

Digital transformation in the food industry –

Opportunities, challenges and solution approaches from the perspective of ongoing research projects

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Digital Industry – Levels and Terms



Digital Transformation

- Digital Products
- Digital business models

Digitalization

- business processes
- manufacturing management
- automation

Digitization

- exchange of data
- interconnectedness
- Analog-to-digital conversion

From Automation Pyramid to Cyber Physical Production Systems



Objectives of the food industry

- cost reduction
 - increase in productivity
 - saving of resources
 - Improved production processes
- Stronger networking of the supply chain
 - Transparency and security
 - traceability
- Better product quality
 - Avoidance of food losses
 - Process stability with fluctuating raw materials
- Greater flexibility
 - Increasing the reaction speed
 - More customized products



[Food economy 4.0 –

VTT's vision of an era of smart consumer-centric food production, 2018]

→ each digital representation challenge requires adequate modelling approaches

Information Models for the Food Industry - Weihenstephan Standards (WS)



Example of a Standard WS Data Point

| Name: | Total Bottles |
|--------------|---|
| Tag-Number: | 50005 |
| Tag-Name: | WS_Tot_Bottles |
| Data Type: | Unsigned32 |
| Read/ Write: | R |
| Description: | This data point provides the number of bottles processed in the machine |



Additional data points may be defined with a different prefix according to specified rules, e. g. data point from company XYZ AG (Bottle capper)

| Name: | closure force |
|--------------|---|
| Tag-Number: | 31101 (from free area for parameters) |
| Tag-Name: | XYZ_Closure_Force |
| Data Type: | Unsigned32 |
| Read/ Write: | RW |
| Description: | Data Point provides the closure force for a closing stamp in N. |



Alternative to current WS communication protocol (based on TCP/IP)

Pros:

- Bidirectional communication, fast data exchange
- Available on all relevant PLCs
- No license costs
- System independent
- Availability of all data
- Direct access to the PLC



WSDeviceType



Data profile libraries for different machine types



- WS Pack Library V08 - All WS-Food machine - 01 Packaging Lachines 01.1 Filling and 01.2 Closing machines 01.3 Labelling, decorating an - 01.4 Cleaning, sterilizing, coc 01.4.1 Cleaning machine — 01.4.2 Pasteurising mach 01.5 Fill and seal machines - 01.6 Inspection machines - 01.6.1 Inspection machin 01.6.1.1 Empty bottle 01612 Full bottle in • 01.6.1.3 Crate inspect 01.6.1.4 Pallet insper 01.7 Container and compone 01.8 Form fill and seal machin 01.9 Carton erecting, carton 01.10 Wrapping machines 01.11 Group or transit packa 01.12 Pallet forming, dismant 02 Transportation device 02.1 Conveyor systems, buffe 02.2 Crates Magazine 02.3 Pallet Transport, Pallet I O3 Technical Process Equipment 03.1 CAF (Cold Aseptic Filling 03.2 CIP 03.3 Flash Pasteurization Ma

- WS_Food_Library_V08 - All WS-Food machine - 01 Processing machinery - 01.1 Units for mermal FO ⊕-01.1.1 Heatin 01.2 Foreign Body Detectors €-01.3 Mixing Units 01.4 Smoke generators 01.5 Smoking and maturing s - 02 Transport machinery 02.1 Conveyors 02.2 Pallet transporters 02.3 Magazines - 03 Manufacturing machines - 03.1 Filling machines +- 03.1.1 Sausage filling ma - 03.2 Pickling machines 03.2.1 Injectors 03.2.2 Tumblers - 03.3 Cutting machines ---- 03.3.1 Slicers - 03.4 Cutting/mincing machin ⊕ 03.4.1 Mincing machines 03.4.2 Meat Cutters 03.4.3 Ultra fine cutting/i - 03.4.4 Separators - 04 Packaging Machines 04.1 Labelling machines 04.2 Pallet loading machines 04.3 Sealing machines 04.3.1 Container sealing 04.3.2 Clip closing machi - 05 Scales/Balances 05.1 Monitoring scales/balar 06 Washing machine

- WS Bake Library V08 - All WS-Bake machine - 01 Silo systems 01.1 Blending silos - 02 Dosing systems 02.1 Gravimetric dosing syste - 02.1.1 Manually Weighin 02.2 Volumetric dosing syster - 03 Processing machinery ⊕ 03.1 Kneading machines 03.2 Dough handling machin 03.2.1 Laminating machin 03.2.2 Forming machines - 03.2.3 Cutting machines + 03.3 Proofing plant - 03.4 Baking ovens 03.4.1 Deck ovens 03 4 2 Tunnel oven 03.5 Cooling systems and fre 03.6 Refining machines 04 Transport machinery 04.1 Conveyors 04.2 Baking plates/modules 04.3 Baking plates/modules 04.4 Box magazines 04.5 Pallet transporters 04.6 Pallet magazines - 05 Packaging Machines 05.1 Labelling machines 05.2 Pallet loading machines 05.3 Clip closing machine - 05.4 Tubular bag machines - 06 Scales/Balances 06.1 Foreign Body Detectors 06.2 Monitoring scales/balar

- WS_Brew_Library_V02 - Datatags for all Machine 01 Raw Materials - 02 Brewhouse 02 1 Mash-Tun/ 02.2 Lauter Tun 02 3 Mash Filter 02.4 Spend Grains Silo 02.5 Underback 02.6 Wort Kettle 02.7 Internal Boiler 02.8 External Boiler 02.9 Vapor Condenser 02.10 Energy_Storage_Vess - 02.11 Whirlpool + 03 Wort Treatment 04 Yeast Management + 05 Cellar - 06 Filter Cellar 06.1 Centrifuge 06.2 Sheet Filter 06.3 Candle/Cartridge Filter - 06 4 Membrane Filter + 07 Pressure Tank Cellar 08 Premix Plants 09 Flash Pasteurisation (KZE) - 10 Utilities 10.1 CIP Plant - 10.2 Media +- 10.2.1 Water Treatment 10.2.2 CO2 Recovery PL - 10.2.3 Compressed Air € 10.3 Energy Supply 11 Tracking & Tracing 12 Production Planning



?

| MES Project | | | | | | |
|-------------|--------------|----------|----------|----------------|-----------|------------|
| 1. | 2. | 3. | 4. | 5. | 6. | 7. |
| Basic | Pre-Planning | Basic | Detailed | Implementation | Operation | Project |
| Evaluation | Stage | Planning | Design | Stage | Stage | Completion |

State of the art:

- Customization
- Specialization
- Parametrization

Consequence:

- Personnel
 - expenditure
- 90 % Software
- 10 % Hardware

Motivation:

Concepts &

Methods

- Saving Potential
- Reduction of Cost

Model-driven Engineering of Manufacturing Execution Systems

Model-driven approach for MES Generation





Beverage filling line – process model



Process Operation

Beverage filling line – MES function model



Beverage filling line – report model

| Name | Туре | |
|-------------------------|--------------|--------|
| StartTime | AM_StartTime | Edit X |
| EndTime | AM_EndTime | Edit X |
| Depalletizer | TS_Machine | Edit X |
| Crate Unpacker | TS_Machine | Edit X |
| Bottle Washing Machine | TS_Machine | Edit X |
| Bottle Filling Machine | TS_Machine | Edit X |
| Bottle Labeling Machine | TS_Machine | Edit X |
| Crate Packer | TS_Machine | Edit X |
| Palletizer | TS_Machine | Edit X |

| ReportElement —— | | | | |
|---|--|----------------|---------------|--|
| Name : | Energy Consumption of 2 Machines | | | |
| ReportElementType : | TextField 🗸 | | | |
| Report Element Link MES Task Constant Value Linked MES Task : | | | | |
| Energy Consumpti | on of 2 Ma | chines | Edit X | |
| Inputs | | | | |
| Port | | ReportI | nput | |
| StartTime <am_s< td=""><td>tartTime></td><td>StartTim</td><td>ne 🔹</td></am_s<> | tartTime> | StartTim | ne 🔹 | |
| EndTime <am_endtime></am_endtime> | | EndTim | e 🔹 | |
| Machine_1 <ts_machine></ts_machine> | | Bottle Washing | Machine 🔻 | |
| Machine_2 <ts_n< td=""><td>/lachine></td><td>Bottle Washing</td><td>Machine 🔻</td></ts_n<> | /lachine> | Bottle Washing | Machine 🔻 | |
| Outputs | | | | |
| | Port | | ReportOutputs | |
| Total Energy Consumption < WS_Cons > | | v | | |
| Energy Consump | Energy Consumption Machine 1 <ws_cons></ws_cons> | | v | |
| Energy Consump | Energy Consumption Machine 2 <ws_cons></ws_cons> | | | |
| | | | | |

Beverage filling line – prototype of generator

| 🖳 Report | |
|----------|----------------------------|
| | Generate User Interface |
| | Execute MES Function |
| | |
| | |
| | |
| | |
| | |
| | |

| 🖳 Report | | _ D X |
|------------------------------------|------------------|--|
| Energ | y Report | Generate User Interface Execute MES Function |
| Input Area | | |
| Start Time | | |
| End Time | | |
| Machine 1 | | • |
| Machine 2 | | • |
| Output Area | a | |
| Energy Consumption Machine 1 (kWh) | | |
| Energy Consumption Machine 2 (kWh) | | |
| Total Energy Co | onsumption (kWh) | |
| | | |

| Energy Consumption of 2 Machines | | Generate User Interface |
|-------------------------------------|----------------------------|----------------------------|
| | | Execute MES Function |
| Input Area | a | |
| Start Time | 23.02.2018 00:00:00 | |
| End Time | 23.02.2018 23:59:59 | |
| Machine 1 | BottleWashingMachine.WS | _Cons_ 🔻 |
| Machine 2 | BottleFillingMachine.WS_Co | ons_El∈ ▼ |

| Energy Consumption Machine 1 (kWh) | 261.3 |
|------------------------------------|-------|
| Energy Consumption Machine 2 (kWh) | 112.5 |
| Total Energy Consumption (kWh) | 373.8 |

Model-based fault localization in bottling plants



Conveyors connecting machines of a bottling plant for returnable bottles [Photo: Deutscher Brauer-Bund e.V.].



Generic structure of a bottling plant for returnable bottles

Physical Component Models



Schematic model of the Material Transporter



| | Material | h |
|-----------|-------------|--------|
| \square | Transporter | \cup |
| | (MT) | |

State variables

 d_0 С

| В | Objects in buffer (#objects) |
|-------------------------|--|
| Bout | Objects buffered for immediate output (#objects) |
| v _{in} | Velocity of input transportation means (m/s) |
| <i>v</i> _{out} | Velocity of output transportation means (m/s) |
| t _d | Minimal transportation time (s) |
| D | |

Parameters

| Diameter of transported | object (in transportation | plane) (m) |
|-------------------------|---------------------------|------------|
| Capacity (#objects) | | |

Interface variables

| in.q _{pot} | Potential inflow (#objects/s) |
|----------------------|--------------------------------|
| $out.q_{pot}$ | Potential outflow (#objects/s) |
| in.q _{act} | Actual inflow (#objects/s) |
| out.q _{act} | Actual outflow (#objects/s) |

Equations

(1)

(2)

(3)

(4)

| $in.q_{pot}(t) = v_{in}(t)/d_0$ if $B(t) < C$ | |
|--|------------------|
| $in.q_{pot}(t) = \min(v_{in}(t)/d_0, out.q_{act}(t))$ if H | B(t) = C |
| $dB/dt = in.q_{act}(t) - out.q_{act}(t)$ | |
| $out.q_{pot}(t) = v_{out}(t)/d_0$ if $B_{out}(t) \ge 1$ | |
| $out.q_{pot}(t) = \min(in.q_{act}(t-t_d), v_{out}(t)/d$ | l ₀) |
| else | |
| $dB_{out}(t)/dt = in.q_{act}(t - t_d) - out.q_{act}(t)$ | |

Qualitative Models allow consistency-based diagnosis

Material Transporter (MT) with Buffer

[1] $[in.q_{pot}(t)] = [v_{in}(t)]$ if C-B(t) > 0

 $[in.q_{pot}(t)] = min([v_{in}(t)], [out.q_{act}(t)])$

| [in.q _{pot} (t)] | [v _{in} (t)] | [out.q _{act} (t)] | [C-B(t)] |
|---------------------------|-----------------------|----------------------------|----------|
| 0 | 0 | * | + |
| + | + | * | + |
| + | + | + | 0 |
| 0 | 0 | + | 0 |
| 0 | + | 0 | 0 |

 $[3] \qquad [out.q_{pot}(t)] = [v_{out}(t)]$

if B_{out}(t)-1≥0

if C-B(t) = 0

 $[out.q_{pot}(t)] = min ([in.q_{act}(t - t_d)], [v_{out}(t)])$

if B_{out}(t)-1<0

| [out.q _{pot} (t)] | [v _{out} (t)] | $[in.q_{act}(t - t_d)]$ | [B _{out} (t)-1] | | |
|----------------------------|------------------------|-------------------------|--------------------------|--|--|
| 0 | 0 | * | 0 | | |
| 0 | 0 | * | + | | |



Principle of consistency-based diagnosis

Evaluation of results for the diagnosis solution



Implementation (screenshot) into an industrial diagnosis tool

Energy simulation in food production systems

- Rising energy cost (especially electric)
- Energy consumption of packaging machinery strongly related to production state
- Prognosis necessary for optimisation
- State related forecast solutions are missing

➔ Goal:



operational state related modelling and simulation to forecast the electric energy consumption

Data Acquisition and Modelling Approach



Power consumption and production states of the bottle cleaning machine Measurements at an industrial bottling and packaging plant consisting of 10 machines

- Production state (operating, failure, held, emergency stop, lack, tailback, idle, prepared)
- Electrical power

Basic modelling idea:

Energy consumption of a machine is correlated with its energetic states at three constant levels:

- Producing
- Suspended
- Inactive

Modelling state changes along intermediate consumption levels IL



Stepwise change of the consumption level of the bottle cleaning machine (maximum variation, average value and confidence interval (a=0.05) of 20 measurements)

Model implementation



Model Validation for single machines



energy parameters for the bottle cleaning machine

example of a validation plot for the bottle cleaning machine

Summary of the validation results

| | TIC | APD | Measured | Simulated | Total deviation | credibility | acceptability |
|--------------------|------|------|----------|-----------|-----------------|-------------|---------------|
| Depalletizer | 0.38 | 27% | 418 kW | 315 kW | -16% | 0.05 | no |
| Depacker | 0.21 | 24% | 356 kW | 334 kW | -6% | 0.48 | no |
| Selective depacker | 0,16 | 13% | 305 kW | 309 kW | 1% | 0,60 | yes |
| Washing machine | 0.16 | 32% | 6007 kW | 5910 kW | -2% | 0.60 | yes |
| Filler | 0.11 | 17% | 1541 kW | 1528 kW | -1% | 0.73 | yes |
| Labeller | 0.20 | 33% | 392 kW | 380 kW | -3% | 0.50 | yes |
| Packer | 0.30 | 41% | 403 kW | 347 kW | -14% | 0.25 | no |
| Mixer | 0,27 | 156% | 1692 kWh | 1805 kWh | 7% | 0,33 | partially |
| Palletizer | 0.29 | 28% | 449 kW | 431 kW | -4% | 0.28 | no |
| Crate Washer | 0.15 | 16% | 2670 kW | 2492 kW | -7% | 0.63 | yes |
| Complete line | 0.12 | 25% | 14233 kW | 13889 kW | -2% | 0.70 | yes |

Validation plot of the complete bottling and packaging line (14



RoboFill - Agent-based bottling in lot size 1





IT-Architecture of the cyber-physical production system





Agent System Architecture



Individualization in the RoboFill Webshop



| Konfigurator | × + | | | | | | - | - 🗆 | × |
|--------------|---|---|-------------------|------------|----------------------|-----------------------------|--------------------------|------------------------|---------|
| | um.portamis.de:8083/onlineb | eschriftung/step10ChooseProduct | .jsf | G | ☆自 | ♥ ↓ | S prache | en • 💝 | ≡ |
| RoboFill4.0 | Startseite Login Meine Produkt auswählen | Kundendaten Meine Projekte Produkt beschriften | Produkt speichern | robofill.w | rzw.tum.de Projek | Impressum te + Besteller | Deutsch Produk Kon | t- / Beschri figura | ftungs- |
| | | Hauptkomponente: | | 61 % | | 1 Entsperrt | | | |
| | | Zusatzkomponente(n) | | 39 % | | 1 Entsperrt | | | |
| | | | | | | | | | |
| | Zurück | | | | | | Weiter 🕨 | | |

| Till | Till | Yaskawa | Beckhoff | Yaskawa | Krones | Krones | Krones | Krones | Krones |
|-----------|-----------|---------|-----------|---------|-----------|-----------|-----------|-----------|-----------|
| Flamer | Printer | MH24 1 | XTS | MH24 2 | Rinser 1 | Rinser 2 | Filler 1 | Filler 2 | Sealer |
| Available | Available | Ready | Available | Ready | Available | Available | Available | Available | Available |
| .• | .= | _ | .= | .= | .= | ." | .= | .= | .= |
| | | | | | | | | | |



Digital transformation in the food industry

Chances

- cost reduction
 - increase in productivity
 - saving of resources
 - Improved production processes
- Stronger networking of the supply chain
 - Transparency and security
 - traceability
- Better product quality
 - Avoidance of food losses
 - Process stability with fluctuating raw materials
- Greater flexibility
 - Increasing the reaction speed
 - More customized products

Challenges

- Consistent internal and external digital networking
 - Standardized) communication interfaces
 - Big data sharing
- Reusable product and process models (Digital Twins) for
 - Product development and plant planning
 - Virtual commissioning
 - production control
- Reference applications in the food industry
 - Decentralized production control (agents)
 - Machine Learning (Analytics)
 - Digital business models