ARGESIM Benchmark C20 'Complex Production System' – Definition and Call

Sebastian Schreiber, Alexander Fay*

Helmut Schmidt University / University of the Federal Armed Forces Hamburg, Institute of Automation Technology, Holstenhofweg 85, 22043 Hamburg, Germany; 85, *alexander.fay@hsu-hh.de; ARGESIM-C20@hsu-hh.de

Abstract. ARGESIM provides several different benchmarks for modelling and simulation. Unfortunately, the only benchmark that can be used as a foundation for analyzing manufacturing control systems, ARGESIM C2 'Flexible Assembly System', does not cover today's requirements for comparing different simulation techniques and/or control algorithms regarding complexity and dynamics. Therefore, the authors propose a new benchmark description: ARGESIM Benchmark C20 'Complex Production System'. The benchmark is based on two dimensions, defining a total of twelve different scenarios that differ in their complexity and dynamic behavior.

Introduction

Today's manufacturing systems show an increasing level of complexity and a growing demand for more system flexibility. To test and compare new algorithms that tackle this challenge, properly defined 'reference systems' are required, especially in the research community of manufacturing control systems. Leitão [1] and Valckenaers et al. [2] underpin this prevalent lack of 'reference systems', i.e. physical systems (test-beds) and/or virtual systems (simulation models).

ARGESIM provides a set of different benchmarks with focus on modelling and simulation of several research fields. Unfortunately, the only benchmark that covers material flow or production system problems – C2 'Flexible Assembly System' (first proposed in July 1991) – does not cover today's complexity and dynamics, as already shown in [3]. Therefore, this benchmark seems to be less suitable for testing or comparing of current modelling and simulation techniques and/or software. For that reason, the authors developed an advanced reference system that covers today's challenges. The proposed system ARGESIM C20 'Complex Production System' is an extended and revised version of the reference system described in [4]. For further details regarding the development and the theoretical foundation of the system's structure and dynamics, we refer to [4] and [5].

For easier reading and better understanding, this benchmark description is divided into two parts. The first part describes the general problem definition, the second compiles all parameters and settings in detail within the Appendix.

The first part is structured according to the framework dimensions presented by Terzi et al. [6] (see also Figure 1). Section 1 describes the reference system regarding its static structure as a 'Production System Model', Section 2 is concerned with its dynamic behaviour as a 'Manufacturing Scenario'. In addition, the 'Measurement of Performance' for this system is described in Section 3, which is also used to formulate tasks for comparison. In Section 4, guidelines for publishing solutions based on this description are given. The Appendix is divided into five sections: (A) physical resources, (B) process plan, (C) system layout, (D) Operational Scenario, and (E) Plant Scenario.

1 Production System Model

The benchmark is based on a fixed system layout, as shown in Figure 2. The manufacturing system consists of a central transport system based on conveyors with an inner and an outer cycle, mono-directional traffic, and a constant conveyor speed. The processors are placed within 'processing areas' which are connected to the outer cycle, each with one input and one output port. Orders are represented as parts within the system, where each order consists of exactly one part. Pallets or either carriers can be used to move them through the system.

1.1 Physical resources

The system consists of five different types of work stations (WS). Each WS type is able to process a defined set of operations. The WS abilities vary from only one operation (WS type I to IV) to multiple operations (WS

SNE Simulation Notes Europe – Print ISSN 2305-9974 | Online ISSN 2306-0271
SNE 21(3-4), 2011, 181-190 | doi: 10.11128/sne.21.bn20.10097

type V). Some WS types have special abilities, like tool abrasion, or they differ in their age ('generation'). The types, quantities, and abilities of the WSs are listed in Appendix A (see Table 2). All WS types are subject to disruption.

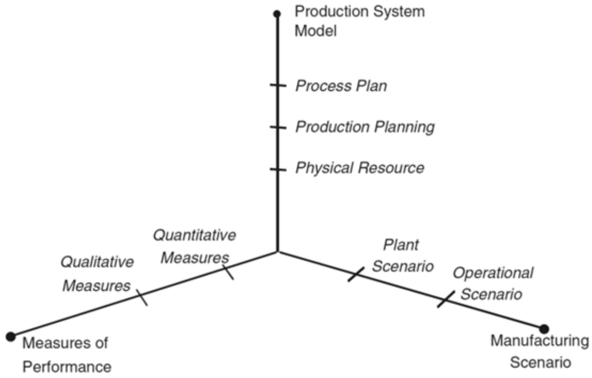


Figure 1. Framework dimensions for the description of the benchmark (taken from [6], Figure 2).

The system's general topology is shown in Figure 2, where processing area 0 represents system input and output. Here, parts are loaded and unloaded, and NOK ('not-okay') parts are discharged. The other three processing areas are divided into a buffering area and a manufacturing cell. Figure 4 and Figure 5 in Appendix C provide a detailed view of the layout including dimensioning.

The transport system is represented through conveyors and junctions. The amount of parts that can be carried by a conveyor depends on its length. In contrast, each junction can hold only one part at a time and represents a decision point. Junctions are represented as a dot within the figures. The sections of the central transport system are clustered into three groups (A to C) by their influence to the system in case of a disruption (see also Figure 2).

1.2 Production planning

Order books define the production planning. Each order book contains a fixed number of orders. The orders in an order book follow a probability distribution.

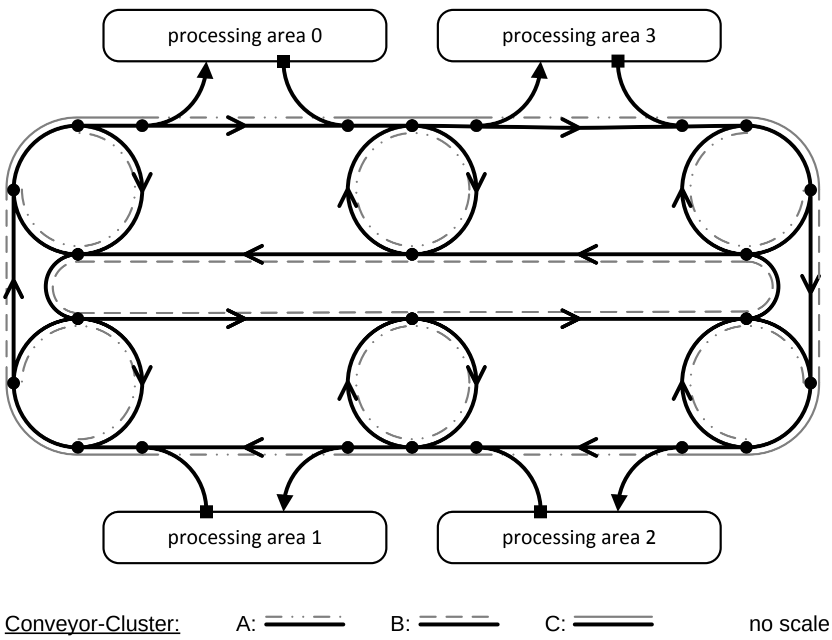


Figure 2. General layout of the proposed reference system with clustering of conveyors (based on [4], Figure 1(a)): without scale.

Thus, order books are similar regarding the distribution parameters and order book size (number of orders), but differ with respect to the individual orders. The general order book definition is summarized in Appendix D (see also Table 2). Each order is defined by its product type, earliest release date, due date, appearance date, and rush order flag. The appearance date is an important parameter for the planning horizon of an algorithm and will be discussed later, as well as the need for a rush order flag.

In [7], Law distinguishes between 'terminating' and 'nonterminating simulations'. Terminating simulations are characterized by a pre-defined point of termination, e.g. number of events, while nonterminating simulations have a continuous input and, in most cases, are characterized by some kind of steady-state behaviour. The indicators that can be analyzed during a simulation study differ for these different kinds of simulations, e.g. makespan is an indicator that is only defined for terminating simulations. Usually, nonterminating simulations can be described by an 'initialisation phase' and a 'steady-state phase' in which the system behaves nearly stable. For analyzing steady-state parameters, a steady-state phase of a length of three to six times the initialisation phase is considered necessary according to different authors' views [8].

The current specification of this benchmark describes a terminating simulation study that terminates when all orders of an order book are finished. For analyzing the system under nonterminating aspects, this order book size should be sufficiently large. Investigations during validation of this benchmark have shown that the initialisation phase for this system has a length of about 1,000 orders, depending on the implemented control algorithm.

1.3 Process plan

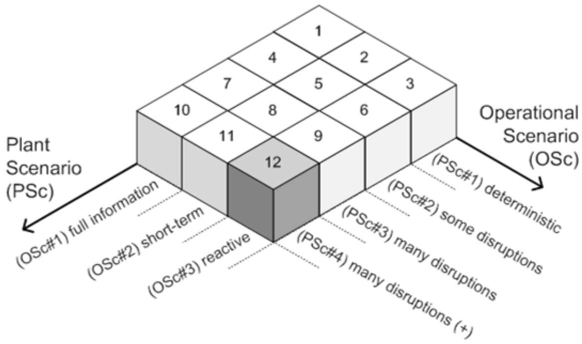
The system processes five different product types (A to E). The product type definitions are summarized in Appendix B (see Table 2). Product types differ in their complexity, especially with regard to the operations (O1 to O6) that need to be processed and the possible sequences of these operations. The operation O1 can be interpreted as a quality control process and may occur more than once. In addition, some operations introduce pre-process constraints to the process plan:

- **[MIN]** The successor of an operation cannot be processed before a given period of time has elapsed (e.g. drying process).
- **[MAX NOK]** The time between the end of one operation and the start of the next must not exceed a given period of time, otherwise, parts need to be discharged as NOK and need to be rescheduled (e.g. dry adhesive).
- **[MAX OK]** The predecessor operation can be repeated if the time between the end of an operation and the start of the next exceeds a given period of time. Thus, the part must not be discharged as NOK (e.g. heating/re-heating process).

2 Manufacturing Scenario

In [5], three Complexity Dimensions and their complexity levels are defined to describe the dynamic environment for a reference system: 'Operational Scenario' (OSc) with three different complexity levels, 'Plant Scenario' (PSc) with four different complexity levels, and 'Transport System Complexity Dimension' with three different complexity levels. To reduce the benchmark's complexity, only the first two dimensions are adopted for this proposed system. These are related to the framework dimension Manufacturing Scenario (according to [6]), more specifically to the Operational Scenario and Plant Scenario levels (see also Figure 1).

For a detailed description of the Complexity Dimensions see [5].



Figufre 3: Design of experiments described by the two dimensions 'Operational Scenario (OSc)' and 'Plant Scenario (PSc)' (based on [5], Figure 2).

The Complexity Dimensions proposed by the authors cover dynamic effects caused by order release, order specification, and processor downtime, and are all built upon an identical benchmark system's structure. They describe a total of twelve different scenarios, representing the experiment designs (Figure 3) to be investigated for comparison. First, the OSc defines the stochastic workload for the system. Second, the stochastic behaviour of the manufacturing system itself is described as the PSc.

In the following, a distinction between the different scenarios for each of the two dimensions is given, enumerated as OSc#(1..3) and PSc#(1..4). Each combination of these two dimensions defines a manufacturing scenario for the reference system. They are numbered consecutively from 1 to 12 for better comparison, as shown in Figure 3. As an example, the highlighted block in this figure describes Scenario 12 with no information ahead of time about the system's workload and the worst case regarding the internal dynamic behaviour, with many disruptions.

2.1 Operational Scenario (OSc)

Variations of the order mix are part of the OSc. The OSc describes 'appearance dates', i.e., the time at which individual orders appear on the planning horizon in relation to their individual release dates. An order book represents external effects only. Therefore, it should be generated independently from the control algorithm and used as an input for the control system. Some orders are generated with a rush order flag, which needs to be taken into account depending on the OSc level.

When a rush order is released, its due date is influenced (decreased) in a predefined way.

Three different OSc levels should be analysed: an environment with full information about all order release dates at the beginning of a simulation run and no occurrence of rush orders (OSc#1), a short-term environment with medium decrease of rush order due dates and a defined appearance date (OSc#2), and a purely reactive environment with an appearance date of zero (i.e., the orders appear at their release date; thus, the planning horizon equals zero), and a high decrease in rush order due dates (OSc#3). The parameters for the Operational Scenario are summarized in Appendix D (see Table 3).

2.2 Plant Scenario (PSc)

The PSc levelss differ in their complexity, i.e. the level of dynamic behaviour of the environment. They are described by 2-tupels MTBF/MTTR (mean time between failure/mean time to repair).

PSc#1 represents a fully deterministic behaviour with no occurrence of disruptions. PSc#2 and PSc#3 only differ in their MTBF, where the former represents behaviour with few disruptions, i.e. high means and low variances, while the latter represents behaviour with many disruptions, i.e. lower means and higher variances.

The fourth level PSc#4 represents the worst case within this reference system. It expands PSc#3 with the possibility of failures of some transport system elements. This introduces the need for rerouting to prevent a system blockade. For the exact distributions and parameters for MTBF/MTTR see Table 5 in Appendix E.

3 Measures of Performance (Tasks for Benchmark)

Many different indicators are reported in the literature to measure the performance of production systems, particularly in the research area of scheduling (e.g. [9]). For presentation of results, median and interquartile range IQR ($IQR = Q_{.75} - Q_{.25}$) should be used as robust statistics. The authors consider the following indicators as suitable performance criteria to compare different algorithms:

Criteria – Task A: Makespan. Median and IQR value of the makespan of the order books for all scenarios.

Criteria – Task B: Throughput Time. Median and IQR value of the throughput time of the orders, i.e. each from release date to sink.

Criteria – Task C: Tardiness. Based on the due dates, the number of tardy jobs and the (weighted) tardiness, summarized as median and IQR value for the order books. For this, the required individual weights for each product type are listed in Appendix B, Table 2 (10).

Criteria – Task D: Violated Constraints. Median, and IQR value of the number of [MAX NOK] and [MAX OK] parts generated during each simulation run.

All tasks should be performed with at least ten runs of simulation experiments and by use of several order books to analyze system behaviour with different sets of internal and external conditions.

4 Guidelines for Presenting Solutions

If questions or remarks come up during modelling, simulation, or interpretation of this reference system, please feel free to contact the authors or have a look at the ARGESIM homepage, where you can find comprehensive information and three order books in CSV format as a reference for comparison.

Solutions (to be sent bx email to *sne@argesim.org, office@sne-journal.org*) would ideally be accompanied by detailed documentation and source code of the simulation model and/or the control algorithm. Such information would be made available on the ARGESIM server under the current software license terms. The solution should use than four to six pages SNE and cover the following aspects (with general layout as technical notes, not as 2-page layout for 'short' comparison solutions..

Authors are asked to give an overview of the

- **Simulator** and its capabilities used, esp. with regard to analysis of simulation runs,
- **Modelling** of the implemented system and modelling techniques used, and
- **Control Algorithm** used for controlling this system and its location with regard to the simulator (embedded/external).

For presenting the results of their solutions with respect to the mentioned criteria, we encourage authors to use tables and figures as appropriate. The set of the four tasks described in Section 3 can only be regarded as an initial set for analyzing the system’s behaviour. Authors should feel free to report additional indicators to analyze different effects that they regard as suitable for comparison.

References

[1] P. Leitão. *Agent-based distributed manufacturing control: A state-of-the-art survey*. Engineering Applications of Artificial Intelligence, vol. 22 (7), pp. 979–91, 2009.

[2] P. Valckenaers, et al., *A benchmarking service for the manufacturing control research community*. Journal of Intelligent Manufacturing, vol. 17 (6), pp. 667–79, 2006.

[3] S. Schreiber, M. Barth, R. Nicolaus, M. Schleburg, A. Fay. *Event-based and State-Automata-based Modelling of FMS - A Comparative Case Study of Flexsim, Dymola and Matlab/Stateflow based on the ARGESIM Benchmark C2*. Simulation News Europe, vol. 20 (1), pp. 38–44, 2010.

[4] S. Schreiber, A. Fay. *A reference system for the benchmarking of manufacturing control systems*. Proc. of the 16th IEEE-ETFA Conference, 2011.

[5] S. Schreiber, A. Fay. *Requirements for the benchmarking of decentralized manufacturing control systems*. Proc. of the 16th IEEE-ETFA Conference, 2011.

[6] S. Terzi, S. Cavalieri, M. Macchi, M. Garetti, H. Panetto. *Development of a Reference Architecture for Benchmarking Service of Manufacturing Systems. 7th IFAC workshop on Intell. manuf. systems*, pp. 193–200, 2003.

[7] A. M. Law. *Simulation Modeling and Analysis.* 4th ed. Boston: McGraw-Hill, 2007.

[8] O. A. Joseph, R. Sridharan. *Evaluation of routing flexibility of a flexible manufacturing system using simulation modelling and analysis.* The International Journal of Advanced Manufacturing Technology, vol. 56 (1-4), pp. 273–289, 2011.

[9] V. Vinod, R. Sridharan. *Simulation modeling and analysis of due-date assignment methods and scheduling decision rules in a dynamic job shop production system.* International Journal of Production Economics, vol. 129 (1), pp. 127–46, 2011.

Received: August 30, 2011
Revised: October 16, 2011
Accepted: November 15, 2011

WS Type (1)	WS no. (gen.) (2)	Operation Capability (3)	Product Type/ Process Time [s] (4)	Processing Area (5)	Additional Remarks (6)
I	I.1, I.2	O1	A-E / 20	1.1, 1.4	
	I.3, I.4			2.1, 2.5	
	I.5, I.6			3.1, 3.4	
II	II.1, II.2 (1st)	O2	A-B / 30	1.2, 1.3	WS instances of the later generation can handle more product types and have shorter process time
	II.3 (2nd)	O2	A-D / 27	1.5	
	II.4 (3rd)	O2	A-E / 24	1.6	
III	III.1, III.2, III.3	O3	B / 40 C-D / 44 E / 50	2.2, 2.3, 2.4	tool replacement after 2,500 s of processing time, takes 120 s
IV	IV.1, IV.2	O6	E / 120	3.2, 3.3	
V	V.1, V.2	O4, O5	C-D / 60 E / 90	2.6, 2.7	setup time of 300 s for switching operation
	V.3, V.4			3.5, 3.6	

Table 1: Technical characteristics of the system and work stations (based on [4], Table 1).

APPENDIX A - Physical Resources

Appendix A lists all detailed definitions and parameters for the physical resources of the benchmark system. The layout and its dimensions are part of Appendix C. The conveyor speed is 1 m/s and parts have a length of 1 meter. Thus, a conveyor that is 10 meters long can transport a maximum of 10 parts simultaneously.

Definition of workstations.

The technical characteristics of the system and definitions of work stations are summarized in Table 2, where columns list:

(1) the five different WS types,

(2) the instances of each WS type,

(3) operations for each of the WS instance,

(4) product types and the required process times for each WS type (the row of WS type II is subdivided into three different generations),

(5) location of each WS within the system, according to the enumeration of Figure 5,

(6) and special abilities of some WS types. During tool change or operation change, parts are not allowed to stay inside the WS.

Disruptions of workstations

Instances of WS type I do not cause any damage to the part and thus the process can be continued at the end of a disruption. All other WS types damage the part inside in case of a disruption, so that the part is classified as NOK and needs to be processed accordingly. The parameters for the disruption profiles are listed in Appendix D, Table 5.

(1) Product Type	A	B	C	D	E	Remarks
(2) Earliest Release Date	exponential distribution with parameter λ = 15 s/pc.					describes the inter-arrival time of orders
(3) Due Date	a = 13 b = 20	a = 10 b = 12	a = 9 b = 26	a = 7 b = 10	a = 6 b = 10	RWK method with parameters *a* and *b*
(4) Appearance Date	depends on Operation Scenario, see Table 3					
(5) Rush Order Flag	0 %	10 %	20 %	20 %	20 %	2-level distribution (rush order %), each
(6) Distribution of Product Types	40 %	25 %	10 %	10 %	15 %	5-level distribution (in total)
(7) Operations Needed	O1, O2	O1, O2, O3	O1, O2, O3, O4	O1, O2, O3, O5	O1, O2, O3, O5, O6	
(8) Sequence of Operations (Process Plan)	O2 → O1	O2 → O1 → O3 → O1	O2 → O1 → O4 → O3 → O1	O2 → O1 → O5 → O3 → O1	O2 → O1 → O6 → O5 → O3 → O1	alternative process plans for product types B to E
		O3 → O1 → O2 → O1	O4 → O3 → O1 → O2 → O1	O5 → O3 → O1 → O2 → O1	O6 → O5 → O3 → O1 → O2 → O1	
(9) Pre-process Time Constraints [s]	none	none		600	600	O5 → [*min*] → O3
			360			O4→ [*max NOK*]→ O3
					300	O6→ [*max OK*]→ O5
(10) Product Weight	0.40	.90	1.42	1.42	2.21	for weighted tardiness

Table 2: Product type definition: specifies order book and sequences of operation (based on [4], Table 2).

Appendix B - Process Plan

Appendix B lists detailed definitions and parameters for process plan and products. These definitions also impact the settings for order books for this benchmark, which is part of Appendix D.

Definition of products.

Each product type differs in its complexity as shown in Table 2, where each order is defined by (1) a product type, (2) an earliest release date, (3) a due date, (4) an appearance date, and (5) a rush order flag. In addition, the (7) operations that need to be processed and (8) possible sequences of these operations are listed. Some operations include pre-process time constraints, as shown in column (9):

- **[MIN]**: between O5 and O3,
- **[MAX NOK]:** between O4 and O3, and
- **[MAX OK]**: between O6 and O5.

Due date parameters

The due date for each order is defined according to the 'random work content (RWK) method' provided in [9], which calculates due dates depending on the arrival time of an order, its total processing time, and a uniform distributed factor, as shown in the following equation:

$$D_i = A_i + U(a,b)\sum_{j=1}^{n_i} p_{ij}$$

In this equation (see [9], p. 131):

- D_i represents the due date of order i,
- A_i the arrival time of order i in the shop,
- p_{ij} the processing time of operation j of order i,
- n_i the number of operation in order i, and
- a and b are parameters for the uniform distribution $U(a, b)$.

Because of the unequal ratios of processing time to necessary transportation time for different product types, these distribution parameters a and b differ for the product types (see Table 2 (3))

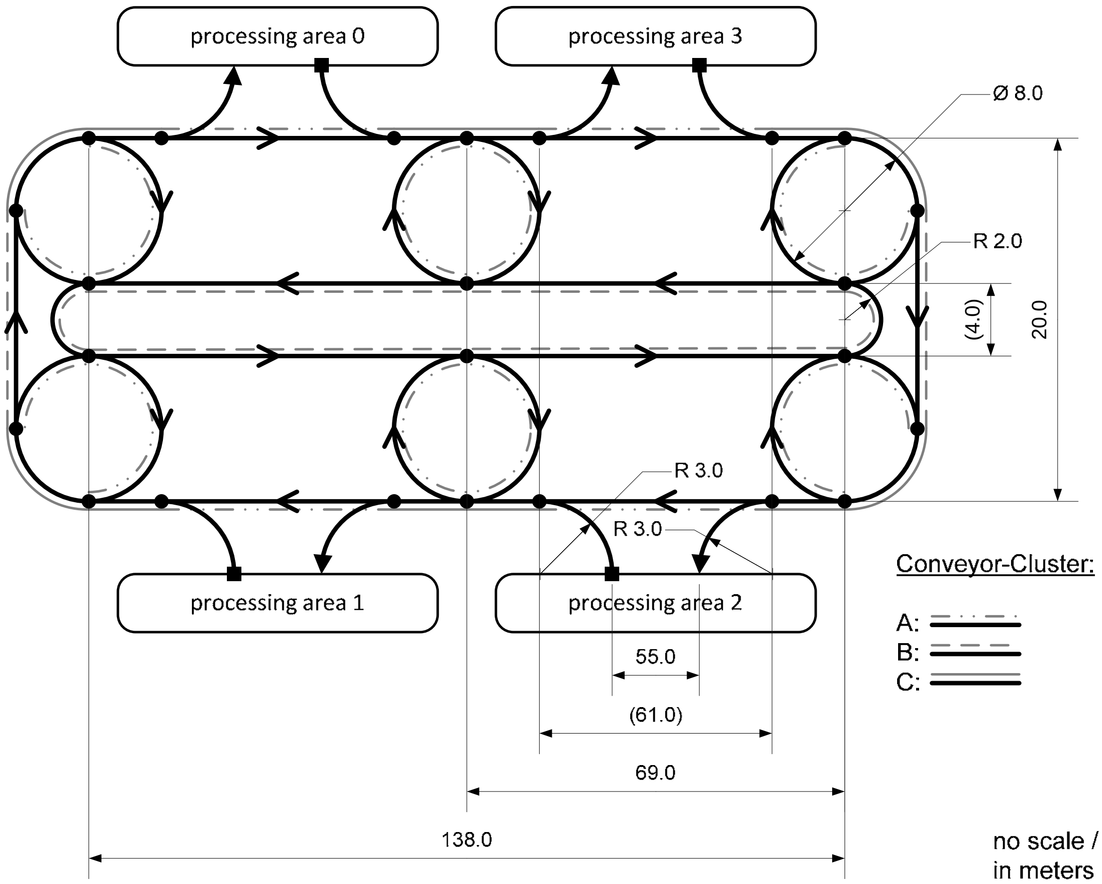


Figure 4. Layout of the reference system (based on [4], Figure 1(a)): dimensions are in meters and without scale.

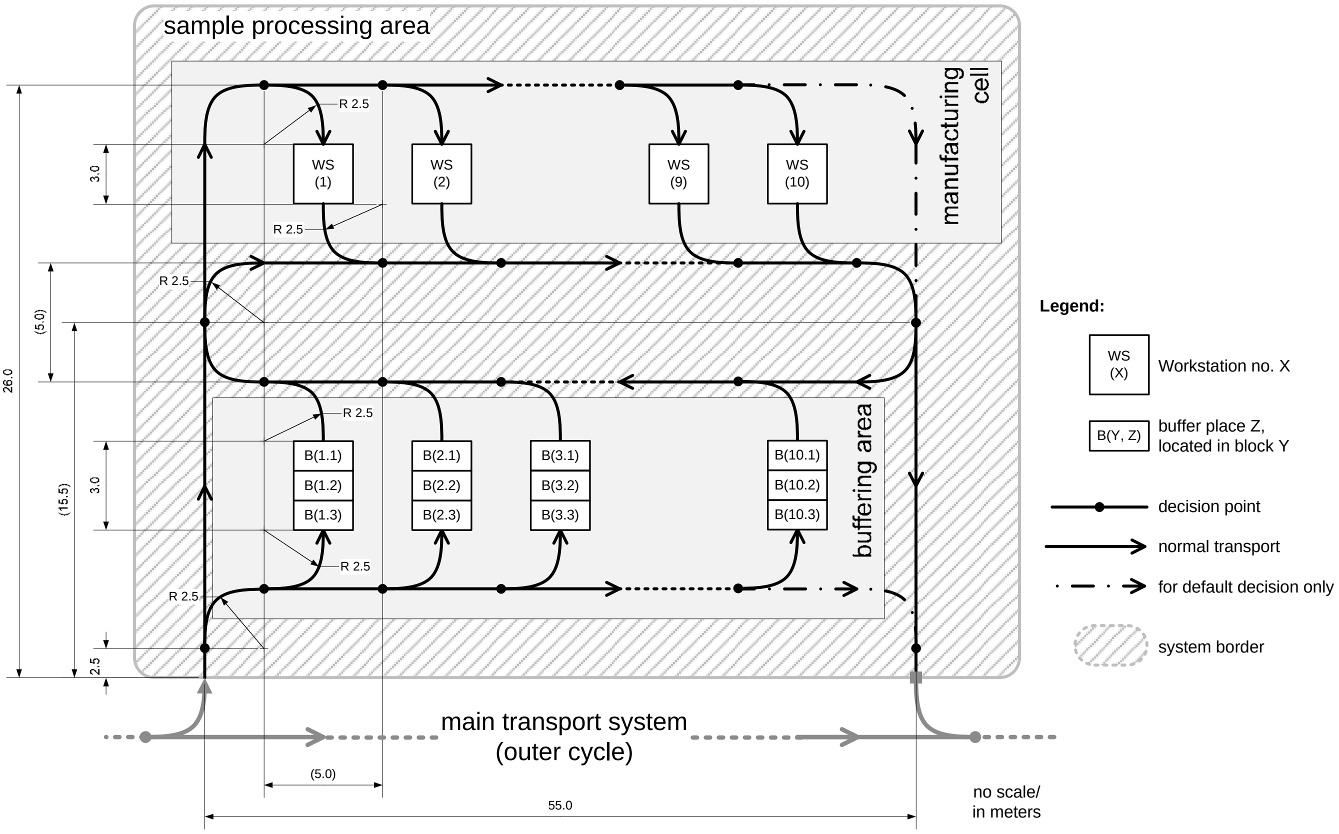


Figure 5. Layout of a sample processing area (based on [4], Figure 1(b)): dimensions are in meters and without scale.

Appendix C - System Layout

The dimensions for the system layout are given in Figure 4 and Figure 5, given in meters. The system layout is designed in a way that it can be modularly extended (a) within a processing area or (b) through the main transport system.

A part which enters a processing area can either move to one of the buffer places or bypass the buffers and move directly to an idle WS. Buffers are used as local processing buffers for parts either waiting for processing or waiting due to pre-process conditions.

The clustering in Figure 4 is related to the whole track, from one dot to the next one.If a modeller decided to model these elements by use of several objects, the probabilities for disruption would need to be divided too.

	OSc#1 (D.1.1)	OSc#2 (D.1.2)	OSc#3 (D.1.3)	Remarks
(1) appearance date [s]	= simulation start	= release date – (offset + ϕ(α, β))	= release date	α = 29.4, β = 1.0, offset = 90.0
(2) rush orders/due date [s]	no decrease of due gap	decrease of due gap by 10%	decrease of due gap by 20%	due gap = due date – release date

Table 3. Specifications for Operational Scenario: due date based on RWK method (see Table 2 (3)) and appearance date based on gamma distribution φ(α, β) with $\mu = \alpha\,\beta$ and $\sigma = \alpha\,\beta^2$ and [α] = [β] = [offset] = s.

ID (1)	Product type (2)	Inter-arrival time (3)	Release date (4)	Due date OSc#1 (5)	Due date OSc#2 (6)	Due date OSc#3 (7)	App. date OSc#1 (8)	App. date OSc#2 (9)	App. date OSc#3 (10)	Rush order flag (11)
1	1	7.8	7.8	822.5	822.5	822.5	0	0	7.8	0
2	2	39.9	47.7	1525.5	1525.5	1525.5	0	0	47.7	0
…										
4999	4	9.9	78959.9	80886.6	80886.6	80886.6	0	78836.8	78959.9	0
5000	5	8	78967.9	81541.2	81283.8	81026.5	0	78844.8	78967.9	1

Table 4. Example of an order book following the requirements for Operational Scenarios OSc#1, OSc#2, and OSc#3.

Appendix D - Operational Scenario

The composition of an order book depends on the product types corresponding to a 5-level distribution defined in Table 2 (6) and a size of 5,000 orders. The parameters for the three Operational Scenario levels are listed in Table 3.

Appearance date

The appearance date is defined in Table 3 (1). For OSc#2, the appearance date is described by a gamma distributed factor with mean of 119.4 s, which is the theoretical average process time of an order. For the other scenarios it either equals zero (simulation start) or the order's release date.

Rush orders

A rush order decreases its due date, by a defined percentage (see Table 3 (2)) when reaching its release date.

Therefore, a percentage of the 'due gap' is used as the starting value.

Example for an order book

An example of an order book that covers the requirements listed above is shown in Table 4, where (1) lists individual order IDs and (2) lists the corresponding product type of this order. The release date (4) is based on the inter-arrival time (3). (5) to (7) list the due dates depending on the Operational Scenario.

The values are either identical if the Boolean rush order flag (11) is false, or decrease, as described above. The appearance date for each OSc level is listed in (8) to (10), where (8) is zero for all orders, i.e. full information at beginning, and (10) is equivalent with the corresponding release date (4) for each order.

	PSc#1 (D.2.1)	PSc#2 (D.2.2)	PSc#3 (D.2.3)	PSc#4 (D.2.4)	MTTR
WS type I	none	α = 4.450, β = 0.100	α = 1.115, β = 0.200		160
WS type II (1st gen.)		α = 2.400, β = 0.125	α = 0.742, β = 0.225		135
WS type II (2nd gen.)		α = 3.750, β = 0.100	α = 0.940, β = 0.200		135
WS type II (3rd gen.)		α = 15.000, β = 0.050	α = 1.667, β = 0.150		135
WS type III		α = 6.120, β = 0.100	α = 1.530, β = 0.200		220
WS type IV		α = 8.340, β = 0.100	α = 2.085, β = 0.200		365
WS type V		α = 10.140, β = 0.100	α = 2.535, β = 0.100		300
Conveyor	none			α = 2.000, β = 0.500	600

Table 5. Plant scenario (PSc) specifications of MTBF for workstations and conveyors based on gamma distribution $\varphi(\alpha, \beta)$ with $\mu = \alpha\,\beta$ and $\sigma = \alpha\,\beta^2$ and $[\alpha] = [\beta] = h$, and a fix MTTR with [MTTR] = s.

APPENDIX E Plant Scenario

The four PSc levels are listed in Table 5 for the different WS types and conveyors, where α and β represent the parameters for gamma distribution. MTTR should be modelled as a constant time.

Disruptions for conveyors only occur during PSc#4 with an average frequency of one disruption per hour, and with only one transport system element affected at the same time. Because of the different influence of an element on system performance in case of a disruption, clustering of these elements is used, as already described above.

The selection of the next element to disrupt is done in two phases: (1) the conveyor cluster, based on a 3-level distribution with {A, B, C} = {.50, .35, .15} is selected, and (2) one of the elements within this cluster is chosen, based on uniform distribution. Following this selection process should provide a nearly similar disruption profile through the simulation runs.