**Project Title:**
Zero-defect manufacturing strategies towards online production management for European FACTORies

FOF-03-2016 - Zero-defect strategies at the system level for multi-stage manufacturing in production lines

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### Project Information

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### Document Information

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### Abbreviations

<table>
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<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>DES</td>
<td>Discrete Event Simulation</td>
</tr>
<tr>
<td>SERG</td>
<td>System Engineering Research Group</td>
</tr>
<tr>
<td>FMS</td>
<td>Flexible Manufacturing System</td>
</tr>
<tr>
<td>GEP</td>
<td>Gene Expression Programming</td>
</tr>
<tr>
<td>PDF</td>
<td>Probability Distribution Function</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
</tr>
<tr>
<td>KPIs</td>
<td>Key Performance Indicators</td>
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1 Introduction

Z-Fact0r will deal with the current trends for customisation and demands for zero defect manufacturing by introducing a holistic approach, not only to achieve zero-defects but also to maximise quality and performance. The Z-Fact0r solution comprises of five multi-stage production-based strategies targeting (i) the early detection of the defect (Z-DETECT), (ii) the prediction of the defect generation (Z-PREDICT), (iii) the prevention of defect generation by recalibrating the production line (multi-stage), as well as defect propagation in later stages of the production (Z-PREVENT), (iv) the reworking/remanufacturing of the product, if this is possible, using additive and subtractive manufacturing techniques (Z-REPAIR) and (v) the management of the aforementioned strategies through event modelling, KPI (key performance indicators) monitoring and real-time decision support (Z-MANAGE)[1]. The correlation of each involved components is presented in Figure 1.

This deliverable (D4.3) describes the design, the development and the deployment of the green optimization solutions. In this optimized solution all production related factors such as production schedule, corresponding energy consumption, quality control etc. are considered. The solution contains two key components, the prescriptive Green Optimiser Model and solver. The prescriptive Green Optimiser Model and Solver platform is designed to provide a near optimized solution for manufacture industry.
The design of the Prescriptive Green Optimiser Model and Solver section provides a general description of the concepts behind. The structure of model and solver is also detailed. Two scenarios are designed for Durit case and Microsemi case respectively.

The implementation of Green optimization/scheduler solutions section introduces two simulators, a glue dispensing model for Microsemi case and a shop floor process model for Durit case. Their corresponding solvers are also described.

The solution deployment section illustrates the implementation of those developed solutions. The implementation is based on the simulated data set. It is worth saying that all simulated data can be replaced with real data generated from our industry partners. As it was done in D4.1, based on the interactions and experiences gained from the data collection at the sites, we also will be investigating methods to compensate for the missing or immeasurable data necessary for the successful implementation of Event Modeller and Green Scheduler (e.g. soft sensors).

This report also presents the current progress UBRUN has made so far for the deliverable (D4.3).

This report is organized as the following:

- Section 2 presents the design of Green optimization solutions
- Section 3 introduces the implementation of Green optimization/Green scheduler solutions.
- Section 4 illustrates the deployment work of Green optimization/Green scheduler solutions.
- Section 5 concludes this report.
2 The design of Prescriptive Green Optimiser Model and Solver

2.1 Background

Green optimization solutions in Z-Fact0r are designed to provide a platform to make sure the production line even the whole factory is to work in an efficient and effective manner. The prescriptive green optimiser model is proposed to model the essential corresponding system components which are selected from the production chain. The modelling criteria selected is to develop a function with which the contributions from each KPIs to production effectiveness are included and expressed in a systematic style. This task involves mathematical modelling of respective KPIs such as customer service and energy/power consumption as functions of decision variables. The prescriptive green optimizer solver investigates the settings of every involved system components. With different objectives such as minimal level of energy consumption, fastest order delivery, a minimal level of environmental impact etc. the solver finds the near best settings for a given production plan.

The Z-Fact0r project mainly focuses on detecting and assessing the impact of system-level events which lead to problems including lower quality, high defect rates and high costs per unit. The events detected from the physical layer of the system are engineered into high-value data. It will be used to generate new and more accurate process models. Such an unbiased systems behaviour monitoring and analysis provide the basis for enriching the existing knowledge of the system (experience) learning new patterns, raising attention towards behaviour that causes operational and functional discrepancies (e.g. alarms) and the general trends in the shop-floor. A large number of the data samples are being considered to increase the precision (repeatability) and accuracy of the prediction models. The estimations for the future system states requires the totality of the selected production line or sections (critical sections) to provide information on machine status within a process linked to the quality properties of the raw material and the jobs being transformed from raw material into finished products. The rationale is that the combination of interlinked events (i.e. input parameters) causes a specific property (captured in quality and other KPI measures – e.g. output). Such a causal relationship will determine the reasons for optimal and suboptimal performance. At the next stage, prognosis models will be developed to predict with acceptable levels of confidence the expected quality, customer satisfaction and other KPIs. It will then lead to production control commands and advice for modifications of the production and machine operations prior to the completion of the production process of the product. In addition, Z-Fact0r can operate in the reverse mode, i.e. insert a Customer Satisfaction Goal and control the parameters accordingly to achieve this target.

2.2 Objectives

The objective of WP4 - SYSTEM MODELLING FOR FAST FORWARD COST FUNCTIONS is the development of the system modelling. Along the product, the Key Performance Indicators
(KPIs) will be tracked, in order to allow prediction of future states from the historical, current and future (predict) data. The numerical representations of the KPIs can be translated into cost functions generating cost indices in order to correlate the heterogeneous events occurring in the system level. The outcome of the system will be capable of optimising the processes in order to have a green scheduling approach to reduce the energy consumption and avoid the generation of future defects or deviations from the optimal output.

As the third step of the, the objective of the D4.3 is to establish a green optimization solution. In this solution, the prescriptive model should be developed to represent the behaviour of each involved system component and the solver should be developed to find the near optimal settings of each involved system component. This solution should have the capability to handle online/offline analyses. Where the online analyses are based on real-time data, the offline analyses refer to the investigation on historical data.

The green optimization solution is designed to provide a generic system for all potential industry partners. In the following subsections two use cases, MICROSEMI and Durit are introduced in detail to demonstrate the idea behind the design of the model.

2.3 Z-Fact0r Use Cases - MICROSEMI

2.3.1 Background of MICROSEMI use case

Microsemi Semiconductor Ltd, a division of the Microsemi Corporation, manufactures miniature electronic modules for medical, security and communication industries. Increased miniaturization pushes the capability of standard electronics to assemble equipment to the limits, particularly during the pre-volume ramp-up period.

In shortage of real operation data from Microsemi's Tresky machine, the Brunel team (IZADPANAH MEHRKISH, 2017) simulates a comprehensive model which represents Microsemi time-pressure dispensing processes. First of all, the characterization of the rheological behaviour of fluids is addressed from time-dependent points of view.

Considering air compressibility and liquid inertia, a model is developed to represent the dynamics of the flow rate of the dispensed liquid, which demonstrates that the dynamics are sensitive to the air volume in the syringe. Based on the model, the inconsistency in the liquid amount apportioned because of the variation of the air volume in the syringe over an administering procedure is investigated, and an off-line control is developed to reduce the amount inconsistency.

A schematic diagram of the system is shown in Figure 1. This is a schematic chart of a conventional time-pressure dispensing process. An air supply is utilized to give pressurized air in a blend with a valve to control the term of the pressurized air. Through a transmission line, pressurized air is connected to a syringe. Under this activity, the liquid in the syringe is constrained through furthermore, out of the needle. Once the liquid is exited from the needle,
it drops onto a board, and after that streams or spreads on the board to the point that a balanced profile is shaped. For such a procedure the flow rate or measure of liquid administered and the pattern of liquid formed on the board are two imperative estimations of the process execution.

The main disadvantage of this method is that the amount dispensed is inconsistent under the same pressure pulses (Chen et al. 2001 and 2002). This is because of the gradual increase of the air volume in the syringe, affecting the dynamics of flow rate and thus the amount dispensed. In this process, the volume and shape of the dispensed glue are the two most important performance indexes.

2.3.2 Solution for MICROSEMI

The green optimization solution for Microsemi is designed to analyse the production line. The glue dispenser system is selected as the investigation target. The deep analyses focus on the correlations among the nature of glue, the surface that the glue is dispensed on (the die and PCB board), the production process and the type of defects (shape/volume of dispensed glue).

Figure 2. Time-pressure dispensing schematic (Chen, Schoenau, and Zhang, 2001).

Figure 3. The correlation among glue, defects and production process.
As it is shown in Figure 3, such correlations are listed below

- The nature of glue provides a direct impact on the defect rate.
- The production process provides a direct impact on the defects rate.
- The change in the nature of glue could also influence the production process. In order to keep the defect rate at an acceptable level, the production process may need to be adjusted.

The green optimization solution for Microsemi is further developed with a Z-PREDICT solution. The system includes a simulator of Tresky 8000 machine (Dispensing Machine and glue model have been simulated in NI LabVIEW 2018). The simulator considers the setting of Tresky and environmental factors (input glue, temperature, pressure etc.). The changes in the setting of the machine and the specification of glue are considered as target system status change. These system status changes which lead to a change in the defects (rate, type etc.) are assigned as the input of the simulator. Event and defects can be synchronized with the time stamp when the defect is generated. Based on the simulator a mathematic optimization model is further generated to represent the correlation between each involved system component. As shown in figure 4, the green optimization model takes the inputs from three potential data sources (historic data, simulated data or real time data). By accumulating enough number of samples generated with the optimization model the solver detects the near optimal settings for different objectives such as energy consumption, environmental impact, order delivery speed etc.

![Diagram](Figure 4. Design of green optimization solution Microsemi case)
2.4 Z-Fact0r Use Cases – Durit

2.4.1 Background of Durit use case

Durit is an intensive user of precision grinding, milling and turning operations particularly for the final stages of hard metals (WC-Co) wear tooling for numerous industrial applications. Tolerances down to +/- 1 micron are usual in this field. Surface finishing, including surface roughness, dimensional tolerances and structural integrity must meet precise standards that demand continuous measuring and quality control. The non-quality is very costly at this stage since the production process is based on powder metallurgy. The recycling process must then be made through the chemical dissolution of the parts to recover the starting powders. [2]

Figure 5 shows an overview of the general production process of Durit. It is worth noting that the Durit’s production is a multi-stage production.

Unlike Microsemi case, the correlations among the nature of the raw material, the production process and the defects are not directly connected in Durit case. The correlations are presented below.

- The Raw material provides a direct impact on a defect in every process stage.
- The production process provides an indirect impact on the defects rate.
- Production process consists of multi-process stages. The indirect impacts on the defect are accumulated.
- The impacts generated in the different stage can influence each other.
2.4.2 Solution for Durit

The green optimization solution for Durit is designed to track and analyses the production line. The metal component processing system is selected as the investigation target. The deep analyses focus on the correlations among the working schedule, the material, and the operator.

The purpose of Durit production line optimisation is to find optimal schedules regarding the orders completion time, the cost, and the quality. These generated schedules have to be evaluated to be certain of their feasibility first, and to assess their performances through key performance indicators (KPI). Discrete Event Simulation (DES) has shown being efficient in the evaluation of Flexible Manufacturing Systems (FMS) and therefore is the type of simulation used to assess these schedules.

In the green optimization solution for Durit, first, a DES model is created to be able to generate different feasible schedules and provide data such as all processing times. This schedules’ goal is to replace the real data of Durit industrial partner’s manufacturing system. The DES model is further developed to build the green optimization model. The model describes the correlation between each involved system component appears in the simulated Durit
production line. The model will be further discussed in section 3.2.1. Furthermore, Several KPIs will have to be calculated such as resource utilization, waiting time at each process, energy consumptions, and time spent to change machine settings, costs of operators, Work in Process (WIP) and lead times to evaluate the general performance of a scenario with this model. The gene expression programming algorithm [2] is employed to investigate and build the green optimization solver.

![Diagram of green optimization solution Durit case](image)

*Figure 6. Design of green optimization solution Durit case*
3 The implementation of Green Optimiser Model and Solver

The implementation of the green optimization solution is introduced in this section. The green optimizer model contains two parts simulator and mathematic model. The simulator part is designed to simulate the production procedure. The model part is designed to represent the correlation between the involved system components. The Green Optimiser Model is explained first.

3.1 Use Case – MICROSEMI

3.1.1 Simulator and Model

A Tresky T-8000 die placer related factors were selected to create the target system. Based on the formulas in glue dispersion literature and Monte Carlo Simulation, which applies to all simulations that utilise stochastic approaches to produce new configurations of the desired system (Earl and Deem, 2008), a simulation of glue dispersion was made. The main purpose of utilising Monte Carlo simulation is the accurate calculation of thermodynamic and physical characteristics of the system (Earl and Deem, 2008). Building the model, the data were taken from Chen et al. (2005) as explained previously, the real data could not have been achieved due to lack of access to Tresky machine’s PLC by preparing of this report.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
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</thead>
<tbody>
<tr>
<td>Magnitude of air pressure</td>
<td>$2.45 \times 10^5$ Pa</td>
</tr>
<tr>
<td>Magnitude of pressure applied</td>
<td>$2.46 \times 10^5$ Pa</td>
</tr>
<tr>
<td>Syringe capacity</td>
<td>32 cc</td>
</tr>
<tr>
<td>Length of needle</td>
<td>16 mm</td>
</tr>
<tr>
<td>Internal diameter of needle</td>
<td>0.92 mm</td>
</tr>
<tr>
<td>Dispenser velocity</td>
<td>3 mm/sec</td>
</tr>
<tr>
<td>Glue density</td>
<td>$1780$ kg/m$^3$</td>
</tr>
<tr>
<td>N (degree of rheological behaviour)</td>
<td>0.95</td>
</tr>
<tr>
<td>K (consistency index)</td>
<td>1.02 Pa.s</td>
</tr>
</tbody>
</table>

*Table 1. Settings for dispensing (Chen et al., 2005)*

To find out the dependency of glue level in the syringe, the amount of glue dispensed per second at different glue level was calculated and plotted in Figure 7.
The relationship between the amount of glue dispensed per second (Q), Glue level in the syringe (Ls), and applied pressure (Pg) can be seen in Eq 1, which can predict the amount of glue dispensed per second with the applied pressure and glue level in the syringe. It can be seen that small changes of glue level and applied pressure can affect Q. The regression model shows that the amount of glue dispensed per second is a linear function of both glue level in the syringe and applied pressure. The coefficient of each predictor variable is the effect of that variable, for a given value of the other.

\[
Q = -4.54 + 0.00032(Ls) + 1.86 \times 10^{-5}(Pg)
\]

The changes of the setting of the machine and the specification of glue are considered as target system status change. These system status changes which lead to a change of the defects (rate, type etc.) are assigned as events of the system. Event and defects are synchronized with the time stamp when the defect is generated. The defect analysis and classification is conducted by Brunel team members.

In this solution, the Event-Modeller provides the detection function for events in the system. These detected events of Tresky T-8000 machine and events of corresponding environmental factors are then classified with Event-Modeller. This classification is based on Rank order Clustering techniques which runs in Event-Modeller algorithm and tries to group and cluster the relevant inputs and the events of the output. The correlations among involved input factors (machine setting, temperature, pressure etc.) are further mined with gene expression programming (GEP) in Green scheduler optimiser.

With the help of good results (events recorded when the system is running in a stable ideal status with zero defects) generated with the Event-Modeller, the ideal setting range which
keeps the Tresky T-8000 machine working in a stable zero defects zone at maximum productivity can be identified. If any event, which has a high probability to bring the system into producing defects are detected, the machine can be adjusted by resetting corresponding factors to avoid defect (in the simulation called re-calibration). An online prediction is achieved with the Event-Modeller. Based on a large number of historical data samples, the GEP generates a mathematic function which describes the interaction among Tresky T-8000 machine, environmental factors and defects.

The optimizer model is developed with the sample generated with the simulator. GEP uses a tree-structured format (Figure 8) to represent the mathematic model (function). The terminal (leaf) node represents the system component considered. The function (branch and root) nodes represent the correlations among system components. The level of tree represents the part of the important level of involved system components.

![Figure 8. Function represented with GEP tree structured format](image)

### 3.1.2 Green Optimizer Solver/Green scheduler

Green optimizer solver provides a platform to investigate and generate the near best solution for the target system. The solver contains three parts, Model translator, objective compass and solution explorer.

The Model translator converts the optimizer model into a generic format which can be expressed by gene expression programming chromosome structure. The objective compass leads the direction evolution progress. It is directed with time, cost or defects oriented functions. The solution explorer provides an efficient mechanism to search the new optimal result of the given problem. As shown in figure 9, the model translator works in the correlation recognition component. The objective compass and solution explorer is implemented in optimization component.
3.2 Use Case – Durit

3.2.1 Simulator and Model

The Durit solution is based on a whole production process which consists of a number of intermediate process stages.

Due to the lack of real data at the time of simulation, this simulation has been made by a hypnosis (but very close) example of Durit productions line and SAP information. The simulator is developed with the following scenario.

Durit has two stages of process line:

1. Line 1 includes powder preparations, pressing, green machining, sintering and finally physical quality control.
1.1. Raw Material powders include RM1, RM2, RM3 and RM4 and respectively cost €50, €60, €65 and €70 per kilogram. Laboratory produces maximum 20kg of raw materials per day and store in an inventory room (Max room capacity is 100 kg) for a maximum of a month. Every a week after this increase 1% of probability of occurring defect type 1 in final products. Two staff work for raw material order and preparation.

<table>
<thead>
<tr>
<th>Product name</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder usage</td>
<td>RM1: 1 kg</td>
<td>RM2: 3 kg</td>
<td>RM1:1 kg</td>
<td>RM2: 2 kg</td>
</tr>
<tr>
<td></td>
<td>RM3:1 kg</td>
<td></td>
<td>RM3:1 kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RM4: 2 kg</td>
<td></td>
<td>RM4: 2 kg</td>
<td></td>
</tr>
</tbody>
</table>

1.2. Furnace 1 and 2 have a capacity of 10 and 15 kg and need to run for 10 hrs and 20 hrs (plus 4 hrs for warming up) respectively to cook the raw materials.

1.3. The dry machine has a capacity of maximum 15kg and takes 8 hrs to dry and dehumanize the raw material and make the final powders. Three operators work for the furnace and Dry machine.

1.4. Press machine 1 and 2 press the powders for products P1 to P4 in 15, 45, 30 and 60 minutes respectively. Set up time for each machine is 15 minutes. Press machine causes defect type 2 over 1% of products.

1.5. Green machine, cut and machine the products coming out of press machines. For products P1 to P4 in 1, 2, 1.5 and 2 hours respectively. Set up time for each machine is 30 minutes. Green machine causes defect type 3 over 1% of products with operator grade 1 and 2% defects with operator grade 2.

1.6. Sintering furnace 1&2 sinter the products in 1hrs for lighter than 2kg and 1.5hrs for heavier products. The defect rate before this stage between 2-3 % of product and costs 10% of product cost to recycle and recover the powders.

1.7. An inspection delivers in this stage overall products before entering to Line 2. All defects detect at the occurring stage to avoid resource waste except for 1% of products which can’t be detected in this inspection stage and enters to Line 2.

1.8. Overall 6 operators (3 Grade 1 and 3 Grade 2) are available for pressing, machining, sintering and quality check.

1.9. All machines work in this line need a week annual maintenance but an un-expected annual failure is inevitable for each machine (takes a day to repair).

1.10. Each shift is 7 hrs work plus an hour breaks (8 hrs overall).
1.11. Electrical power usage of machines are as the following:

<table>
<thead>
<tr>
<th>Machine</th>
<th>Furnace 1</th>
<th>Furnace 2</th>
<th>Dry machine</th>
<th>Press machine</th>
<th>Sintering machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical power</td>
<td>50 kw</td>
<td>60 kw</td>
<td>20kw</td>
<td>10kw</td>
<td>25kw</td>
</tr>
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</table>

2. Line 2 includes finishing department which has 3 finishing machines use to surface finishing to meet customer precise requirements.

2.1. Machines process are as the following:

<table>
<thead>
<tr>
<th>Machine</th>
<th>Machine 1</th>
<th>Machine 2</th>
<th>Machine 3</th>
<th>Machining order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup time</td>
<td>15 min</td>
<td>15min</td>
<td>30min</td>
<td>P1--P2 or P2--P1</td>
</tr>
<tr>
<td>P1</td>
<td>1 hr</td>
<td>1hr</td>
<td>-</td>
<td>P1--P2 or P2--P1</td>
</tr>
<tr>
<td>P2</td>
<td>1 hr</td>
<td>1hr</td>
<td>-</td>
<td>P1--P2 or P2--P1</td>
</tr>
<tr>
<td>P3</td>
<td>-</td>
<td>1hr</td>
<td>2hr</td>
<td>P2--P3</td>
</tr>
<tr>
<td>P4</td>
<td>1 hr</td>
<td>1 hr</td>
<td>2hr</td>
<td>P1--p2--P3</td>
</tr>
<tr>
<td>Electrical Power Usage</td>
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<td>10 kw</td>
<td>12 kw</td>
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</table>

2.2. 70% of whole defects occur in this stage which called tolerance defect (type 4). There are 6 operators work in a shift (3 grade 1 and 3 grade 2). Grade 2 operators have twice more defect rate than Grade 1 operators.

2.3. Defects in this line are non-recyclable and should be sold to scrapyard with 2% of their raw material weights.

2.4. Quality control will be delivered on the final product and 2 operators (both grade 2) works in this department.

**General points:**

1. All non-mentioned points should be assumed by modellers including recruiting new staff or purchasing a new machine.

2. Electricity costs for 1 KWh: day rate: 5p and night rate: 3p

**Wages:**

Grade 2 operator: 10 €/h, Grade 1 operator: 15€/hr, Line managers: 20 €/hr
The green optimizer model is generated with the same setting of above simulator. Unlike Microsemi case, a linear structure format is selected to represent the sequence correlation of production process procedure. The model is described as an accumulating format of time, cost, and defect rate etc.

3.2.2 Green Optimizer Solver/Green scheduler

Similar to Microsemi case the optimizer solver, the model translator, objective compass and solution explorer in this case also share the similar functionality. The only difference is the Model translator converts the optimizer model into a generic format which can be expressed by a linear formatted chromosome. This linear chromosome represents a solution/schedule of the production plan. The detail of chromosome format is list below.

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4 The Deployment of Green Optimisation Model and Solver solutions

This section presents the deployment of Green Optimization solutions. It includes three steps integration, adjustment and execution. The integration plan and strategy are introduced first.

4.1 Integration plan and Strategy

The integration plan and strategy of Green Optimisation Model and Solver describes how the proposed solution can be deployed into Z-Fact0r system. The correlation between the proposed solution and its environment is illustrated in figure 10.

As a data source independent platform, the integration plan of Green Optimisation Model and Solver contains steps.
1) Locate the position:
Where the solution is deployed in this step. From the local machine level to cloud server level. The system needs to be modified to suit the requirement of different implementation platform.

2) Establish a connection:
The connection between the proposed solution and its environmental component need to be created. An existing data repository or internal database needs to be decided when the solution is deployed. If the data from data repository is not ready, an internal database generated with simulator will be involved.

3) Execution of a solution:
The execution mode of the solution is considered in this step. The solution supports offline or online mode.

The deployment strategy provides a setup guidance of the proposed solution. As shown in Figure 10, the deployment strategy considers two types of input data sets.

a) The data repository contains real-time data generated from the production line. Online, sensors produce real-time measurement results for the data repository. The solution takes online data directly from the data repository.

b) If the data required is not ready the solution will take input from the simulated data. The simulator produces “real” data and feeds the data loader which can be provided with our partner in charge of integration.

4.2 Demonstration example
The green optimization solution was executed with Microsemi and Durit cases. The demonstration of the two cases is provided in this section.

4.2.1 Microsemi Case
Microsemi case is based on a simulator which simulates the glue dispensing procedure. The simulator is introduced below. Figure 11 presents an overview of the setting page of the simulation. Glue properties, Temperature, Machine settings and operation control in this page.
Figure 11. The glue Simulation parameters setting

Figure 12.a and 12.b show the prediction page in two different times. The 12.a presents the input/output parameters plus the contribution of each input on the outputs (output here is glue expansion plus needle decay) before occurring a defect and 12.b. shows the model after occurring a defect.

Figure 12.a. The glue Simulation status, parameters value and different parameters contribution in a predicted defect in no defect
Figure 12.b. The glue Simulation status, parameters value and different parameters contribution in a predicted defect in defected glue drop

Figure 13 (left) presents the KPIs of the Tresky machine. Overall quality rate, Glue drop rate, machine availability, machine utilisation and consumption, total productivity, idle/busy time, OEE, Total GHGs and total energy consumption are calculated KPIs. The right image presents the perspective core model results, i.e. the optimal setting of the system which leads to the accepted KPIs value.

Figure 13. The glue Simulation KPIs (the left) and perspective model to optimisation of KPIs (the right)
Figure 14. Correlation recognition process of green optimization solution

With the process shown in Figure 14, the relationship between these KPIs has been analysis by GEP algorithm. The green optimization model is then extracted for the simulator with a larger number of data samples. Figure 15 and 16 show a snapshot of the model input, output and KPIs for almost 600 sample.

GEP further provides a mathematical formula which represents this relationship between KPIs. Two examples, Total energy consumption-oriented and Total GHG omission-oriented formula are provided.

- **Total energy consumption** = \[ \left( Power \left( Power(UC + \frac{PR}{TP}) \right) \right) + (Or(MU < 0, TG < 0) + (IM + BM)) \]
- Total GHG omission = \( TE \times \left( (I_f ((TP + IM) < UC, 1,0) - T\tan(150635.802187)) + O_r (O_r (T < 0, PR < 0), (I_f (BM < MU, 1,0)) < 0) \right) \)

**Figure 15. A sample Glue Simulation inputs/outputs**

**Figure 16. A snapshot of the model KPIs**

Two examples of the green optimization solver result are provided in Figure 17 and Figure 18. Figure 17 illustrates the actual value of the total energy consumption and the estimated value
of the total energy consumption. Figure 18 presents the information generated for the comparison between the actual and estimated total GHG omission value. As shown in figure 17 and 18 the estimated and actual value are highly matched. That means the green optimization solution has the capability to track, to represent and to provide an adjustable platform for different objectives.

![Figure 15. Estimation of the total energy consumption](image1)

![Figure 18. Estimation of the total GHG omission](image2)

### 4.2.2 Durit case

Durit case is based on a simulator which simulates the metal production procedure. The simulator is introduced below.

The Arena 2018 Discrete Event Simulation (DES) Simulation package has been used to simulate Durit manufacturing system (Barroy, 2018). The results explained here are related to a creation of 100 scenarios with the first DES model. These scenarios have been generated from the same inputs which are an example of 100 orders composed of 4 different product types (31 products type 1, 26 products type 2, 22 products type 3 and 21 products type 4).
The operators were working in an 8-hour shift (7 hours work plus one-hour break) and the machine a 24-hour shift. The presence of an operator to start a process on any machine is required, but the machine can end the task itself and direct the processed entity to the next queue without an operator’s presence.
Figure 21. Arena simulation part-3

Figure 22. Arena simulation part-4
The DES model is taking into account all processing times from the green scheduler, an example of the inputs is shown in Figure 23. Raw materials creation times and operator grades which are used to form each product is required as well. These times entail an increasing defect rate if the gap between the first process and the raw material creation is important. These inputs are the minimal required to simulate a scenario correctly according to the quality constraints in this example.

However, more inputs could have been considered, such as the operator shift for instance. For time reason and because the green scheduler wouldn’t be able to fill this input in the expected version, the operator shift hasn’t been introduced in the model. The other reason to not incorporate them is the lack of information we have in this example. Many processes have processing times of several hours, and we don’t have information about how processes are handled.
The following inputs are required for each order (Figure 24):

- Order Number
- Index Type
- Raw material Creation
- Scheduled time for each process
- Operator index to each task

With these inputs, a working schedule of an order can be created and represented for the DES model. An example is provided in the following Figure 24. The example contains the delivery schedule of several orders. All involved factors are considered in the model.

![Figure 16. Example of all required inputs to evaluate a scenario with the DES model](image)

And processing times are shown in Figure 25.

![Figure 17. Example of output for a generated scenario with the first DES model (processing times)](image)
Figure 26 shows the KPI evaluated for a specific scenario generated with the first DES model. These KPIs are complementary of the processing times shown in Figure 25.

![Table showing energy consumption and cost](image)

*Figure 18 Example of output for a generated scenario with the first DES model (key performance indicators)*

Figure 27 shows the first output of scheduled and processed times for a specific replication of a scenario evaluated by the second DES model. Only a few processes are shown in Figure 27. All times in bold are processed times exported by Arena. Other information is the user inputs reported in each replication sheet to ease a comparison between scheduled and seized times.
Figure 27. Example of an output of scheduled and processed times with the second DES model

Figure 28 shows the right side of a replication sheet of an evaluated scenario by the second DES model. The KPIs are divided into parts with resource KPIs, entity KPIs, operators KPIs, quality KPIs, the overall cost of the replication and its completion time.
Figure 19 Example of an output of all KPIs of a replication evaluated by the second DES model

Figure 29 presents all KPIs of an evaluated scenario with the second DES model. These KPIs are calculated based on the average of all replications’ KPIs.

On the process side, for each process, the utilisation, average waiting times by entities before the process, the time spent to change settings and the energy consumptions at days and nights in Kwh and €.
On the entity side, some KPIs are calculated as well (Figure 30). The end user can find details about entity time spent in the system. The KPIs are different for each type of product as their processing times are not the same.

![Average (in hours)](attachment)

**Figure 20.** Entity related key performance indicators

With regard to quality indicator of performance the products manufactured must be manufactured in the best quality possible even if it requires a longer lead time, however, in accepted other KPIs range. The KPIs evaluated in the tool are shown in Figure 31.

![Average Quality Defect](attachment)

**Figure 21.** Quality related KPIs

The manufacturing process is composed of two production lines. At the end of the first line, if a product is detected with a quality defect, it can be recycled and has a minor cost. If the defect is detected in line two, then the product is sent for scrap and has a major cost. For the scenario evaluated, the average done with each replication of the number of the product being recycled is 2.05; the average of the number of the product being sold for scrap is 0. This second value is exactly 0 because, in all replications, no products have been sold to scrap. This
is because the chance considered that a defect from line 1 goes to line 2 is less than 1%. The figures which have been used in the DES model to allocate defect and detect them are exactly the one in the information we have from the case study. More information will be needed on this side from the company itself to go further and evaluate more meaningful KPIs.

The last KPIs summarises all replications are shown in Figure 32 and 33. In Figure 32, the completion time of the scenario is reported in hours and days. These values are the average of the 20 replications values. In Figure 33, the overall cost of the scenario is detailed with the energy consumption at day and night, the operator cost and the quality cost. These values are the average as well on the 20 replications.

![Figure 22. Time-related KPIs](image)

![Figure 23. Cost-related KPIs](image)

It is worthy mentioning that for each scenario simulated; the replications values were all very close to the average KPIs. Indeed, only the quality defects occurred are different for each replication.

The green optimization model is based on the simulator. Its mathematics version is provided below. The $Contribution_x$ represents the contribution to a specific part of production line.

$$Total = Contribution_{furnace} + Contribution_{dry} + Contribution_{press} + Contribution_{green} + Contribution_{sintering} + Contribution_{finishing}$$
With the direction of the objective compass, the solution explorer part of the green optimization solver, in this case, can use it linear structure solution representation to search a sequenced schedule. The schedule is further developed as the recommendation of the production plan.

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5 CONCLUSION

This deliverable presented is based on the development of the D4.3. It is further extended from D.4.1. An overview of the current situation of the development work in D.4.3 is discussed in this report.

The design, implementation and deployment work carried out on Green optimization model and solver/green scheduler solution was discussed respectively. Two models were developed to represent/simulate the industrial production procedure. A glue dispensing simulator was developed for MicroSemi case and a DES simulator was developed to represent the metal item production procedure for Durit case. The models are further extended to investigate the optimization solver solution for each case.
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[1] Z-fact0r_Deliverable 4.1
[3] Z-fact0r_D1_V2