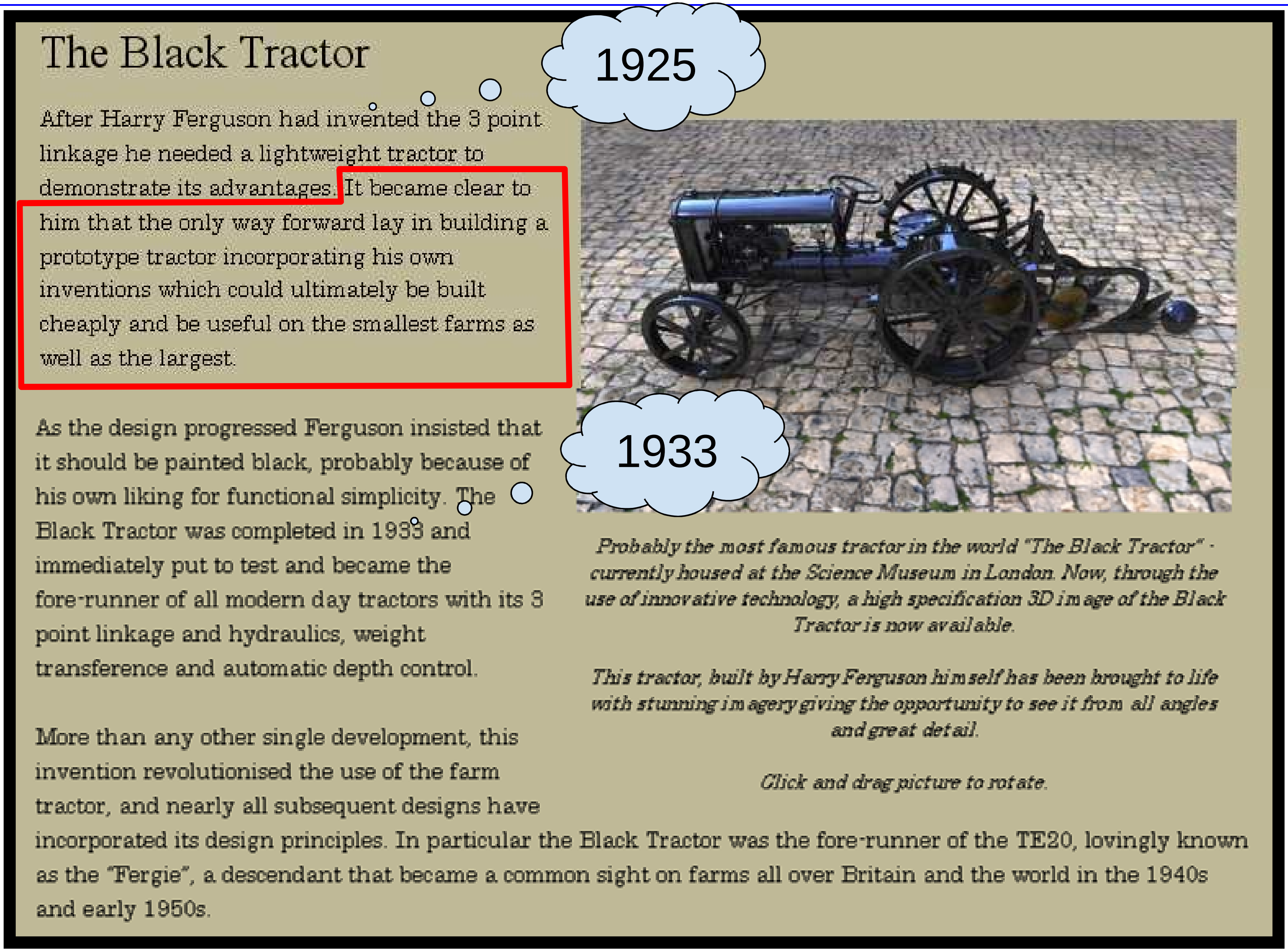
2. **Automation from yesterday**
   - Draft control
   - Auto guidance
   - Continuous variable transmissions

3. **Automation, state-of-the-art**
   - Availability
   - Main influences
   - Reasons for tomorrow

4. **Automation tomorrow**
   - Tractor
   - Self-propelled technology only
   - Tractor implement combinations

5. **Conclusions**

# The idea of Harry Ferguson – Draft Control



## The Black Tractor

After Harry Ferguson had invented the 3 point linkage he needed a lightweight tractor to demonstrate its advantages. It became clear to him that the only way forward lay in building a prototype tractor incorporating his own inventions which could ultimately be built cheaply and be useful on the smallest farms as well as the largest.

1925

As the design progressed Ferguson insisted that it should be painted black, probably because of his own liking for functional simplicity. The Black Tractor was completed in 1933 and immediately put to test and became the fore-runner of all modern day tractors with its 3 point linkage and hydraulics, weight transference and automatic depth control.

1933

More than any other single development, this invention revolutionised the use of the farm tractor, and nearly all subsequent designs have incorporated its design principles. In particular the Black Tractor was the fore-runner of the TE20, lovingly known as the "Fergie", a descendant that became a common sight on farms all over Britain and the world in the 1940s and early 1950s.

*Probably the most famous tractor in the world "The Black Tractor" - currently housed at the Science Museum in London. Now, through the use of innovative technology, a high specification 3D image of the Black Tractor is now available.*

*This tractor, built by Harry Ferguson himself has been brought to life with stunning imagery giving the opportunity to see it from all angles and great detail.*

*Click and drag picture to rotate.*

http://www.ferguson-museum.co.uk/black_tractor.htm

# Gigantic simple, as ...

*Probably the most famous tractor in the world "The Black Tractor" - currently housed at the Science Museum in London. Now, through the use of innovative technology, a high specification 3D image of the Black Tractor is now available.*

*This tractor, built by Harry Ferguson himself has been brought to life with stunning imagery giving the opportunity to see it from all angles and great detail.*

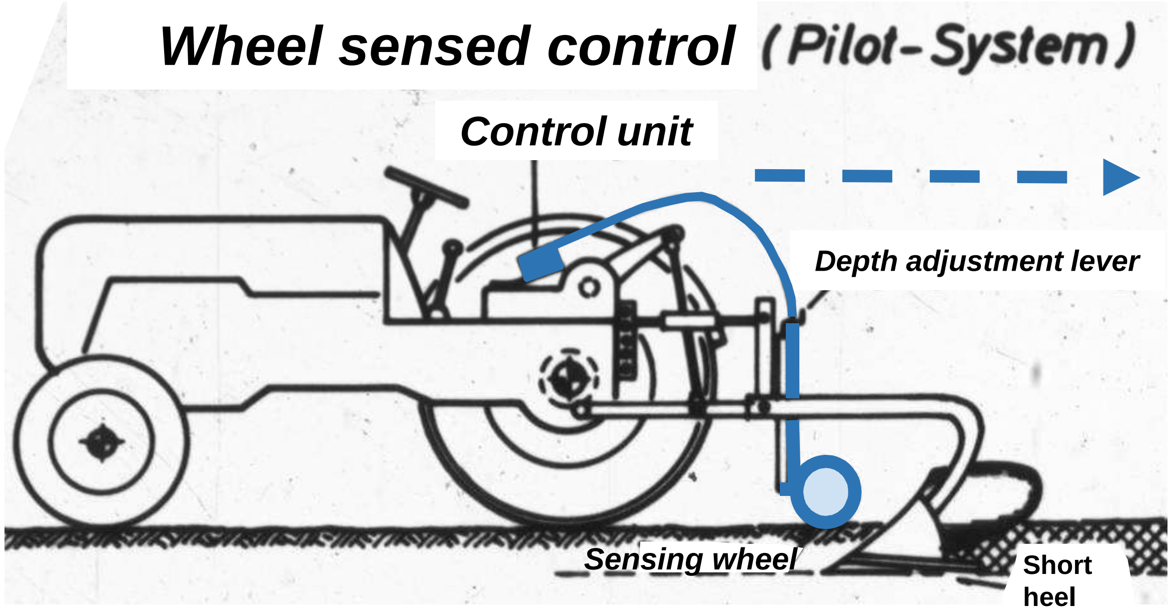
*Click and drag picture to rotate.*

- **… the upper link engages the actuator** *(no additional equipment)*
- **… the actuator is an internal part of the tractor**
- **… it guarantees 100 % of reliability**
- **… it enables slip reduction**
- **… it enables light weight construction**
- **… handling is simple**

**But (keep in mind) there is …**

- **… diverse working depth**
- **… getting stuck at abrupt change in soil type** *(mainly with rubber tires)*

# An idea 30 years later – equal working depth



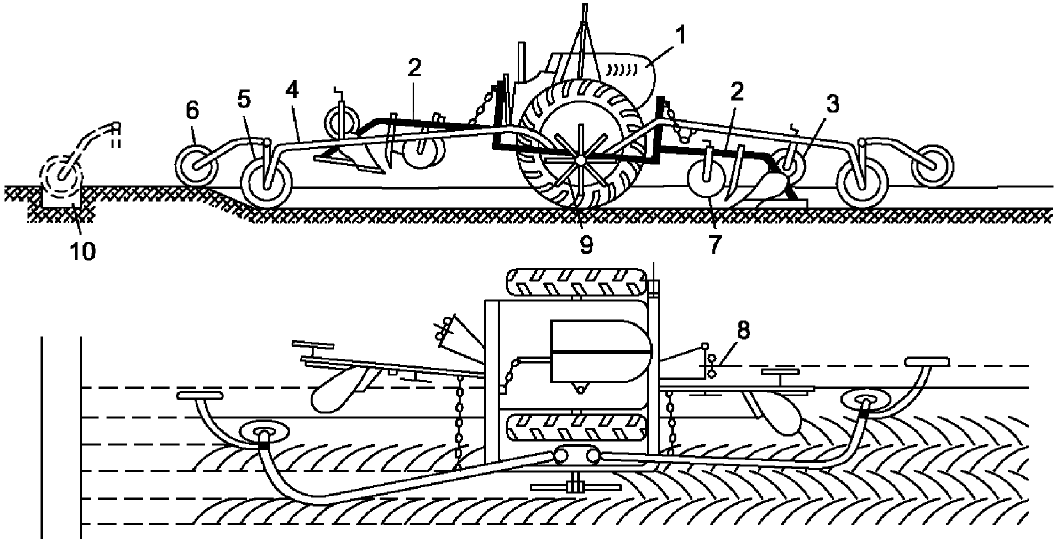
*“Sensing wheel(s) measure the depth of the plough and transfer control signals to the control unit. Small unevenness is neglected. Plough is permanently carried by the hydraulics. Weight transfer to tractor rear axle is well (e.g. Hanomag).”*

*Brenner, 1963*

- **Similar working depth with constant hydraulic pressure**
- **Useable for different implements with the need of constant surface distance**
- **Handling trivial**

- **Sensor is an additional implement element (sensing wheel)**
- **Control unit** *(actuator)* **is an additional tractor element**
- **Manufacturer specific solution**
- **Missing standard prevent wider use on farm level**
- **No beneficial agronomic proof of constant working depth**

# Robotic Plough (Eicher 1964)



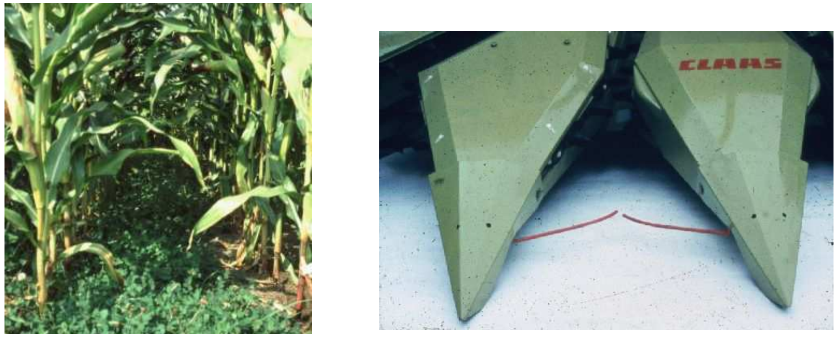
**Agrirobot**, a one-body autonomous plough with mechanical control. Driving direction was changed at field end after passing with the “switch wheel” across a previously established lateral furrow.

Source: Grundl. Landtechnik 18 (1968) 17

- **Simple field preparation** *(lateral furrow)* **with no headland**
- **Able to work 24 hours/day** *(with 1-body similar to a 3-body tractor plough)*
- **Build from existing serial production parts** *(engine, axle, gearbox, plough)*

- **Mechanical sensing of the lateral furrow is difficult**
- **Stabile operation only in clean furrows**
- **Used in a time when tractors and laborers are not restricted**
- **No safe and problem-free work at all !**

# Row guidance – Self propelled harvesters



- **Company specific control integration** *(independent from competitors)*
- **High accuracy with increased productivity**
- **No additional infrastructure required**
- **Handling trivial by steering wheel activation**
- **Simple manual over-steering**
- **Retrofitting possible**

- **Stabile field conditions for automation required** *(walking-stick-like rows/plants or clean edges)*

# Variable rate application (VAR) – Fertilizer and pest control

Resistance


System ATB

Near infrared reflectance


System Kiel


System (Kiel)Yara


System IKB


System GreenSeeker

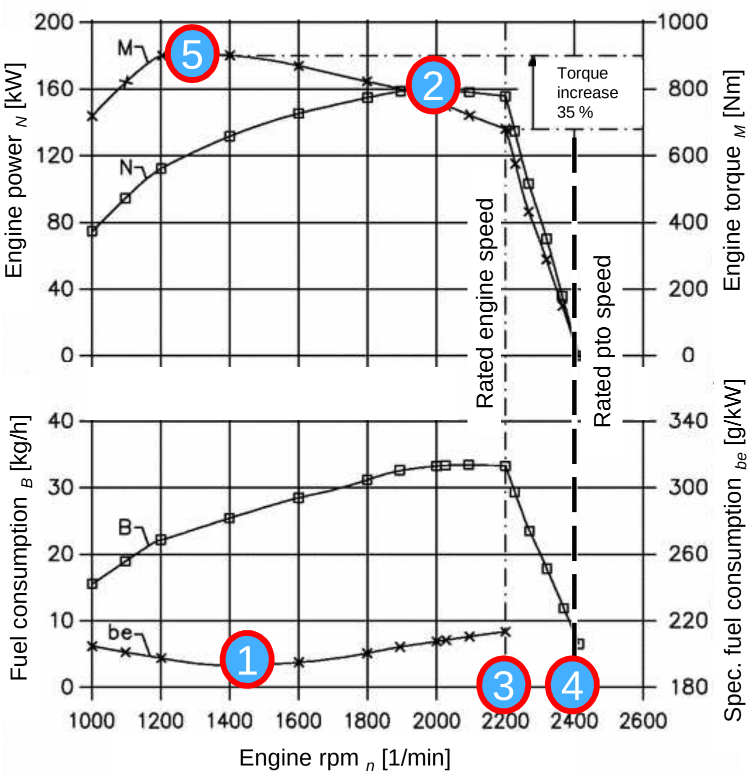
Induced laser fluoreszence


System DLR

- **Procedure follows the well-known manual control** *(creates best conditions for acceptance)*
- **Reacts on in-field variability**
- **Allows high control quality even with less-/no-trained laborers**

- **Expensive sensor technology**
- **Specific non-standardized integration to the used spreaders/sprayers**
- **Shortage of well adopted control algorithms related to crops and varieties**
- **Lack in the integration of additional data sources** *(field history, soil, weather, previous treatments, … )*

# Continuous variable transmissions (CVT) – Tractors

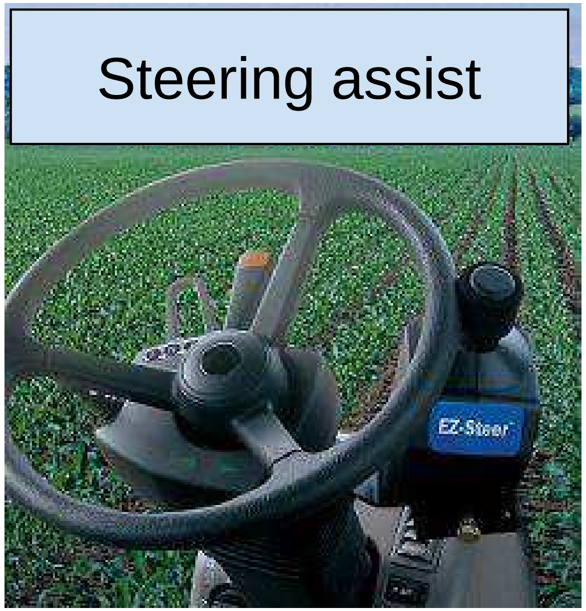


http://mediatum.ub.tum.de/?id=731564

- **Adjustable to any needed implement speed by**
  1. *Lowest fuel consumption*
  2. *Max. engine power*
  3. *Any or rated/max. engine speed*
  4. *Rated pto speed*
  5. *Max. torque*
- **Driver comfort** *(less work load)* **by pre-programmed** *(finger-tip)* **driving strategies**

- **Still higher investment costs**
- **Still lower rate of efficiency related to stepped transmissions**

# GNSS guidance – Tractors and self propelled harvesters



Steering assist

Automatic Guidance

Source: Grundl. Landtechnik 18 (1968) 17

- **Company specific control integration** *(independent from competitors)*
- **High accuracy with increased productivity** *(reduced working time, no overlapping)*
- **Handling trivial** *(comfort)*
- **Simple manual over-steering**
- **Retrofitting possible**
- **Extension to headland management possible**

- **Additional infrastructure required** *(but worldwide available for free in the future too with increasing accuracy)*
- **A-B line adjustment or route planning required**
- **In tractor implement combinations tractor guidance accuracy only**

# Automation – State-of-the-art in mobile Equipment (Field-level)

| *Control criteria* | *Tractor* | *Implement* | *Self-propelled machinery* |
|---|---|---|---|
| *Draft control* | Manufacturer specific sensors, actuators, control units, standardized three-point-linkage | Standardized three-point-linkage | |
| *Drive line management* | CVT automation through<br>- engine management<br>- velocity management | pTIM stop-and-go<br>pTIM speed control | Header control<br>Cruise control |
| *Guidance* | A-B-guidance<br>Map-guidance | Track-guidance of towed<br>- sprayer vehicles<br>- spreader vehicles | Row-guidance<br>A-B-guidance<br>Map-guidance |
| *Headland management* | PTO on/off<br>Lift control & adjustment<br>A-B adjustment | | |
| *Variable-Rate-Control* | | Map-based-control with ISOBUS UT and ISOBUS TC | Map-based control (ISOBUS like) |
| *Loading/Unloading* | | | Filling adjustment |
| *Documentation* | ISOBUS TC tractor internal data acquisition, processing and transfer | ISOBUS data acquisition and processing | Proprietary data acquisition, processing and transfer (ISOBUS like) |

# Automation – Consequences or “Where to we go from here”

## Where do we go from here ?*

## A challenging question as it means:

- What’s now ?
- What would/could/should be ?
- What might be ?

## The only clear thing:

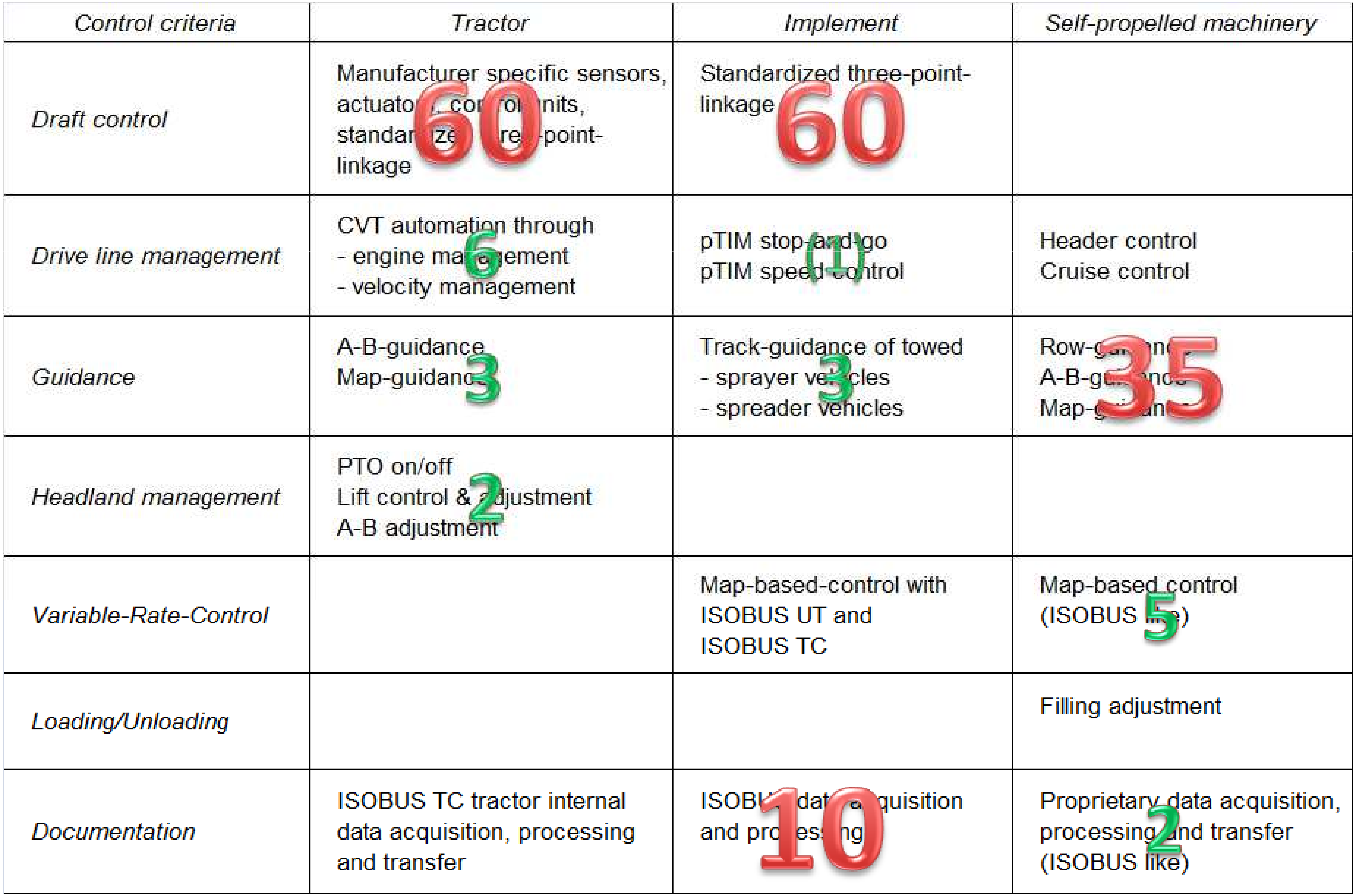
- Nothing is clear

or

- No answer at all !

**But “why” …**

# Automation – at Field-level since **?** Years (rough estimations)



| *Control criteria* | *Tractor* | *Implement* | *Self-propelled machinery* |
|---|---|---|---|
| *Draft control* | Manufacturer specific sensors, actuators, control units, standardized three-point-linkage<br>60 | Standardized three-point-linkage<br>60 | |
| *Drive line management* | CVT automation through<br>- engine management<br>- velocity management<br>6 | pTIM stop-and-go<br>pTIM speed control<br>(1) | Header control<br>Cruise control |
| *Guidance* | A-B-guidance<br>Map-guidance<br>3 | Track-guidance of towed<br>- sprayer vehicles<br>- spreader vehicles<br>3 | Row-guidance<br>A-B-guidance<br>Map-guidance<br>35 |
| *Headland management* | PTO on/off<br>Lift control & adjustment<br>A-B adjustment<br>2 | | |
| *Variable-Rate-Control* | | Map-based-control with ISOBUS UT and ISOBUS TC | Map-based control (ISOBUS like)<br>5 |
| *Loading/Unloading* | | | Filling adjustment |
| *Documentation* | ISOBUS TC tractor internal data acquisition, processing and transfer | ISOBUS data acquisition and processing<br>10 | Proprietary data acquisition, processing and transfer (ISOBUS like)<br>2 |

# Automation – at Field-level since ? Years (rough estimations)

| Control criteria | Tractor | Implement | Self-propelled machinery |
|---|---|---|---|
| *Draft control* | Manufacturer specific sensors, actuators, control units, standardized three-point-linkage<br>60 | Standardized three-point-linkage<br>60 | |
| *Drive line management* | CVT automation through<br>- engine management<br>- velocity management<br>6 | op-and-go<br>speed control<br>(1) | Header control<br>Cruise control |
| *Loading/Unloading* | | | Filling adjustment |
| *Documentation* | ISOBUS TC tractor internal data acquisition, processing and transfer | ISOBUS data acquisition and processing<br>10 | Proprietary data acquisition, processing and transfer (ISOBUS like)<br>2 |

- **Open to everyone (no patents)**
- **Simple in handling**
- **Standard equipment in tractors as well as in mounted implements**
- **May be used with new implements without extra investment**

**→ Standardized and worldwide accepted !**

# Automation – at Field-level since ? Years (rough estimations)

| *Control criteria* | *Tractor* | *Implement* | *Self-propelled machinery* |
|---|---|---|---|
| *Draft control* | Manufacturer specific sensors, actuato , co rol nits, standar ze re -point-linkage 60 | Standardized three-point-linkage 60 | |
| *Drive line man* | | | Header control<br>Cruise control |
| *Guidance* | | towe | Row-g nc<br>A-B-g nce<br>Map-g n 35 |
| *Headland man* | | | |
| *Variable-Rate-Control* | | with ISOBUS UT and ISOBUS TC | Map-based control (ISOBUS e) 5 |
| *Loading/Unloading* | | | Filling adjustment |
| *Documentation* | ISOBUS TC tractor internal data acquisition, processing and transfer | ISOB dat quisition and pro es ng 10 | Proprietary data acquisition, processing and transfer (ISOBUS like) 2 |

- **Company specific solution**
- **Target optimization**
- **M2M integration**
- **Increase in machinery performance**
- **Often protection by patent**

**→ Market independence !**

# Automation – at Field-level since ? Years (rough estimations)

| *Control criteria* | *Tractor* | *Implement* | *Self-propelled machinery* |
|---|---|---|---|
| *Draft control* | Manufacturer specific sensors, actuators, control units, standardized three-point-linkage<br>**60** | Standardized three-point-linkage<br>**60** | |
| *Drive line management* | | | |
| *Guidance* | | | |
| *Headland management* | | | |
| *Variable-Rate-Control* | | | |
| *Loading/Unloading* | | | Filling adjustment |
| *Documentation* | ISOBUS TC tractor internal data acquisition, processing and transfer | ISOBUS data acquisition and processing<br>**10** | Proprietary data acquisition, processing and transfer (ISOBUS like)<br>**2** |

- **Pre-definition in a coming standard (LBS, ISOBUS)**
- **Available data dictionary**
- **Increase of program performance**
- **Challenge for software companies**
- **Lead against market competitors**

**→ Protection of investments !**

# Automation – Driving forces at Field-level

| *Control criteria* | *Tractor* | *Implement* | *Self-propelled machinery* |
|---|---|---|---|
| *Draft control* | Manufacturer specific sensors, actuators, control units, standardized three-point-linkage<br>60 | Standardized three-point-linkage<br>60 | |
| *Drive line managem* | | | er control<br>e control |
| *Guidance* | A-B-gu<br>Map-g | | Row-guidance<br>A-B-guidance<br>Map-guidance<br>35 |
| *Headland management* | PTO on/off<br>Lift control & adjustment<br>A-B adjustment<br>2 | | |
| *Variable-Rate-Control* | | Map-based-control with ISOBUS UT and | Map-based control (ISOBUS like)<br>5 |
| *Loading/Unloading* | | | ustment |
| *Documentation* | ISOBUS TC tractor internal data acquisition, processing and transfer | ISOBUS data acquisition and processing<br>10 | Proprietary data acquisition, processing and transfer (ISOBUS like)<br>2 |

→ Standardized and worldwide accepted !

→ Market independence !

→ Protection of investments !

# Automation tomorrow - Draft Control still needed ?

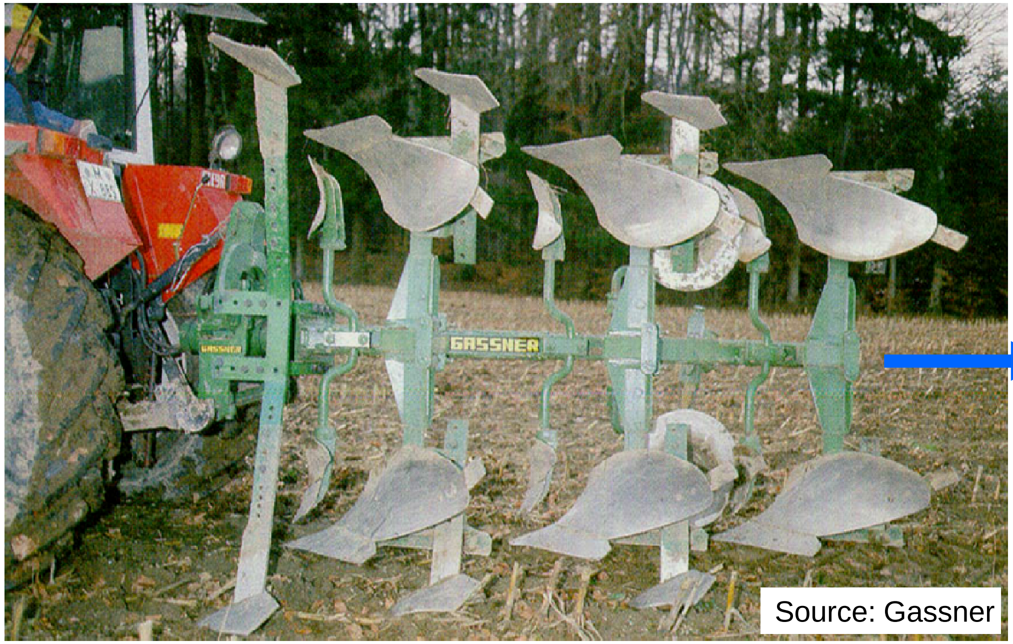
http://www.ferguson-museum.co.uk/black_tractor.htm

No as …

… invented mainly for plowing and plowing worldwide is avoided when ever it is possible

… mounted ploughs (up to 6 boddies) today differ in dimensions and kinematics referred to the “original ballanced draft control system”

… implements with extended working width are towed



Source: Gassner

**Yes as …**

**… in more humid areas plows eliminate soil compaction caused by heavy harvesters**

**… organic farmers need the plows for weed control**

# Automation tomorrow – Large self propelled systems only ?

The “missing link” in “Combinable Crop Rotations” related to “Self Propelled Tillage”

http://www.househamsprayers.co.uk/library

http://www.househamsprayers.co.uk/library

**Trends:**

- Increasing usage of self propelled vehicles worldwide
- Mainly used by contractors
- Attempts in logistics to follow either climatic and/or agronomic conditions

The “missing link” in “Combinable Crop Rotations” related to “Cover Crops”

**No as …**

**… very high investment costs**

**… less working hours/year**

**Partly „Yes“ as …**

**… nearly no preparation time**

**… nothing is twice**

**… optimized for specific tasks**

**… friendly to any type of field structure**

**… automation may be quickly realized**

**Fully „Yes“ when …**

**… contractors overtake all field work**

**… transport is overtaken by trucks and tractors loose in importance**

**… green surface is required** *(cover crops with no time lag behind main crop)* **and tractors are engaged in transportation**

# Automation tomorrow – Small autonomous systems only ?

Tillage

Plant Husbandry

- Scouting
- Fertilizing
- Pest control

Harvesting

**No as …**

**… legislation allows no "unmanned vehicles"** *(Convention Road Traffic Vienna,1968)*

**… harvesting of large yields** *(up to 180 t/ha)* **seems to be impossible**

**Partly „Yes" when …**

**… legislation is adapted**

**… no or little load is required**

**… cheaper sensors from mass-production can be used**

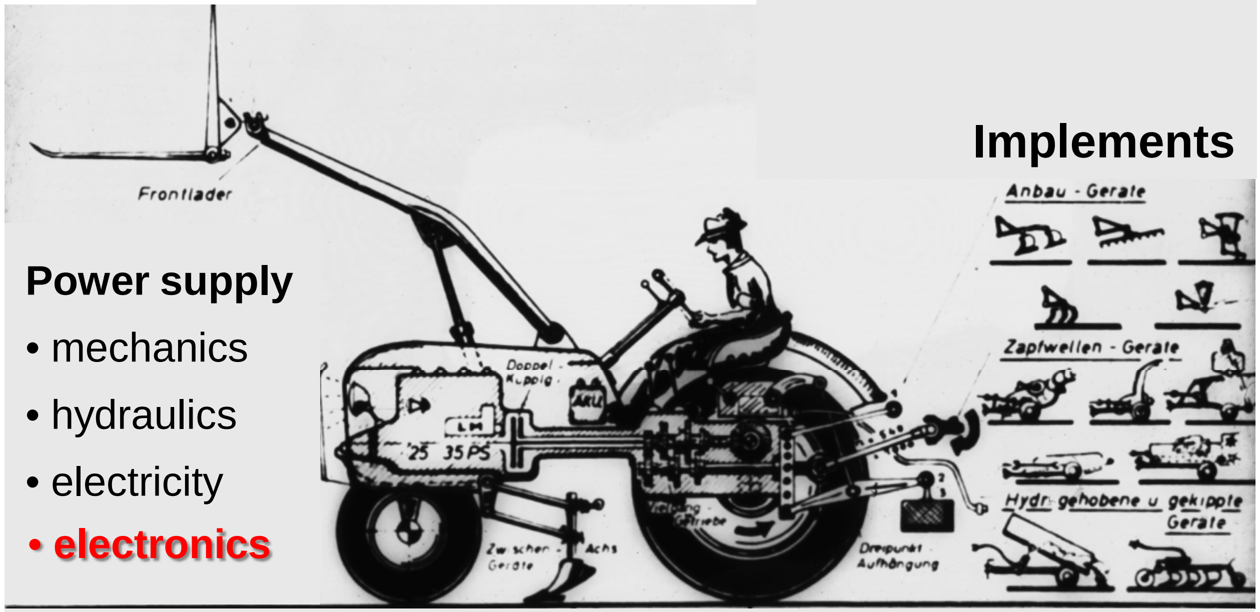
**… communication standards are available and accepted**

**Fully „Yes" when …**

**… "one" company offers the whole system to "one" specific crop or specific crop rotation**

Source: Blackmore, S.: A specification for an autonomous mechanisation system. Guangzhou (China) 2008

# Automation tomorrow – Tractor and implements



**Power supply**

- mechanics
- hydraulics
- electricity
- **electronics**

**Implements**

Brenner 1960 http://mediatum.ub.de/?id=697320

***A tractor itself does nothing,*** *it/he only offers*

- *power supply*
- *mobility*
- *(loading capacity)*

***Work is done by implements/tools …***

- *but still tractor manufacturers believe that they know what implements need for doing optimized field work*
- *and now we have electronics*

**Yes as …**

**… tractors will dominate agricultural mechanization in the future too**

**… no tractor manufacturer will share more than 50 % of the market**

**… implements will be produced by small and medium sized enterprises**

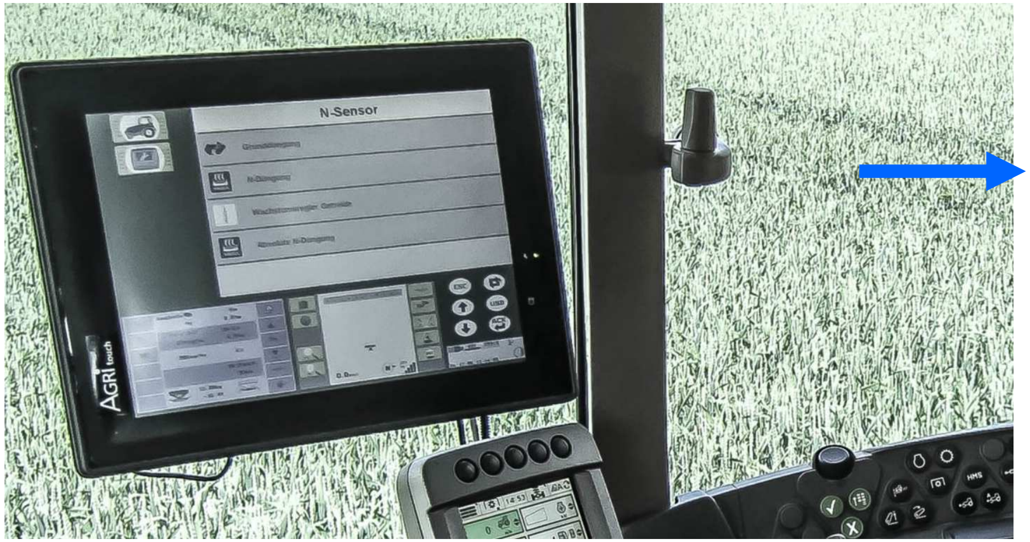
**… implements will be more and more intelligent**

**… implements have specific requirements to optimize its work**

**Automation requires “Tractor Implement Management” (TIM)**

# Automation tomorrow – Sensor-based field work (fertilizing)

**Inside the cab yesterday and today**



http://www.yara.de/doc/39944_Broschuere_N-Sensor_201206.pdf

No as …

… sensors are still not ISOBUS integrated

… sensor fusion with on-line information and historical data, soil data, water flow, inclination and others is proprietary

**Yes as …**

**… more sensors will be available**

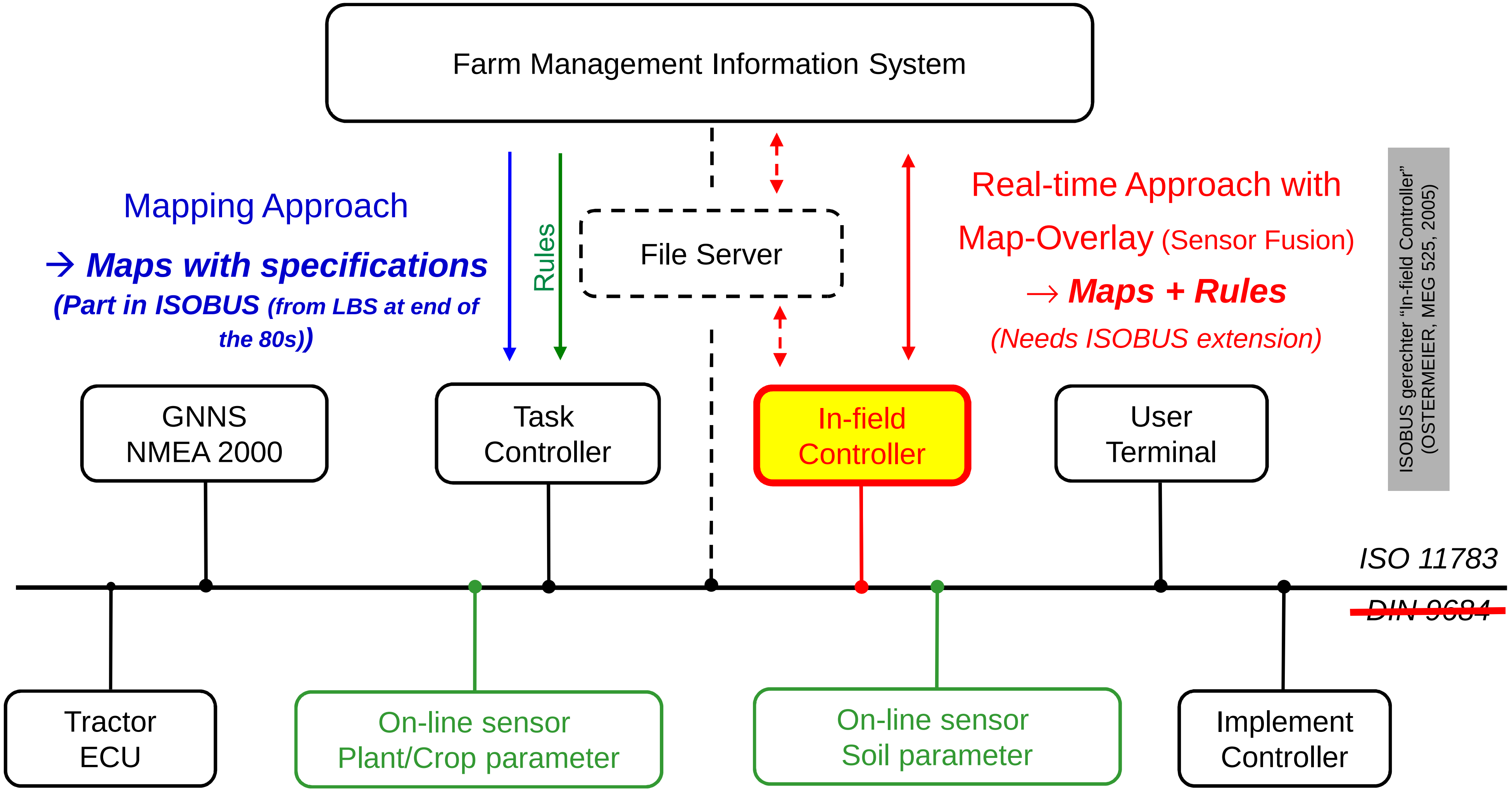
**… site-specific application requires comprehensive data sources**

**… production agents increase in prices**

**… over-application result in extra cost and in environment pollution**

**“we can, if … ”**

# Automation tomorrow – sensors in an extended ISOBUS !



Farm Management Information System

Mapping Approach

→ ***Maps with specifications***

***(Part in ISOBUS** (from LBS at end of the 80s))*

Rules

File Server

Real-time Approach with

Map-Overlay (Sensor Fusion)

→ ***Maps + Rules***

*(Needs ISOBUS extension)*

ISOBUS gerechter "In-field Controller"
(OSTERMEIER, MEG 525, 2005)

GNNS
NMEA 2000

Task
Controller

In-field
Controller

User
Terminal

*ISO 11783*

*~~DIN 9684~~*

Tractor
ECU

On-line sensor
Plant/Crop parameter

On-line sensor
Soil parameter

Implement
Controller

Real-time Approach → ***Rules***

*(Needs ISOBUS extension)*

# Automation tomorrow – implement controlled production

deere.de/de_DE/products_ag/ams/automation/tractor_baler/index.html

Allowed (in one color) as …

… proprietary messages are part of ISOBUS (TIM → *p*TIM)

… advantage over competitor

… system safety in “one hand”

**Birth defect in ISOBUS !?**

http://www.poettinger.at/de/coveo.aspx?q=schwadscanner&LCID=1031&c=DE&LcidParameter=lcid

**But farmers target to get …**

**… freedom in choice of products**

**… optimized implement performance**

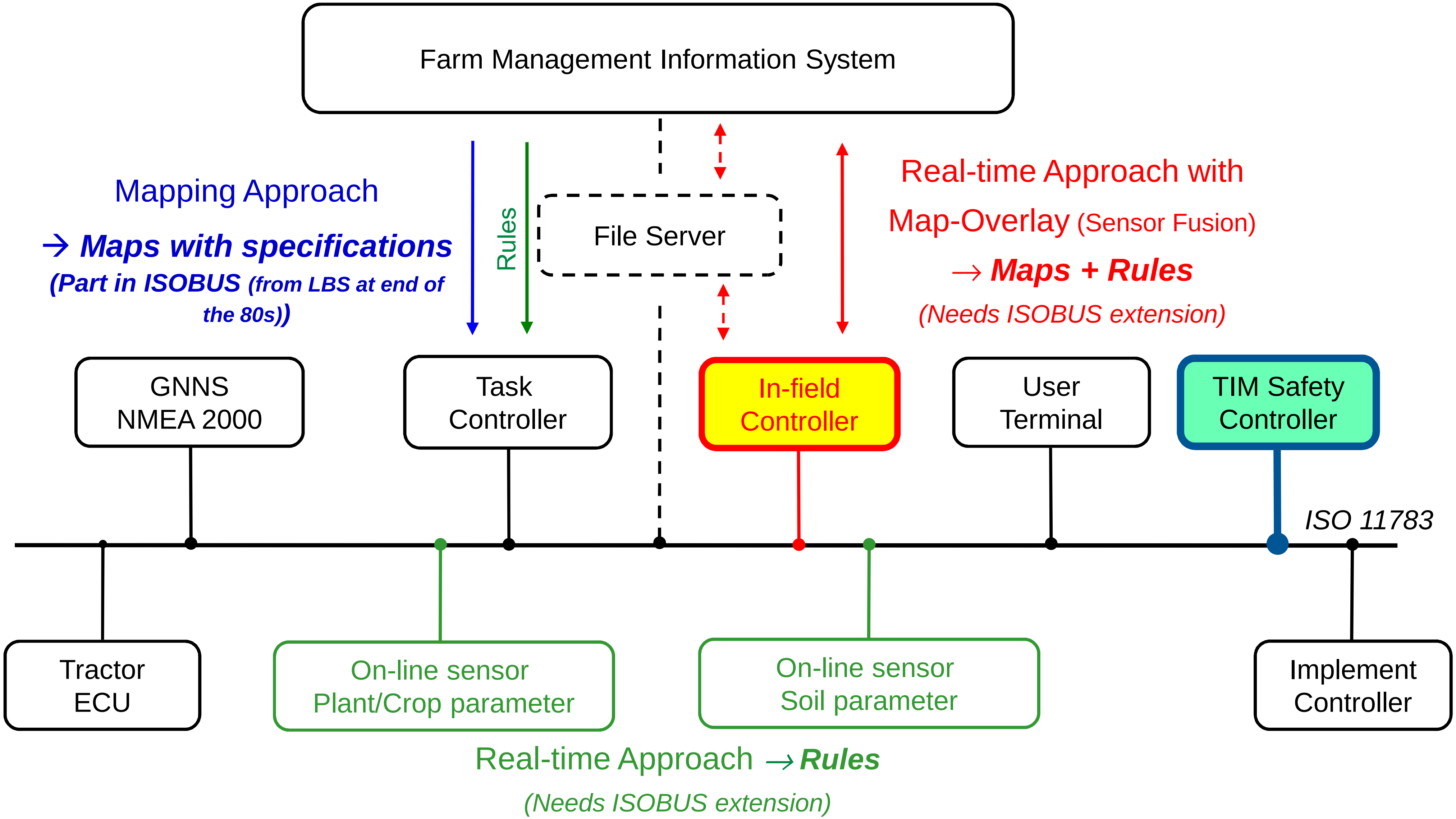
**… simple handling and operation**

**… high comfort**

**… trusted fail-safe status**

**Independence**

# Automation tomorrow – no TIM without "Safety Controller" !



Farm Management Information System

Mapping Approach

→ ***Maps with specifications***

***(Part in ISOBUS** (from LBS at end of the 80s))*

Rules

File Server

Real-time Approach with

Map-Overlay (Sensor Fusion)

→ ***Maps + Rules***

*(Needs ISOBUS extension)*

GNNS
NMEA 2000

Task
Controller

In-field
Controller

User
Terminal

TIM Safety
Controller

*ISO 11783*

Tractor
ECU

On-line sensor
Plant/Crop parameter

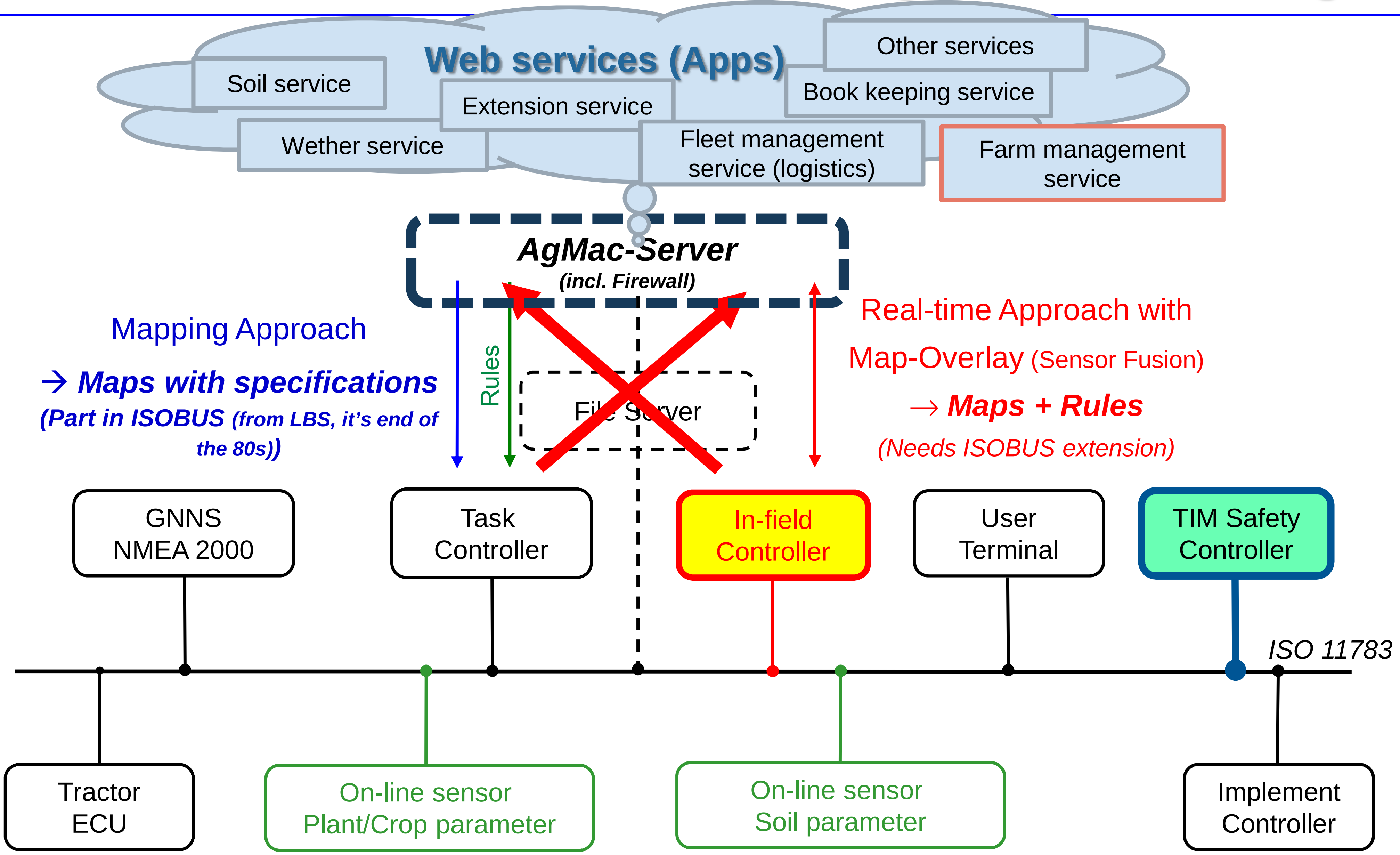
On-line sensor
Soil parameter

Implement
Controller

Real-time Approach → ***Rules***

*(Needs ISOBUS extension)*

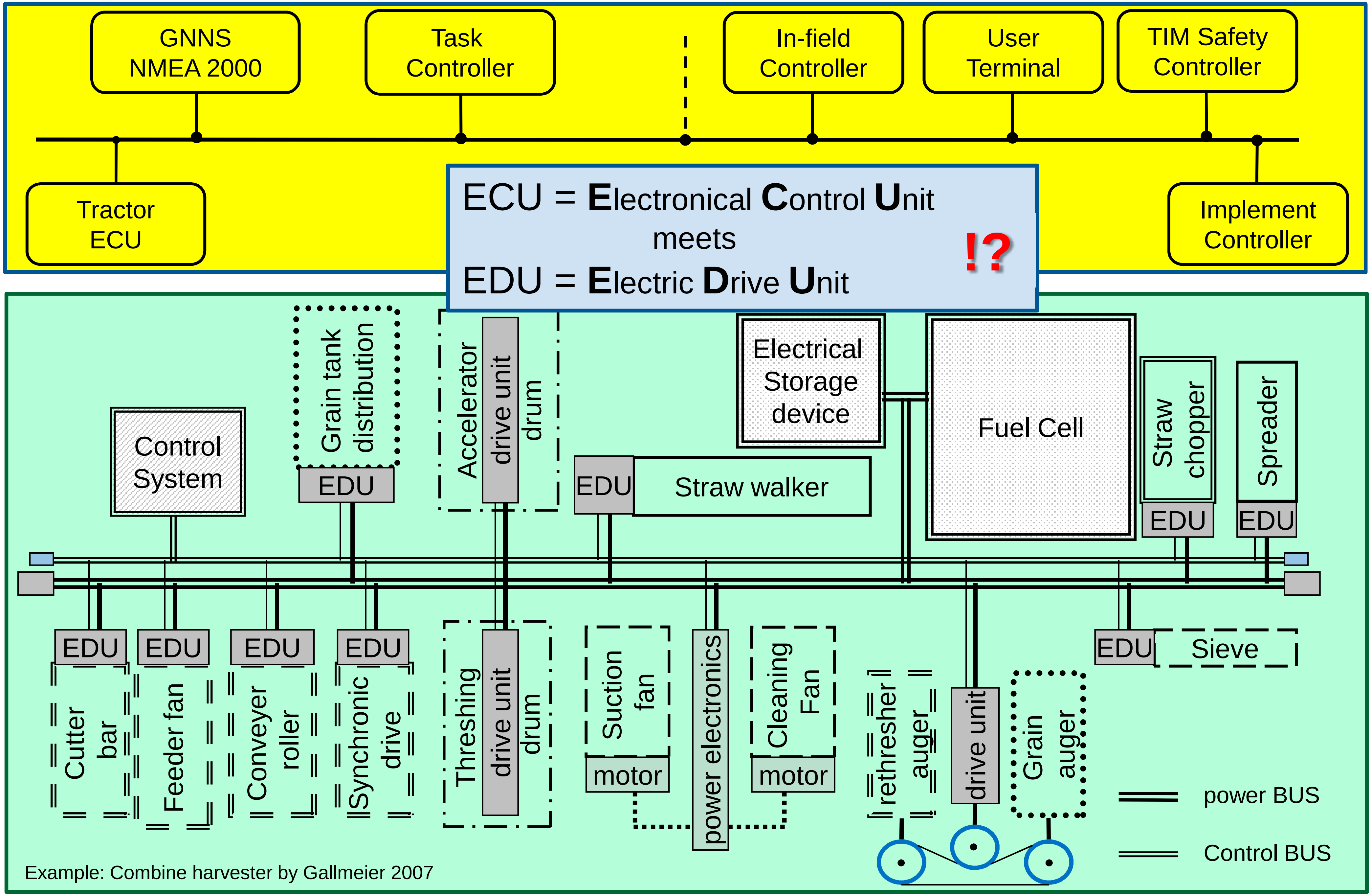
# Automation tomorrow – Precision Farming → Cloud Farming



Realtime-Approach → ***Rules***

*(Needs ISOBUS extension)*

# ISOBUS & Power-BUS – two worlds migrate (standardized ?)

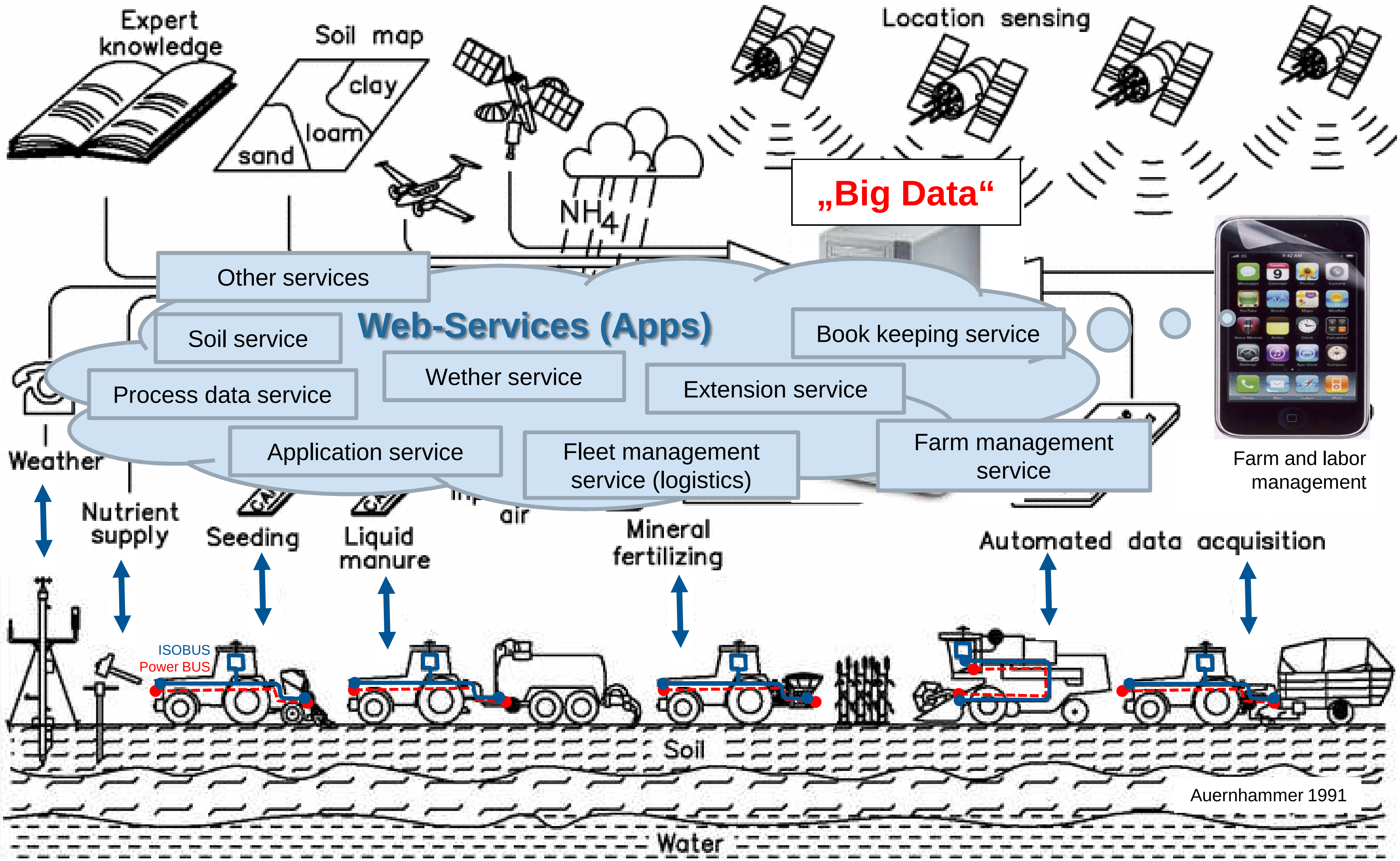


ECU = **E**lectronical **C**ontrol **U**nit
meets
EDU = **E**lectric **D**rive **U**nit

!?

Example: Combine harvester by Gallmeier 2007

# Automation tomorrow – the „Big Data“ challenge



Auernhammer 1991

# Conclusions

There is **no prescription** for Automation in crop production at all

**Draft control in tractors and auto steer** in self propelled harvesters, lately in tractors, are predominantly used automation technologies in crop farming worldwide today and tomorrow

Automated variable rate control is **still one-dimensional** based on maps or online sensors and has to be multi-dimensional

**Automation in self propelled technology** is well accepted on farm level when it comes from “one hand” even if this are small autonomous vehicles

**Sensors and sensor fusion** offer a wide range for automation if they are standardized members in an electronic communication environment

Improved crop production needs **standardized tractor implement management (TIM)** systems for optimized field work

**Automatic data acquisition** systems and web services allow for “Automation in cloud farming of tomorrow”