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Machine internal and Machine to Cell Controller (M2C) embedded Communication with Machine internal non TSN-communication subsystems

Contribution Beckhoff Automation

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Machines and Cells share Network Infrastructure

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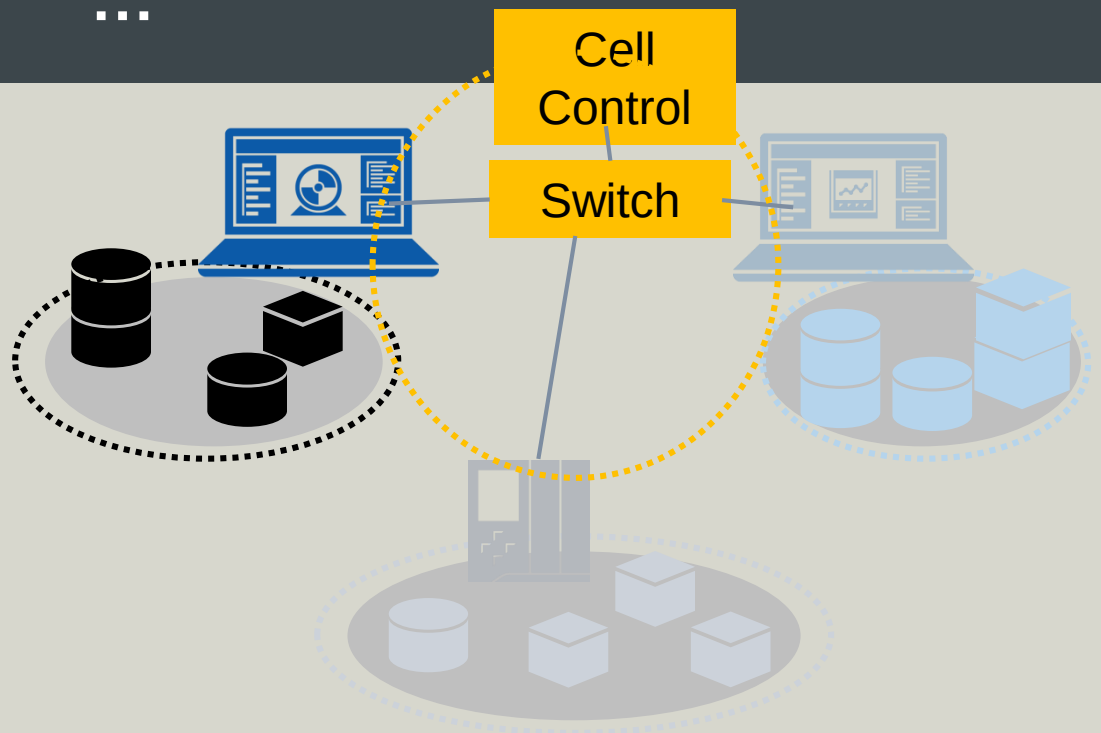
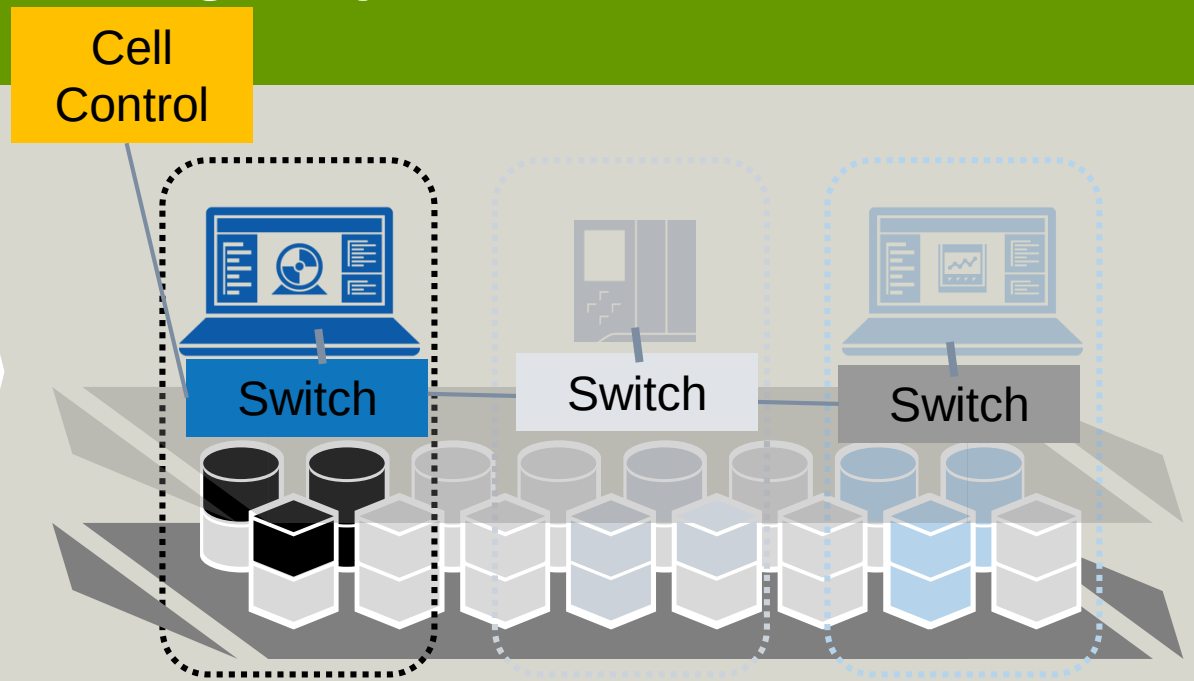
From physically isolated networks …



Each application owns its network

… to logically isolated networks



Multiple applications share a single network and its resources

System structure

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- A **Machine** has typically a Control Unit and couple of Field Devices
  - Field Devices can have only Inputs or only Outputs or both as process data
  - Smart Devices include a control loop that is controlled by the Control Unit by Set-Points with Feed-Back values from the devices
  - Examples for smarter field devices are drives

- A **Cell** (Line) includes a set of Machines as Executing Devices and a Cell Control Unit
  - Again, a loop structure is required to control the machines

- The roles of the end stations are denoted as control unit and device

Machine internal networks are isolated (physically/logically) from Cell networks

➔ the structuring of both networks are done independently
… different persons, different organizations …

Machine internal clustering

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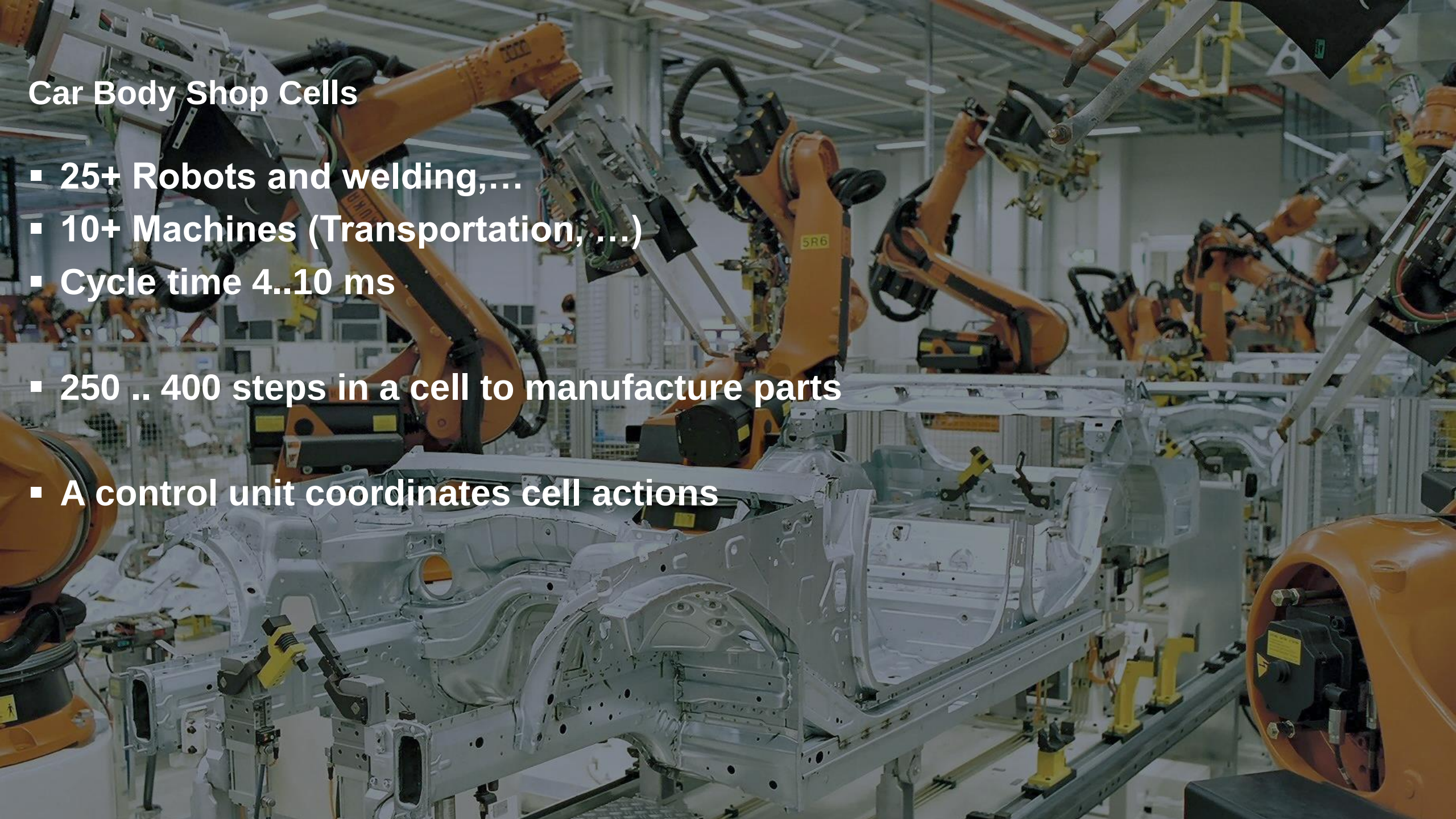
1. Quite a few sensors and actuators per machine (500+)
2. Not directly connected to the control unit
3. Terminal blocks(around 8 I/O), clustered with a backplane are connected with a interface module to a fieldbus
   ➔Some communication infrastructure in front of Ethernet
4. TSN may connect these clusters or clusters of clusters



Car Body Shop Cells

- 25+ Robots and welding,…
- 10+ Machines (Transportation, …)
- Cycle time 4..10 ms

- 250 .. 400 steps in a cell to manufacture parts

- A control unit coordinates cell actions

Coordination of communication interaction

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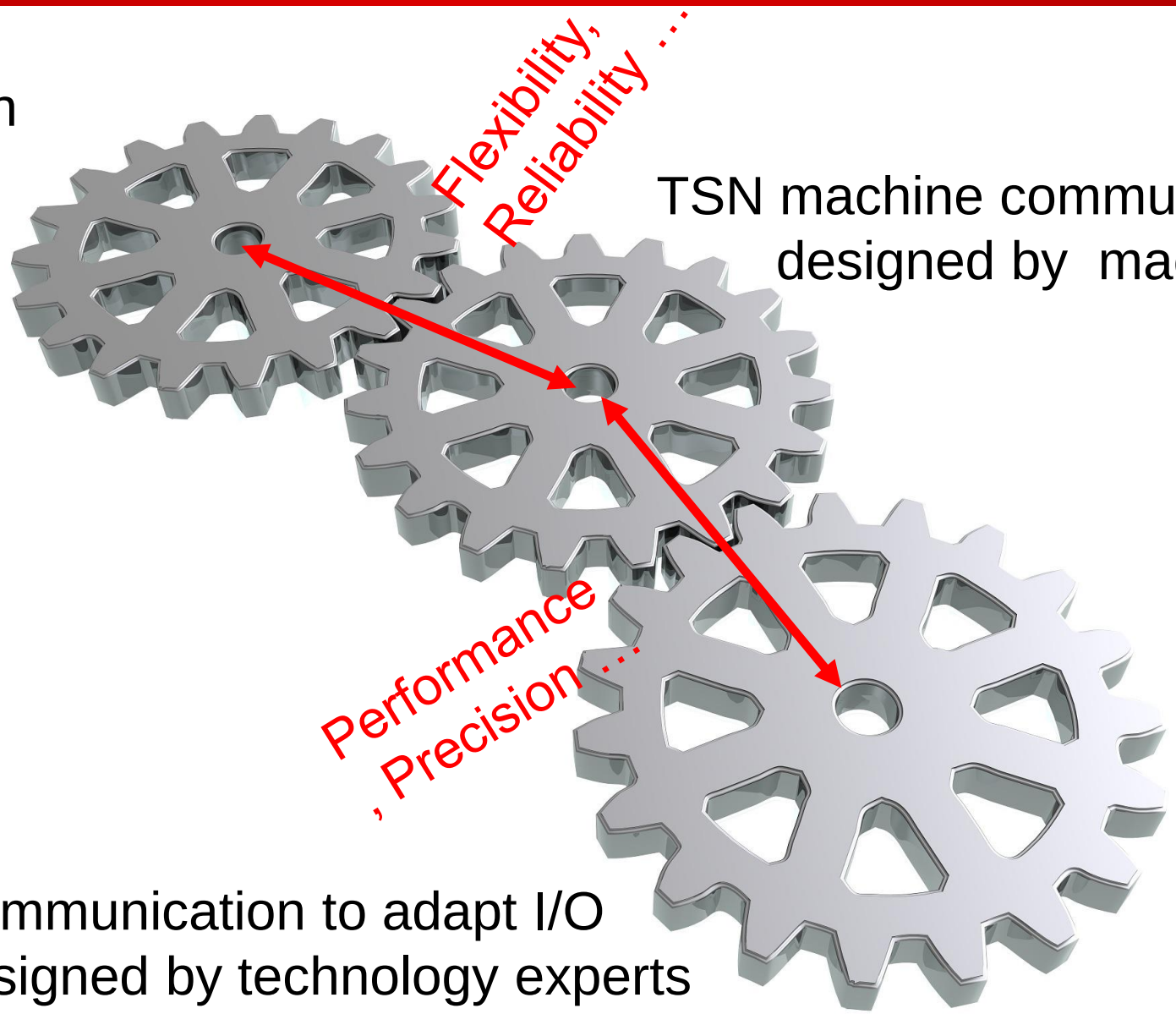
TSN cell communication designed by plant builders



TSN machine communication designed by machine builders

Communication to adapt I/O designed by technology experts

Structure as of today

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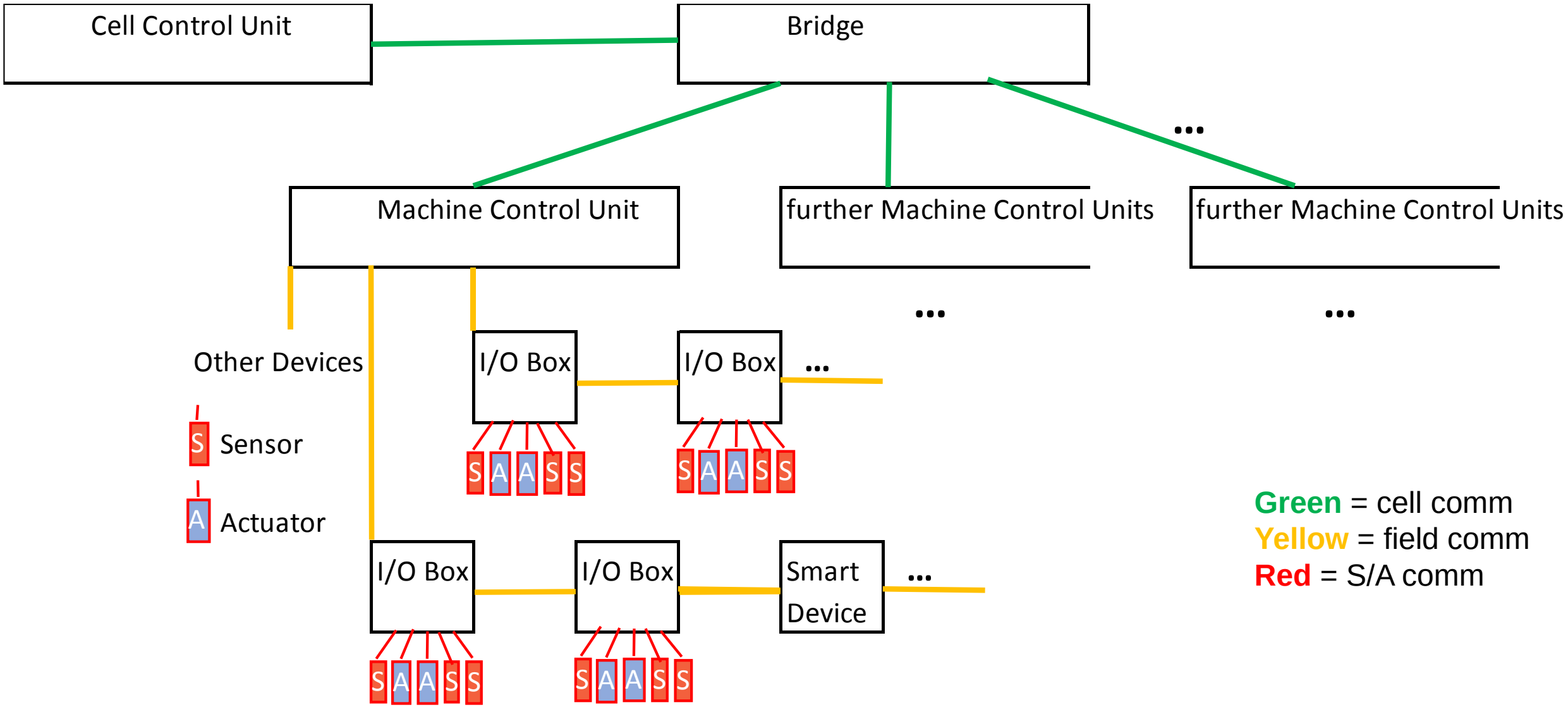

Possible structure with TSN

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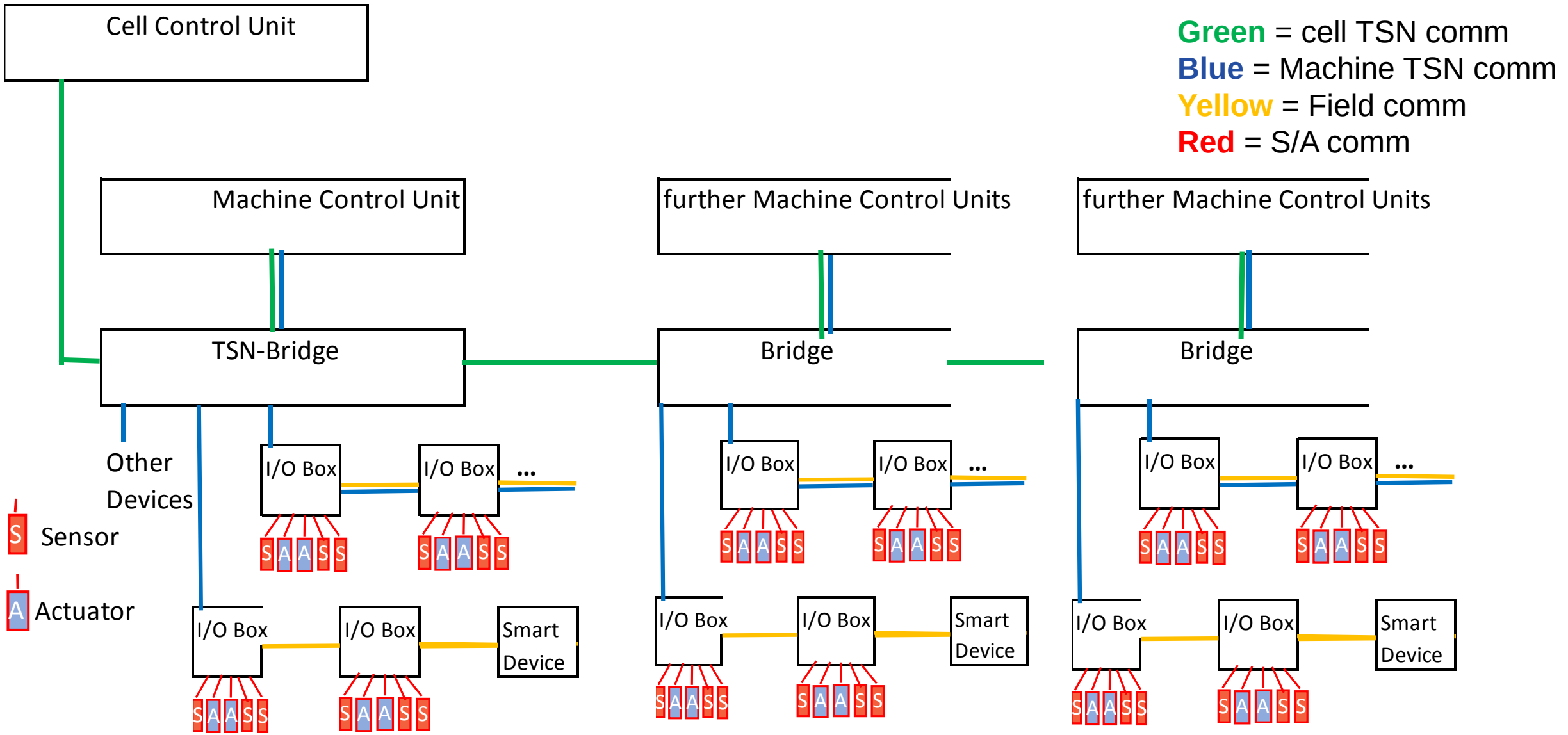

Properties related to Machine internal communication

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1. The data flow is organized with a **stream** from the **machine control** unit to a (group of) **field devices** and a **stream** from the **field devices** to the **machine control unit**.
2. A Machine may run in **stand-alone** mode for testing or special modes of production
3. Machine internal communication is totally **isolated** and two **identically** configured **machines** can be connected to the same network without interference
4. Internal communication **configuration** is embedded in PLC configuration which is done **offline** and with a formal description of the communication elements (text form)
5. **Machine internal** communication may use **field communication** to cluster sensors/actuators that can be connected to TSN (coordination required)
6. Provide **resources** for interaction with cell communication **within machine**
7. A **short** failure reaction time with precise error location
8. An outstanding TSN property can be the **synchronization** of a large number of nodes.
9. High **availability** can be required at cell level (IEEE 802.1CB).

Bidirectional streams between machine control unit and field devices

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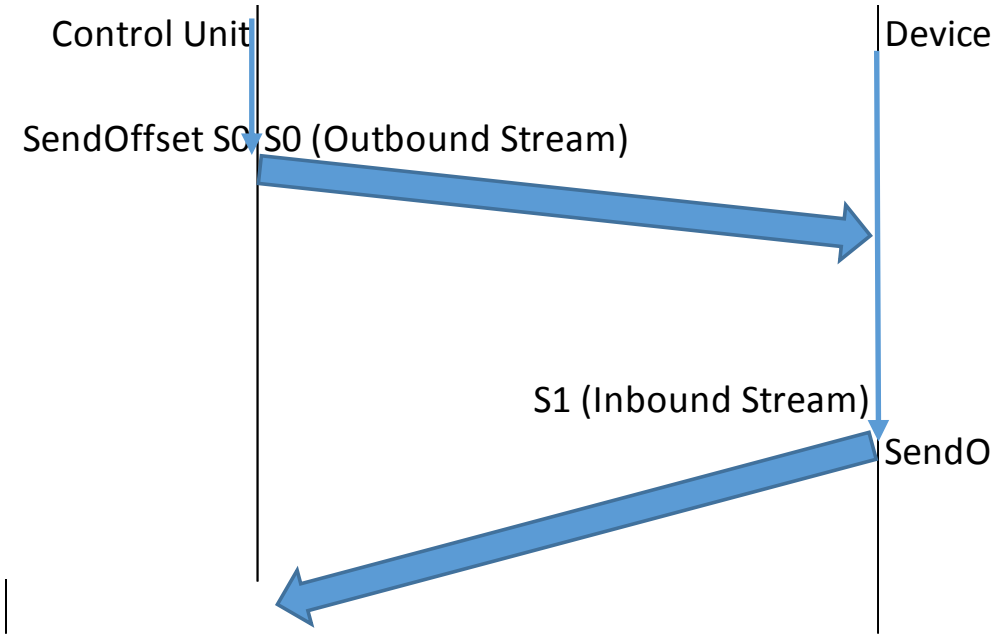
- Control and Feedback required
- At least 2 Streams needed
  - One from the Controller to the Devices
  - One from the Devices to the Controller
- Typical RT communication pattern
  - Single source for Outbound
    =No Outbound interference
    (Outbound frames arrive on one port)
  - Single destination for Inbound
    (Inbound frames send on one port)
- Schedule constrains not so sophisticated as usual



Machine can work without cell communication

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- Stand alone operation requires local clock
- Change of operation mode between online/offline possible
  (from the cell communication point of view)
- Migration to a cell clock useful if the machine is online

- Synchronous cell communication is a great TSN enhancement
  BUT shall not affect the higher quality
  of machine internal sync

Machine Communication isolated

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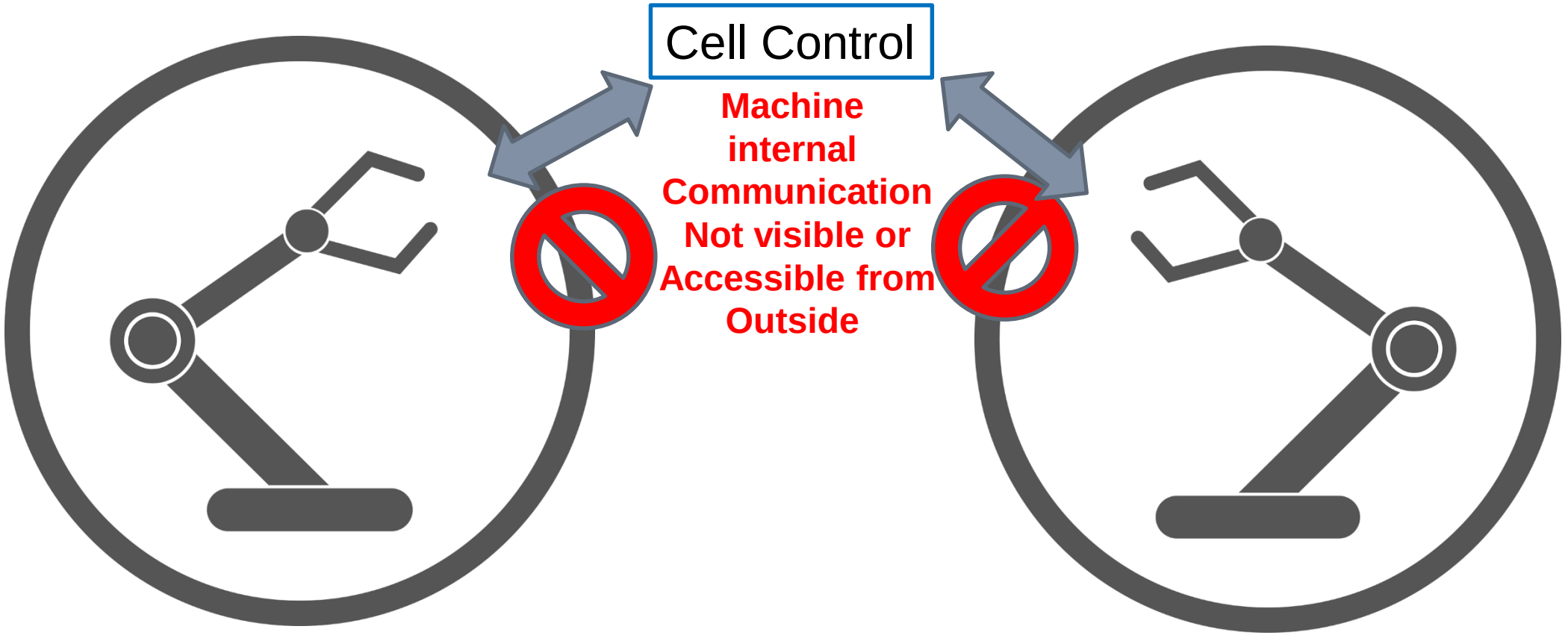
Cell related communication allowed



TWINs: Identical machines have identical configurations when shipped

Embedded Machine communication config

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- Main Machine **configuration** is done in a **single tool**
- Communication is a **result** of application setup
- Configuration is a blueprint of a machine
- This requires a **electronic data sheet** (EDS) of the components
- This is available in xml or similar **textual form** as of today

xxEDS.xml
<VendorID = 1234>
<DeviceID = 777>
<Interface1 = 100BASE-TX>
<minCycleTime = 125>
<OutputElements = o1, o2, ..
<InputElements = i1, i2, ..

- Fill out the blanks and choices to adjust the device to machine
- During configuration a couple of device type descriptions will be filled out and combined to describe the machine behavior

Configuration and Set-Up

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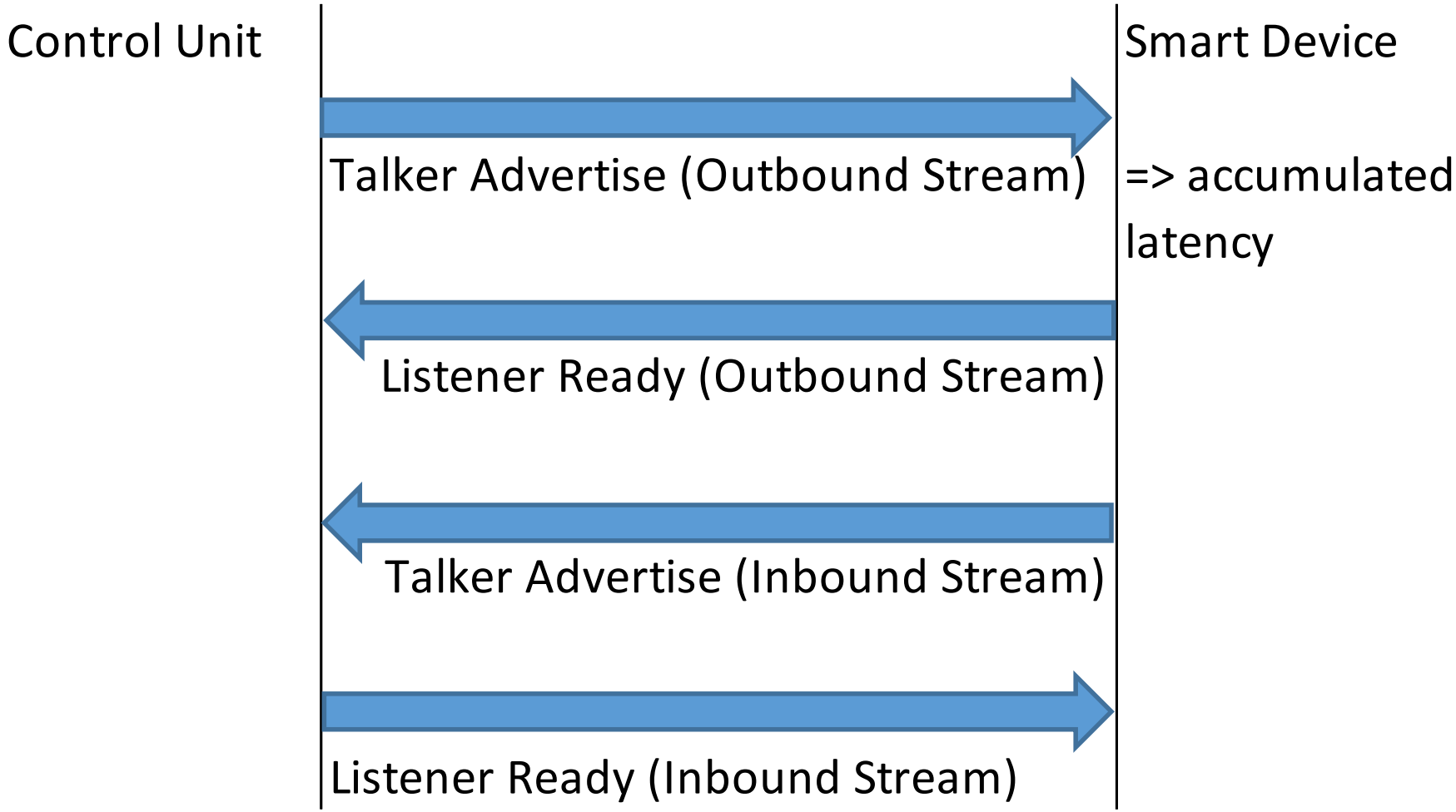
The term configuration is related to general parameters
while set-up is related to establish a relationship

- A machine has typically a **configuration** which describes resources, tasks
- Configuration means often a configuration file in textual form
  Main Config elements are the IO-Modules used + communication parameters

- A system with **distributed** components requires a **set-up** procedure
  between end nodes (control unit and smart devices and forwarding)
- This is **initiated** by a control unit with the **use** of the **configuration**
- But it requires the inclusion of the devices
- This is done currently by **binary** protocols to keep implementation footprint **low**

- Need a way for offline configuration

- MSRP style is a good start for setup, however, a few parameters are missing



Integration of non-TSN communication

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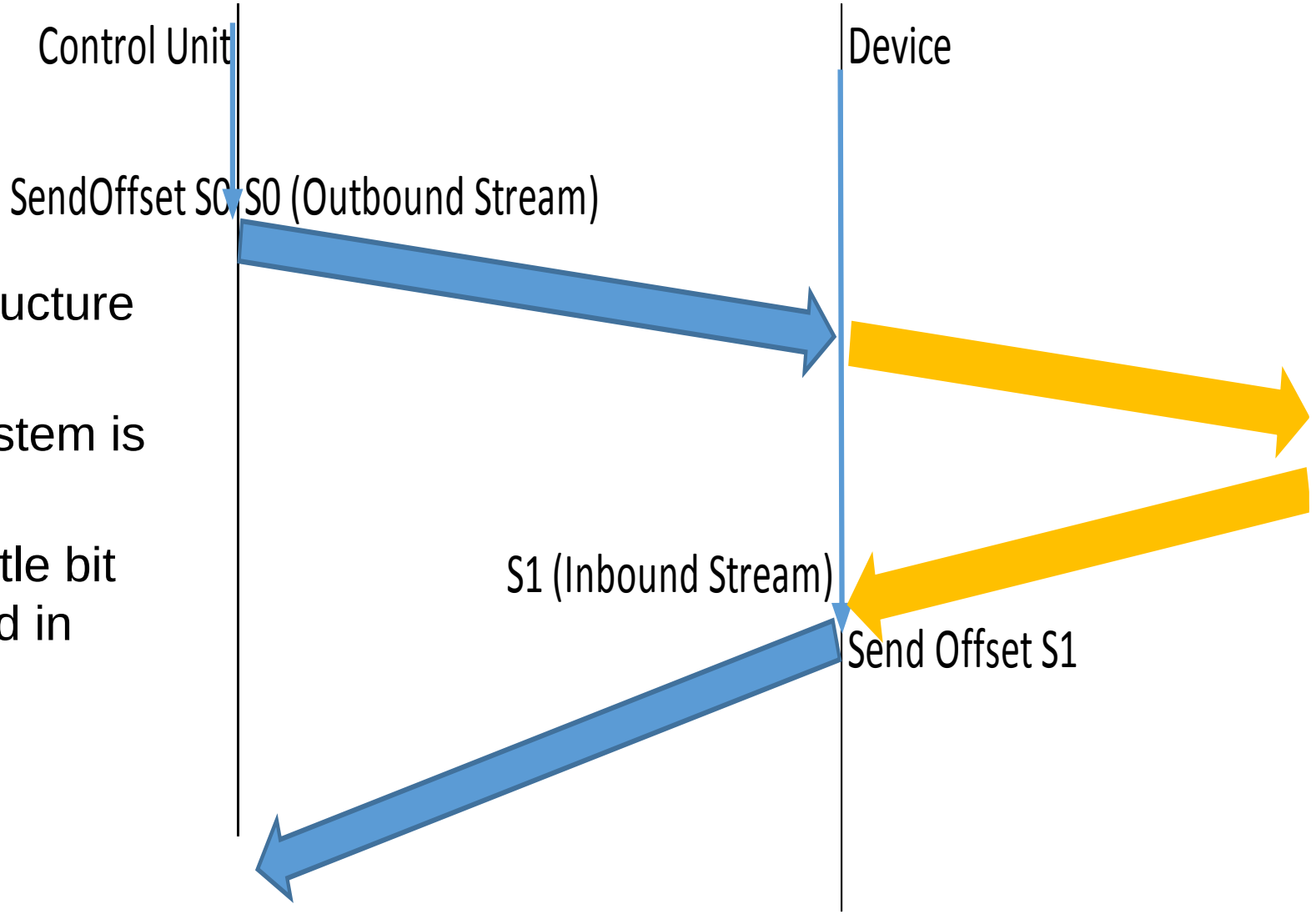
- Critical element
- Not possible to change the behavior of an existing communication structure
- For an optimized timing the reaction of the local system is required
- The dependencies are a little bit more complex as described in IEEE 802.1Qcc



Channel from cell to machine

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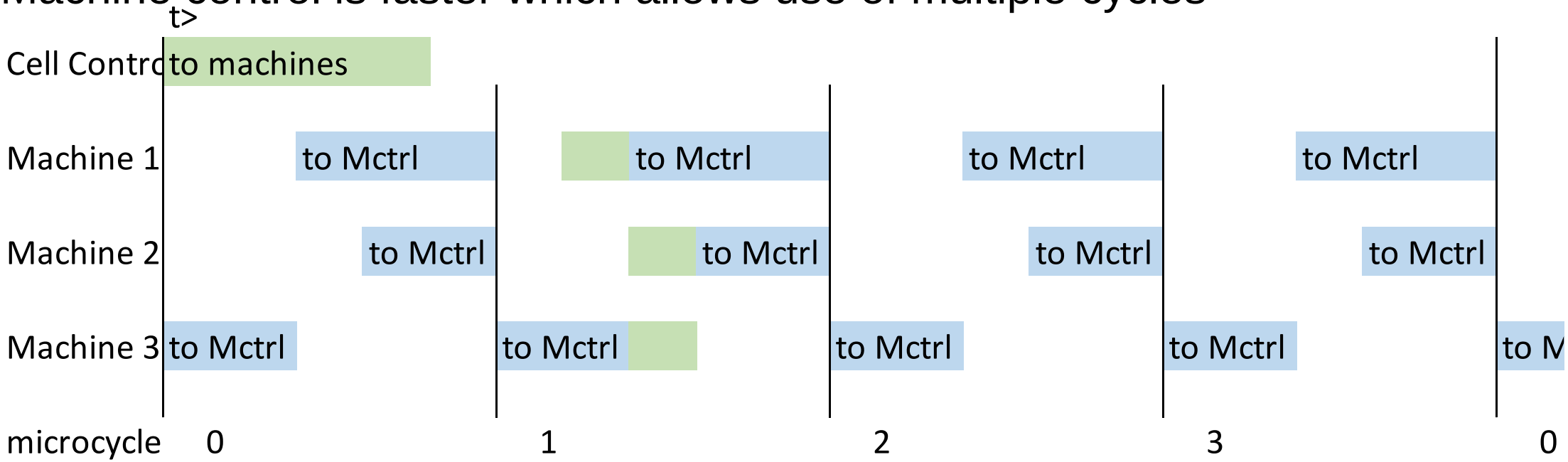
- The machine internal data path can be hardly coordinated with cell communication
- The internal setups of the machines may not allow a common cell schedule
- The communication can be shifted into the next microcycle
- The processing may be located in the next but one cycle
- Machine control is faster which allows use of multiple cycles



Short failure reaction time

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- A fast error reaction shall limit the damage caused by the error and minimize the machine downtime. The limitation of damage shall be done automatically.
- The handling of damage means first, that people in the proximity of the cell must not be affected. This is supported by a special safety application layer protocol which shall operate in a way that communication errors are detected (Black channel).
- But the availability of a machine can be reduced by communication system errors which requires a very robust infrastructure.
  - TSN provides services that helps to reduce losses due to congestion.
  - But TSN allows larger networks which are more vulnerable and synchronization
    ➔Sync master take over at the machine level with a very small time error.
- The error detection shall be done within a few cycles and reaction shall be specified precisely in the case of an error. Machine stop is not always the right reaction on errors.
- Repairs are done by the service persons on site with no specific communication knowledge.
  - Indication of the components to be repaired shall occur within a few seconds.
  - A typical repair time goal is below 15 min. This includes restart

Large Synchronization domain

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- An outstanding feature of TSN is the synchronization beyond a single machine.
  - Allows correlation of machine data
  - Reduction of cycle time or more precise machine interactions possible

- Problem in case of failures
  - the local interactions shall be decoupled from sync beyond machine.
  - This could result in a time offset between a machine and the cell level
  - it may be necessary to run temporarily different clocks.

Redundancy at cell level

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- Cell level redundancy is required more frequently as machines may be turned on and off while other machines are operational.
- Cell control may be crucial.
- Redundant cell control units may be used.
  - Hot standby ➔multiple streams to the machines,
    one of them being active and the other one passive.
    ➔should be supported by the machine internal structures.
  - Cold standby is the more frequent use case with a spare control unit for several cells.
  - It is expected that cell control tasks move away from a close to machine position to a more suitable place at the factory site.
    This may require a cell backbone connected in a resilient way to a supervisory network.