Industrielle Gemeinschaftsforschung

Action Guide: Simulation Model for Quality and Order Management in Global Production Networks

Contact

wbk Institute of Production Science at Karlsruhe Institute of Technology (KIT)

Prof. Dr.-Ing. Gisela Lanza

Phone: +49 721 608 44017

E-mail: gisela.lanza@kit.edu

Forschungsnetzwerk Mittelstand

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

Table of Contents

Table of Contents 2

1. Funding Notes 3

2. Scope of the Simulation Model 4

3. Simulation Input: Necessary MS Excel files to parametrize a Production Network 7

4. Simulation Output: System of Indicators for Performance Assessment 12

I. List of Figures 16

1. Funding Notes

This simulation model is a result of the research project PlanQ (19421 N/1). This research has been supported by the Bundesvereinigung Logistik (BVL) e.V., Schlachte 31, 28195 Bremen, Germany which is funded by the AiF within the programme for sponsorship by Industrial Joint Research (IGF) of the German Federal Ministry of Economic Affairs and Energy based on an enactment of the German Parliament.

Figure 1: Logo of the research project PlanQ

2. Scope of the Simulation Model

This chapter describes the possibilities of using the simulation model. The first subchapter deals with the possibilities of setting up the simulation of the production network. Subsequently, the possible processes within the simulation of production locations are described.

The Entity Relationship Model of the simulation model

The implemented simulation model for production networks is shown in Figure 2 with an entity relationship model. The model essentially consists of two entity types, which represent the main components of the network: Production sites (*Produktionsstandorte*) and customers (*Kunden*). Further partial components of the entity type production sites are production resources (*Produktionsressourcen*) and customer stocks (*Kundenbestand*).

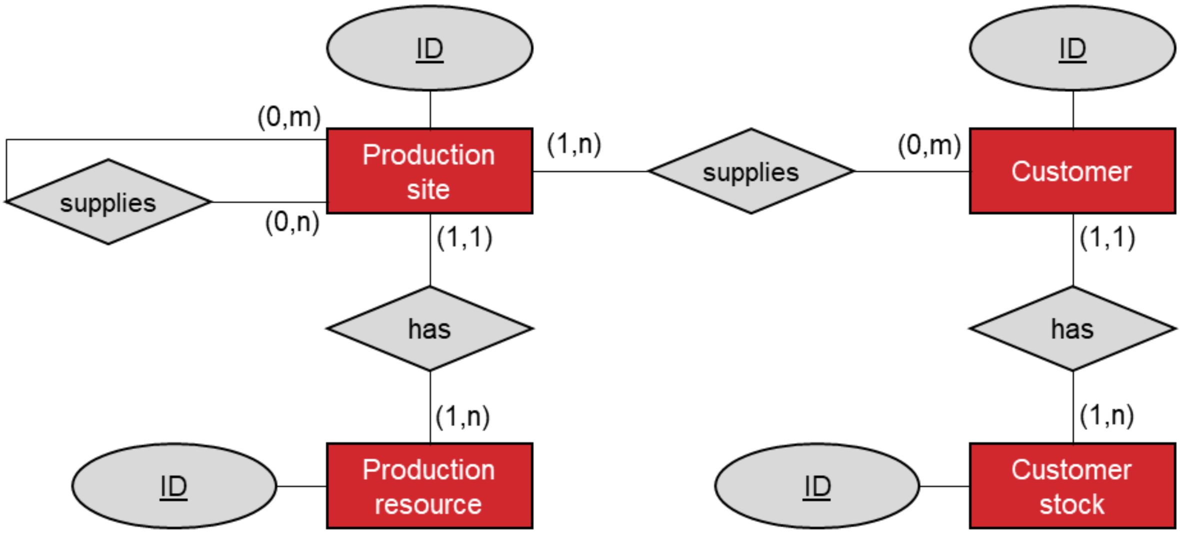

Figure 2: Entity Relationship Model of the simulation model

The customer entity type represents an actor in the network that requests products from production sites. Then it stores the products sorted according to the type of product as customer stock. A finite number of entities of the entity type customer can be modelled. Each of these customers has the possibility to enter a supply relationship with any number of production sites.

The entity type production site can supply any number of customers with products. It may also be necessary to continue using products from other production locations as supplier products. Therefore, a production site can be supplied with vendor products by any number of entities of the type production site. Conversely, each production site can finally supply many other production sites. The modelled production sites consist of any number of entities of the type production resource. They represent the production of the products. Each production resource is uniquely assigned to a production site.

In the simulation, the production sites supply the customers with products. Products are shipped using shipments based on delivery orders. Transports always take place in form of full truck loads in order to ensure a high utilization of the means of transport. Within the production sites, the products pass through the production steps of production according to the push principle. Exactly one production resource is assigned to each production step. A production resource, on the other hand, can be assigned to several production steps.

With the simulation, the production of any number of product variants can be mapped for each production location. Individual product variants differ in the production process. This results in a variable combination of production step sequences to which the production resources are assigned. In addition, different vendor products can be required for different product variants. This makes it possible for several production groups to be part of the production network.

Operations within the entities

The customer entity type has two main tasks: The "Ordering" and the "Goods Receipt". With regards to the "Ordering", the customer can be in the "Neutral" or "Ordering" state. In the original state, the customer is in the "Neutral" state. The transition to the "Ordering" state depends on the past time and is defined by the order rate. The order rate indicates the period of time between an order and the next order. The status "Ordering" triggers the creation of a delivery order for a product at a production site. The second task, "Goods Receipt", is to accept deliveries of products. With the "Goods Receipt", the products are stored in the customer stock and the ordering process is completed.

The entity type production site performs three tasks: “Order processing", "Production control" and "Procurement control".

“Order processing" accepts customer orders according to the first-in-first-out (FIFO) principle. Each sales order triggers a reduction of the available stock of the ordered product. The reduction of the warehouse stock can result in the required minimum stock level being undershot and "production control" being triggered. After reducing the available stock, the system checks whether the physical stock is sufficient to deliver the order. If this is the case, the shipment of products to the customer is triggered. If there is insufficient physical stock, the execution of the sales order is interrupted until the physical stock is increased by "production control".

The "production control" simulates the production of production orders and the occurrence of quality defects during production. If the stock level falls below the available stock level, a new production order is created and the available stock level is increased by the production quantity of the production order. The available stock of all vendor parts required for the production of the order is then reduced by the required quantity. If the minimum stock level for supplier parts is not reached, the task "procurement control" is triggered. The production of the production order is implemented as a sequence of identically modelled tasks "Production" of production resources. The sequence of production steps is arbitrary and makes the multiple use of production resources in the production expiration possible. After completion of production, the produced products are stored and the physical inventory is updated. This ends the "production control" process and the production order is completed.

The "procurement control" coordinates the ordering and goods receipt of supplier parts. The task starts when the production control shows that the available supplier stock of a product has fallen below the limit. In this case, a delivery order is sent to the supplying production site, the available vendor stock is increased by the order quantity, and the system waits for the delivery. As soon as the delivery arrives at the production site, it is received at “goods receipt” and checked for errors during the goods receipt inspection. An incorrect delivery is scrapped and a new delivery order is placed if the quantity falls short of the available vendor stock. If the delivery is free of errors, the physical vendor stock is increased by the putaway quantity and reported back to production control.

The entity type production resource simulates the task "Production". During production, production orders are processed on production resources. During processing, the parameter "error probability" is used to represent the occurrence of quality errors. A quality defect that has occurred can be detected and reworked in a subsequent inspection at the production department. The quality inspection is mapped according to the following principles:

- Result of inspection Option 1) No defect is detected.
- Result of inspection Option 2) A defect is discovered that can be reworked.
- Result of inspection Option 3) An error is detected which leads to scrapping.

The results of the quality inspection have different consequences: If no defect is detected, the product is passed on to the next production resource. If a defect is discovered that can be reworked, the product is reworked at the production resource. If reworking is not possible due to the severity of the defect, the product is scrapped. An error history logs all quality errors in the production order that occurred but were not discovered. Based on the defect history, the defects can be discovered and reported in the goods receipt inspection of a downstream production site or the customer.

When implementing processes such as order processing, production control, production and troubleshooting, care was taken to be able to map as wide a range of production system types as possible. Regarding ideal production system structures, the literature distinguishes between so-called stock manufacturers and contract manufacturers. Stock manufacturers manufacture standard products in large quantities according to the principle of series and flow production. Their products have a simple structure. The external procurement is insignificant and the production takes place in stock. Contract manufacturers, on the other hand, manufacture products with customer-specific variants to order. The product structure is more complex than that of the warehouse manufacturer and external procurement is more important. With the simulation model both ideal types can be represented. This increases the application of the simulation model across companies of different sizes and industries.

3. Simulation Input: Necessary MS Excel files to parametrize a Production Network

In order to use the simulation model, the software AnyLogic 8.3.2 (University Researcher or Professional) is required (the model may also be compatible with older or newer versions of the software. However, this has not been tested.). It is a multi-method modelling software developed and distributed by The AnyLogic Company. The AnyLogic file must be opened in the program.

All variable parameters used in this simulation model are stored in MS Excel files. It is therefore not necessary to make changes to the program code of the simulation model. This ensures that even users without experience with AnyLogic or Java programming can use the simulation model. In this chapter, required MS Excel files with their parameters and structure are presented. In order to ensure that the model is functional, the structure of all MS Excel files must be adhered to. In addition, all MS Excel files must be located in the *Produktionsnetzwerk* folder, in which the AnyLogic file *Produktionsnetzwerk.alp* is stored, without changing the document names.

The network is parameterised via four independent MS Excel files. All parameters stored in these files are presented below. In particular, it will be discussed how the structure of the Excel files enables a variable structure of the production network.

The Transport Matrix

The MS Excel file *Transportmatrix* consists of a spreadsheet containing information on the average cost per kilometre of a fully laden commercial vehicle (€/km), the average speed of the commercial vehicle (km/h) and a distance matrix. The structure of the distance matrix is shown in Figure 3. The entry at which the column of one site and the row of another site intersect indicates the distance in kilometres between the two sites. The size of the table can be adjusted to the number of existing suppliers and customers in the production network. When importing the data into AnyLogic, the simulation model automatically expects a matrix of the size $\#production\ sites\ \times (\#production\ sites + \#customers)$.

Distance in km	Production site 1	…	Production site n	Customer 1	…	Customer m
Production site 1	0	d_{1j}	d_{1n}	$d_{1(n+1)}$	$d_{1(n+k)}$	$d_{1(n+m)}$
…	d_{i1}	0	d_{in}	$d_{i(n+1)}$	$d_{i(n+k)}$	$d_{i(n+m)}$
Production site n	d_{n1}	d_{nj}	0	$d_{n(n+1)}$	$d_{n(n+k)}$	$d_{n(n+m)}$

Figure 3: Structure of the MS Excel file *Transportmatrix*

The Ordering Information

The MS Excel file *Bestellinformationen* contains a spreadsheet for each customer simulated in the network. The structure of all worksheets is identical, whereby the stored values may differ. Fields with a light grey background are automatically calculated, while fields with a white background must be filled in by the user. The header of the spreadsheet contains the values of the following parameters: the customer index, the order rate in days, the number of different product variants ordered by the customer, the total number of customers in the network, the number of suppliers with whom the customer places direct orders, and the number of orders per year. The main part of the table, as shown in Figure 4, depends on the number and product range of the suppliers: A row is created for each product variant of each production site. Each row contains information on the production site index, the product variant, the total order quantity per year and the quantity of products for a full load. This is used to calculate the number of purchase orders per year and the cumulative purchase orders per year. When importing the data into AnyLogic, the simulation model expects a table length adapted to the number of product variants and suppliers.

Production site	Product variant	Total order quantity/year	Quantity of products/FTL	# purchase orders	Cumulated
1	1	b_{11}	f_{11}	calculated	calculated
…	…	…	…		
1	m	b_{1m}	f_{1m}		
2	1	b_{21}	f_{21}		
...	...	…	…		
n	p	b_{np}	f_{np}		

Figure 4: Structure of the MS Excel file *Bestellinformationen*

The Stock

The MS Excel file *Bestand* (Figure 5) contains a spreadsheet for each production site. The number of lines depend on the number of product variants of each site and is automatically saved in the correct length in the simulation model, which is why a corresponding number of lines must be filled in. In the table, the initial stock level and the minimum stock level for each product variant of a supplier must be stored.

Product variant i	Initial stock level $\mathbf{a}_i$	Minimum stock level m_i
1	a_1	m_1
…	a_i	m_i
n	a_n	m_n

Figure 5: Structure of the MS Excel-file *Bestand*

The Simulation Basis

The MS-Excel file *Simulationsbasis* contains all data relevant for the production process, which is why a spreadsheet is created for each production site. Basically, a spreadsheet can be divided into three areas: The header of the document contains general information on the production site, while the other areas (structure shown in Figure 6) contain data on the individual production steps.

Here, a distinction is made between the area additionally dependent on the product variant (area 2) and the independent area (area 3). In the following sections, the parameters of the individual areas are presented.

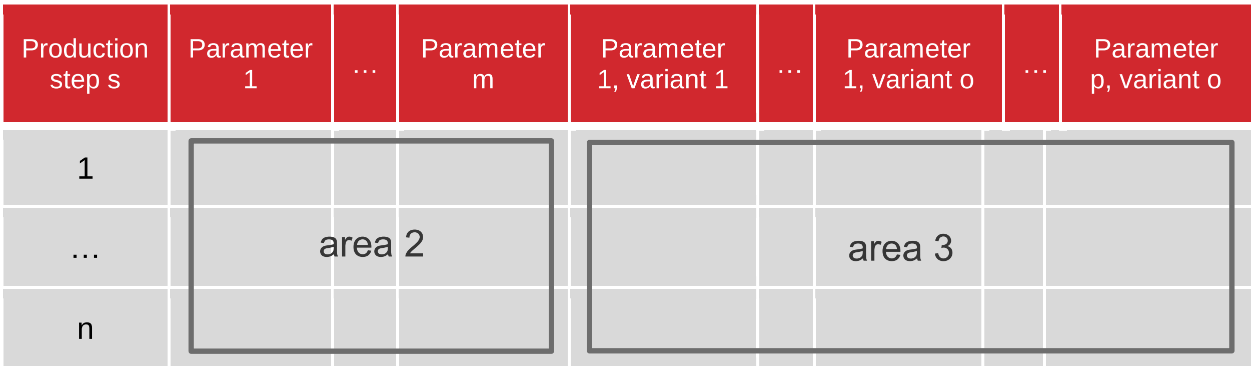

Figure 6: Structure of the MS Excel file *Simulationsbasis*

The header of the document contains information on the index of the production location and the number of production locations, the total number of production steps for all product variants and the number of production steps per product variant, the total number of production resources and the number of production resources required per product variant and the number of product variants. The lot size must also be specified for each product variant. For order processing and execution, it has to be specified how long order planning (in hours) and the loading and unloading process (in hours) take and how many commercial vehicles are available. Two further parameters must be specified for the calculation of key performance indicators: The production locations can be weighted to calculate some key performance indicators and thus have different degrees of influence on them. A number twice as high means a double weighting of the location key figure. The parameter "Critical error" indicates the severity (between 0 and 1) of a critical error.

Before the range depending on the production steps begins, the column structure is used for three additional steps: Packing, final inspection and goods receipt inspection of vendor parts. These steps are fixed and must therefore be parameterized. However, not all parameters of a normal production site can be defined. Fields that are highlighted in dark gray are not used for the respective additional step. Then the range of production step parameters starts (area 2 in Figure 6), which is why a row is created in the MS Excel file for each production step. The parameter "Number of production steps", which is determined automatically, ensures that the data is completely read into AnyLogic. The individual parameters are presented below.

- **Produktionsschrittbezeichnung**: Describes the production step in words. This information is for clarity only and is irrelevant for the function of the simulation model.
- **Produktionsschritt**: Index of the production step. It is a consecutive number.
- **Produktionsressource**: Index of the production resource that is required for processing the production step.
- **Anzahl der Einheiten einer Produktionsressource:** Number of existing resources of the required type in the production site.
- **Fläche** je Einheit einer Produktionsressource (in m^2): Area occupied by a unit of the production resource.
- **Vollzeitäquivalent** je Einheit einer Produktionsressource: Number of 100% manpower required to operate a unit of the production resource.

- **Mittlere verfügbare Zeit** je Produktionsressource (in min): Average available time of a production resource before it becomes "not available".
- **Standardabweichung der mittleren verfügbaren Zeit** je Produktionsressource (in min): Standard deviation of the average available time.
- **Mittlere nicht verfügbare Zeit** je Produktionsressource (in min): Average time that a production resource is unavailable before it becomes available.
- **Standardabweichung der mittleren nicht verfügbaren Zeit** je Produktionsressource (in min): Standard deviation of the mean unavailable time.
- **Verfügbarkeit** je Produktionsressource (in %): Percentage of availability of a production resource resulting from the combination of losses due to plant holidays, the shift model, and machine failures.
- **Betriebsferien** je Produktionsressource (in %): Percentage of loss of total time due to plant closure.
- **Schichtmodell** je Produktionsressource (in %): Percentage of the total time available due to the selected shift model compared to a full 21-shift model.
- **Maschinenstörungen** je Produktionsressource (in %): Percentage of loss due to production resource failures per production resource.

The third area is directly adjacent to the second and is adapted in format to the line structure of the parameters already introduced. The parameters presented in the following do not only depend on the production step, but also on the product variant. For each parameter, therefore, several columns are provided in the worksheet: Each product variant occupies one column. Accordingly, the table sheets of different production locations may differ in the total number of columns. The clearly defined structure allows all data to be read into AnyLogic automatically and correctly. The individual parameters are defined as follows:

- **Verwendung des Produktionsschritts**: Indicates whether the production step is relevant for the production of this variant (value "1") or not (value "0").
- **Bearbeitungsdauer** (in h/piece): Time in hours required to process a product at this production step.
- **Lieferantenindex** (if used): Index of the supplier from whom products are required to perform this production step ("0" if no supplier parts are required).
- **Verwendete Produktvariante des Lieferanten**: Index of the product variant required by the vendor to process the production step.
- **Anzahl der Lieferantenprodukte** je Produkt: Number of supplier products required for processing the production step.
- **Mindestbestand Lieferantenteile**: Minimum physical stock of required vendor parts in the warehouse of the production site.
- **Physischer Bestand Lieferantenteile**: Actual physical stock of required vendor parts in the warehouse at the production site.
- **Disponibler Bestand Lieferantenteile**: Disposable stock of required vendor parts in the warehouse at the production site.
- **Höchstbestand Lieferantenteile**: Maximum physical stock of required vendor parts in the warehouse at the production site.
- **Fehlerwahrscheinlichkeit** (in %): The probability that this production step will be processed incorrectly.

- **Nacharbeitsschwelle** (in %): The probability that a product that has been processed incorrectly at this production step can be reworked. The alternative to reworking is to scrap the product.
- **Prüfhäufigkeit** (in %): The probability that a product will be inspected for defects after machining at this production step.
- **Prüfdauer** (in h/piece): Time required to test a product at this production step.
- **Teilewert** (in €/piece): Monetary value of a product after this production step.
- **Prüfkosten** (in €/piece): Costs incurred in testing a product at this production step.
- **Nacharbeitskosten** (in €/piece): Costs incurred by reworking a product in this production step.
- **Ausschusskosten** (in €/piece): Costs incurred by scrapping a product after processing at this production step.
- **Zulieferteilewert** (in €/piece): Monetary value of a supplier product required for this production step.
- **Bearbeitungskosten** (in €/piece): Costs incurred by processing a product in this production step.

These parameters are necessary to adequately describe the network and parameterize the simulation model. By adhering to the structured format of all MS Excel files, it is ensured that the parameters are read into the simulation model in AnyLogic at the correct position. The parameterization of the network therefore does not require any changes to the simulation model itself and thus guarantees user-friendly operation.

4. Simulation Output: System of Indicators for Performance Assessment

The key figures are calculated at various production system levels: Key figures are calculated at production resource, production site and production network level. At the production resource level, key figures evaluate the performance of a production resource across all orders processed at this production resource. At the production site level, the performance of a site is mapped by summarizing key figures at the production resource level. The combination of the key figures of all production sites of a network enables the evaluation of the efficiency of the production network. The individual key figures are presented in the following in four categories. The levels at which they are available are also mentioned. Figure 7 provides an overview of this.

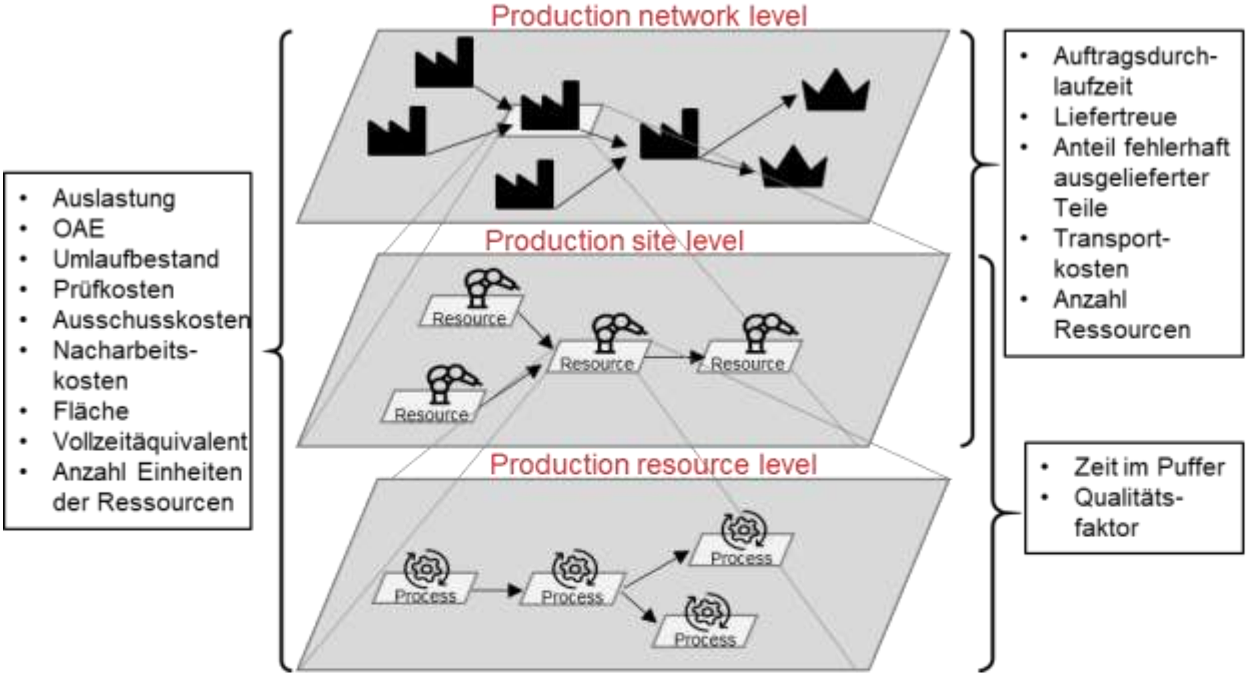

Figure 7: Key figures and their availability on production system levels

Performance Figures

The *average order throughput time (durchschnittliche Auftragsdurchlaufzeit)* is defined at production site and production network level. It indicates how much time elapses between the acceptance of an order and its delivery. At the site level, this means that the average order throughout time of all orders processed at a site up to the current time of the simulation run is calculated. It is irrelevant whether the order is a procurement order or a sales order. At the production network level, the average of all customer orders processed up to a certain point in time is calculated for all production locations in the network. The order throughput time of procurement orders is not directly included here, because this indirectly influences the order throughput time of customer orders and is thus also taken into account.

The *average time in buffer (durchschnittliche Zeit im Puffer)* is defined on the production resource and location level. At the production resource level, the average of the time in buffer of each production order previously processed at this production resource is formed and recorded as a key figure. At production site level, the time in buffer of all production resources of a site is totalled for each production order and the time in buffer of the final audit is added. The average time in buffer of the production site is then determined for all production orders.

The utilization (Auslastung) is defined at the production resource, production site and production network level. It indicates what portion of the time available after deducting losses from the shift model, plant holidays, or machine failures was used to process products up to a certain point in time. The key figure is calculated at production resource level as the sum of the processing time of all products already processed at this production resource divided by the time in which the production resource was ready for operation. At the production site level, utilization is defined as average of the utilizations at the production resource level of all production resources at the site. Utilization at the production network level is the average of the utilizations of all production sites. The key figure *percentage of order-free time (Anteil auftragsfreie Zeit)* is also defined at all three levels and is just the opposite of the utilization at all levels: $(1 - \text{utilization})$.

The Overall Asset Effectiveness (OAE) is also defined at all three production system levels: At the production resource level, the OAE indicates how much time, measured against the maximum time available up to a specified point in time, is spent at this production resource on processing products that have not been re-produced due to rejects. To do this, the machining time is multiplied by the number of products not machined due to scrap. The result is then divided by the maximum available time. The key figure at production site level is defined as the average of the OAEs of all production resources at the production site. The average of all OAEs of the production sites in the network represents the OAE at production network level.

Quality Figures

The average delivery reliability (durchschnittliche Liefertreue) is calculated at production site and production network level. At the production site level, it is defined as the percentage of customer and procurement orders delivered in time by the site out of the total number of orders delivered up to a defined point in time. The average delivery reliability of the network is calculated as the average of the delivery reliability of all delivered customer orders in the network up to a certain point in time.

The average proportion of faulty parts delivered (durchschnittliche Anzahl fehlerhafter Teile beim Kunden) is also defined at production site and network level. For a production site, this key figure specifies the proportion of parts delivered with errors in the total number of parts delivered at a site up to a specific point in time. Products that are delivered to customers or other production sites are taken into account. At the network level, the average proportion of faulty parts delivered is defined as the proportion of parts delivered incorrectly to a customer up to a certain point in time to the total number of parts delivered to customers.

The quality factor (Qualitätsfaktor) is calculated at production resource and production site level. It indicates the share of reworked products in the total number of processed products. At the production resource level, the key figure indicates the proportion of parts not reworked at this resource to the total number of products processed at this resource up to a specified point in time. At the production site level, the share of products that have never been reworked in the course of the production process to the total number of products processed up to a specified point in time is calculated.

Business Figures

The figure *work in process (Umlaufbestand)* is available at three levels: production resource level, production site level, and production network level. The key figure indicates the value of the parts that are in stock at different points in the network at a specific point in time. At the production resource level, the work in process is calculated as the sum of the part value of all products and all vendor parts that are in the respective buffer at this production resource at a specified point in time. For the work in process at production site level, the work in process of all production resources located at the site is totalled. In addition, the partial value of all products currently in the end product warehouse is added. The work in process at network level is the sum of the work in process of all production locations.

The inspection costs (Prüfkosten) are calculated at the production resource, production site and production network level. The product of the inspection costs per part and the number of parts that were inspected at a production resource up to a specified point in time specifies the key figure at production resource level. The inspection costs can be different for each product variant and production step. To calculate the key figure at site level, the inspection costs of all production resources at the site are totaled. In addition, the inspection costs for the goods receipt inspection and the final inspection of the site are added together. Both are calculated analogously to the inspection costs of a production resource by multiplying the number of inspected parts by the inspection costs of a part of this product variant. The inspection costs of the production network are defined as the sum of the inspection costs of all locations in the network.

The definition of *reject costs (Ausschusskosten)* follows the structure of the inspection costs and is also implemented on all three levels. At the production resource level, the scrap costs are calculated as the sum of the reject costs of all scrapped parts at this production resource up to a specified point in time. The reject costs are composed of the current part value of the product and the costs incurred by scrapping. The part value and the scrapping costs depend on the product variant and the current production step. The key figure at production site level is the sum of the reject costs of all production resources at the site and the reject costs incurred in goods receipt and in the final inspection up to the specified point in time. These are also calculated using the sum of the reject costs of all rejected parts, which represent the product of part value and scrapping costs. The reject costs on network level are defined as the sum of the reject costs of the production locations located in the network up to a fixed point in time.

Rework costs (Nacharbeitskosten) are calculated at the production resource, production site and production network level. The rework costs of a production resource are defined as the sum of all reworked parts multiplied by the rework costs of a part of the product variant in this production step. The rework costs at production site level are the sum of the rework costs of all production resources located at the site. Since neither the final inspection nor the goods receipt inspection can be reworked, no further reworking costs are incurred. The sum of the rework costs of all locations in the network forms the key figure rework costs at production network level.

Transport costs (Transportkosten) are defined at the production site and network level. They indicate which costs result from the transportation of goods between locations. At the production site level, the key figure is calculated by adding the costs for all orders sent from the production site to other production sites or customers up to a specified point in time. The transport costs are made up of twice the distance in kilometres between the start and destination multiplied by the average costs per kilometre. To calculate the key figure at network level, the transport costs of all production locations in the network are totalled.

Quantity and Structure Data

The number of resources (Anzahl der Ressourcen) is recorded at network and production site level. It indicates how many different resources are available at the production site or in the network. The key figure at network level is calculated as the sum of the production sites. *The number of units per resource (Anzahl der Einheiten einer Ressource)* is also defined at production resource level. It specifies at the production resource level how many units exist for each resource. At production site level, the key figure is calculated as the sum of the key figures at resource level for all resources. The key figure is calculated at the production network level as the sum of the key figures at the production site level.

The area (Fläche) is defined at all three levels. At the production resource level, it is calculated as the product of the area requirements of a unit of this resource and the number of units of this resource. The area of the production site is determined as the sum of the key figures at production resource level of all resources located at the site. The key figure is also determined at network level according to the same principle: it is thus calculated as the sum of all areas at site level.

The full-time equivalent (Vollzeitäquivalent) is also defined on all three levels and is calculated analogously to the area calculation. The key figure at resource level results from the product of the full-time equivalent for a unit of the resource and the number of units of this resource. At location and network level, the sum of the key figures of the lower level is then formed again.

I. List of Figures

Figure 1: Logo of the research project PlanQ 3
Figure 2: Entity Relationship Model of the simulation model 4
Figure 3: Structure of the MS Excel file *Transportmatrix* 7
Figure 4: Structure of the MS Excel file *Bestellinformationen* 8
Figure 5: Structure of the MS Excel-file *Bestand* 8
Figure 6: Structure of the MS Excel file *Simulationsbasis* 9
Figure 7: Key figures and their availability on production system levels 12