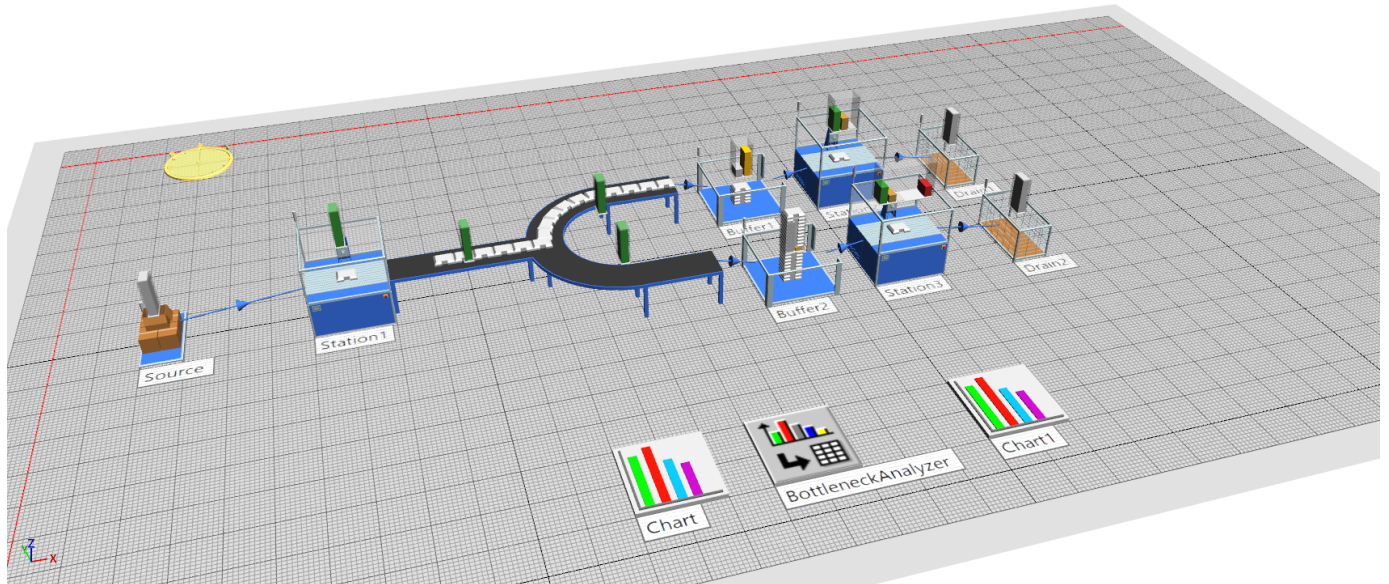




CHALMERS
UNIVERSITY OF TECHNOLOGY



Life-long learning materials enabling the growth of Digital Twin competences

Master's thesis in Production Engineering
Alalvanan Lingam Ashok Kumar
Rahul Rao Jagadeeswar

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS 2023

Life-long learning materials enabling the growth of Digital Twin competencies

An IMS Master Thesis

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Alalvanan Lingam Ashok Kumar
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Abstract

In recent times, Digital Twin and Discrete Event Simulations are some of the promising technologies in enabling industry 4.0. Since the developments of these technologies are recent, their definitions and representations vary. Accordingly, there is a need to develop learning materials for these concepts to better help users seeking to develop or improve in these areas academically and professionally. The thesis focuses on the main goal, which is the creation of learning materials with an emphasis on lifelong learning. For this, the learning materials are developed on the guidelines of constructive alignment and Bloom's taxonomy to better facilitate lifelong learning among the users. The developed learning materials are also developed around real-world problems such that the content is relatable and relevant.

In the next phase, the evaluation of these learning materials is done. This is done by procuring feedback from the focus groups stakeholders, industry-level simulation experts, self-analysis and reflection; the pilot study undergoes revision and necessary changes are made. The procured revised learning material hopes to serve as a guide for users seeking to develop learning materials to improve competence in the field of Digital Twin and Discrete Event Simulation.

Keywords: Bloom's Taxonomy, Constructive alignment, Digital Twin, Discrete event simulation, Lifelong learning material.

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Alalvanan Lingam Ashok Kumar & Rahul Rao Jagadesswar
Gothenburg, February 2023

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

ARD	Action Research Design
DES	Discreet Event Simulation
DT	Digital Twin
LOs	Learning Objectives

Contents

List of Acronyms	ix
List of Figures	xv
List of Tables	xix
1 Introduction	1
1.1 Aim	2
1.2 Objectives	2
1.3 Tasks	3
1.4 Research questions	3
1.5 Delimitations	3
2 Theory	5
2.1 Digital Twin	5
2.2 DES and its integration with Digital Twin	8
2.3 Lifelong learning materials	9
2.4 Simulation education	10
2.4.1 Why software benchmarking?	10
2.4.2 Constructive alignment	11
2.4.3 Blooms taxonomy	12
3 Methodology	15
3.1 Literature Study	15
3.1.1 Choice of database	15
3.1.2 Keywords and initial work	16
3.1.3 Inclusion and exclusion criteria	17
3.2 Case Study	18
3.2.1 Case study 1	18
3.2.2 Case study 2	18
3.3 ARD Methods	19
3.3.1 Extraction of Learning Objectives from the existing course	19
3.3.2 Understanding	20
3.3.2.1 New and updated Learning Objectives	20
3.3.3 Planning	20
3.3.3.1 Flexibility	20
3.3.3.2 Usability	21

3.3.3.3	Robustness	21
3.3.3.4	Portability	22
3.3.3.5	Popularity	23
3.3.3.6	Learning materials used in institutions	23
3.3.3.7	Learning materials used in industries	23
3.3.4	Acting	24
3.3.5	Observing	24
3.3.6	Reflecting	24
4	Results	25
4.1	Designing the learning objectives	25
4.2	Designing the learning materials	26
4.2.1	Pilot Study	27
4.3	Evaluating the learning materials	31
4.3.1	Results on learning materials used in institutions	31
4.3.2	Results on learning materials used in industries	33
4.3.3	Redesigning the learning materials	36
4.4	Results on benchmarking categories	42
4.4.1	Flexibility	42
4.4.2	Usability	43
4.4.3	Robustness	44
4.4.4	Portability	44
4.4.5	Popularity	45
5	Discussion	47
5.1	Discussing and answering Research Questions	48
5.2	Discussion on the results of Learning Objectives	48
5.3	Discussion on the results of development and evaluation of learning materials	49
5.3.1	Discussion on benchmarking categories	49
5.3.1.1	Flexibility	49
5.3.1.2	Usability	49
5.3.1.3	Robustness	50
5.3.1.4	Portability	50
5.3.1.5	Popularity	50
5.3.1.6	Overall benchmarking discussion	50
5.3.2	Discussion on the result of pilot study	51
5.3.2.1	Learning materials used in institutions	51
5.3.2.2	Discussion on the learning materials used in industries	51
5.3.3	Discussion on the revised study material	52
5.4	Discussion on the methodology	52
6	Conclusion	53
6.1	Future work	54
A	Revised Lab 1 material	I

B	Revised Lab 2 material	XV
C	Revised Lab 3 material	XXXI

List of Figures

2.1	Technologies involved in smart manufacturing referred from (Sahoo and Lo, 2022)	6
2.2	Function of Digital Twin referred from Semeraro et al., 2023	7
2.3	Maturity Levels of Digital Twin referred from Madni et al., 2019	8
2.4	Grapical description of constructive alignment. Figure referred from https://www.ru.nl/en/lecturers/designing-education/integrating-learning-objectives	11
2.5	Grapical description of bloom's taxonomy. Figure refereed from https://citt.ufl.edu/resources/the-learning-process/designing-the-learning-experience/blooms-taxonomy/	12
3.1	The flow of methodology	15
4.1	Learning objectives developed with the actions words from Bloom's Taxonomy	27
4.2	Introduction to the lab materials	28
4.3	Hints/Instructions that's been provided in the form of an image to visualise and learn	28
4.4	Tasks that have been provided after the instructions to improve the knowledge of the user	29
4.5	Subtasks that help in developing additional knowledge	30
4.6	Questions formulated after the tasks to test the user if they have gained the required learning outcome	30
4.7	Feedback on the learning outcomes of the course Simulation of Production Systems	32
4.8	Feedback on how the students have reached the learning expectations of the course Simulation of Production Systems	32
4.9	Feedback on the assessment of the course Simulation of Production Systems	33
4.10	Improve in directions	37
4.11	Creating MU in UserObjectes "TableTop and Tableleg"	38
4.12	Directions on how to create MU parts in UserObjects	38
4.13	Extra task on getting familiarized with workers.	39
4.14	A recap of learning objectives used in the previous lab	40
4.15	An introduction to what these extra tasks are for.	40
4.16	The complete overlook of Task 2 in Lab 3 that was developed on the idea of how to start the final project.	41
4.17	Creating conveyor on Plantsim	42

4.18	Comparison table of the DES software vs Portability attributes . . .	45
4.19	Scoring distribution list referred from (Dias et al., 2016)	45
4.20	Comparison table of the DES software vs Portability attributes re- ferred from (Dias et al., 2016)	46
5.1	Information flow	47
A.1	Revised Lab1 Page 1	II
A.2	Revised Lab1 Page 2	III
A.3	Revised Lab1 Page 3	IV
A.4	Revised Lab1 Page 4	V
A.5	Revised Lab1 Page 5	VI
A.6	Revised Lab1 Page 6	VII
A.7	Revised Lab1 Page 7	VIII
A.8	Revised Lab1 Page 8	IX
A.9	Revised Lab1 Page 9	X
A.10	Revised Lab1 Page 10	XI
A.11	Revised Lab1 Page 11	XII
A.12	Revised Lab1 Page 12	XIII
A.13	Revised Lab1 Page 13	XIV
B.1	Revised Lab2 Page 1	XVI
B.2	Revised Lab2 Page 2	XVII
B.3	Revised Lab2 Page 3	XVIII
B.4	Revised Lab2 Page 4	XIX
B.5	Revised Lab2 Page 5	XX
B.6	Revised Lab2 Page 6	XXI
B.7	Revised Lab2 Page 7	XXII
B.8	Revised Lab2 Page 8	XXIII
B.9	Revised Lab2 Page 9	XXIV
B.10	Revised Lab2 Page 10	XXV
B.11	Revised Lab2 Page 11	XXVI
B.12	Revised Lab2 Page 12	XXVII
B.13	Revised Lab2 page 13	XXVIII
B.14	Revised Lab2 Page 14	XXIX
B.15	Revised Lab2 Page 15	XXX
C.1	Revised Lab3 Page 1	XXXII
C.2	Revised Lab3 Page 2	XXXIII
C.3	Revised Lab3 Page 3	XXXIV
C.4	Revised Lab3 Page 4	XXXV
C.5	Revised Lab3 Page 5	XXXVI
C.6	Revised Lab3 Page 6	XXXVII
C.7	Revised Lab3 Page 7	XXXVIII
C.8	Revised Lab3 Page 8	XXXIX
C.9	Revised Lab3 Page 9	XL
C.10	Revised Lab3 Page 10	XLI

C.11 Revised Lab3 Page 11	XLII
C.12 Revised Lab3 Page 12	XLIII

List of Tables

2.1	Action words used for Bloom’s taxonomy for each stage. The words were referred from { https://www.miamioh.edu/cte/assessment/writing-student-learning-outcomes/blooms-action-verbs/index.html .}	14
3.1	Keywords used in the Initial study	16
3.2	Keywords used in the Initial study	16
3.3	Exclusion/Inclusion criteria	18
3.4	Benchmarking categories	20
4.1	List of learning objectives	26
4.2	Feedback for usability table 1	43
4.3	Feedback for usability table 2	43
4.4	Feedback for usability table 3	44

1

Introduction

With the upward trend of smart manufacturing and digitalization, Digital Twin being a core part of it has added value in making the production industry more efficient (Yao et al., 2023). As Digital Twin is an umbrella term for a lot of digitalization and digital technologies, this research will focus on Discrete Event Simulation software (DES). The use of simulation improves planning and optimises the industries (Kritzinger et al., 2018). People need to learn what Digital Twin is and how to use them to enable the transition towards Digital Twin. Humans as an organism display a significant level of range in their cognitive abilities, which differentiates humans from other living organisms. The ability to develop and learn new languages, solve a variety of issues by cooperating and contributing in groups, plan ahead and the capability to show empathy to their species (Holte and Ohmann, 2021). Out of all the abilities displayed by humans, learning is the most important as it is a continuous and lifelong ability. There is no singular accepted definition of learning, as it varies depending on the context in which it is being used. However, to align with the theme of the research, ‘the experience of learning’ according to (Mahar and Harford, 2004) is defined as *“Through learning we recreate ourselves. Through learning, we become able to do something we were never able to do. Through learning, we perceive the world and our relationship to it. Through learning, we extend our capacity to create and to be part of the generative process of life. There is within each one of us a deep hunger for this type of learning”*.

According to (De Houwer et al., 2013) learning has been advocated in all fields. Even authoritative or influential books have a certain amount of learning in them. The base concept of learning is not only just memorizing the concept but it is understanding the concept, absorbing the information and trying to implement it in one way or the other. Learning builds future problem-solving and improves awareness and creative behaviours (Alt et al., 2023). But learning doesn’t change the behaviour immediately, learning about something and its effects and behaviour can occur after a certain amount of time and that time is subjective to the person, the way the person learnt and the learning material used (De Houwer et al., 2013).

The problem formulation for this research focuses on developing a specific type of learning material. By performing an initial study on searching for articles on topics such as lifelong learning materials and Digital Twin competencies, the results obtained were not substantial enough to draw a conclusion from. Instead, the articles

gave results on materials that promoted learning and not lifelong learning. The initial problem formulation slightly changed towards using elements and guidelines that promoted lifelong learning.

This project is a department project of the Industrial and Material Science department at Chalmers University of technology. The project looks into how with the help of lifelong learning materials, Digital Twin competence can be improved. It starts with looking into developing three learning materials for the course "Simulation in Production System (MPR271)" which is handled by Dr Anders Skoogh. Throughout the project, various topics like Bloom's taxonomy, benchmarking of DES software, and comparison of learning materials used in institutions and industries will be discussed.

The key contribution will be with the discussed topics, it will give the project the needed information on how to improve the Digital Twin competence. The data used for this project will be from research articles and a major part will be from action-oriented research. This method is used to collect data because as this project involves developing learning material for students and having a focus group with a Simulation engineer from an industry. This gives the researcher a good opportunity to talk to the students and gather real-time feedback and make good interpretations of learning materials and on how to improve Digital Twin competence. It also gives feedback on the benchmarking of DES software as well. To validate this action-oriented research, research articles have been used.

1.1 Aim

This thesis aims to improve competence in the field of Digital Twin by developing correlated learning material that enables lifelong learning. This will be supported by choosing the right DES software, establishing objectives and using pedagogical frameworks to create and develop the learning material. This thesis showcases the continuous improvement loop, the learning materials ensure longevity and stay relevant to the current topics and concepts. This overall process contributes to improving the competence in the field of Digital Twin and DES.

1.2 Objectives

- Develop requirement-specific learning objectives on the guidelines of Bloom's taxonomy.
- Formulate a pedagogic design for the learning material on the guidelines of constructive alignment.
- Evaluating and improving the learning materials to align with the theme of lifelong learning.

1.3 Tasks

- Identify the limitations of AutoMod that can be addressed by Tecnomatix Plant Sim by Siemens relevant to Digital Twin.
- Revisit, reframe and establish the learning objectives of the course if required.
- Design tutorial tasks and problems that comply with the learning objectives of the course and also real-world problems.
- Design and develop a working simulation model that can be used as a foundation to formulate the final project.

1.4 Research questions

To stay relevant to the topic two research questions have been framed to govern the research on the right path. These two questions prepared will be answered throughout the project. As the objectives are developed based on the research question. Thus answering the objectives directly answers the research questions which will be mentioned in the Conclusion chapter 6.

- *What are the guidelines for designing and developing effective objectives and learning materials in the area of Digital Twin ?*
- *What are the specific experiences and aids that enrich learners seeking competence in the field of Digital Twin ?*

1.5 Delimitations

- The benchmarking performed is only done between Automod and plant sim, this serves as a limitation as there is other simulation software that could be benchmarked and used.
- The stations and production process are simulated virtually and real-life parameters such as weather, human factors and ergonomics will not be considered.
- The results could be well expanded by including the acceptability and difficulty faced by the users during the pedagogical changes and the overall feedback for multiple iterations.

2

Theory

2.1 Digital Twin

Manufacturing has come a long way. From the stone age to the modern manufacturing era. The ripples created by manufacturing have shifted the consumer's behaviour to a cleaner and greener movement that has led the manufacturing firms to be environmentally conscious in their ways of producing and delivering products to the consumers. Under the paradigm of manufacturing, smart manufacturing is a concept that is defined as an integration of collaborative manufacturing systems that have been created to satisfy the needs of customers, factories and supply chains in real-time ("Smart Manufacturing and smart industry in context", 2022). The realization of usage of the technological advancements in manufacturing such as Digital Twin, cloud technology, automation, artificial intelligence and big data have led to drastic development in the field of smart manufacturing (Shao et al., 2023). On a global scale, this has led to various smart manufacturing strategies being adopted by different countries for example. In Germany, the country has adopted an Industry 4.0 strategy where the focus is predominantly on the computerization of the manufacturing processes by integrating the cyber-physical into the manufacturing systems to procure and transfer real-time data. In Japan, their approach is to create an industrial value chain by improving collaboration and competitive areas between companies, organizations and individuals. (Sahoo and Lo, 2022)

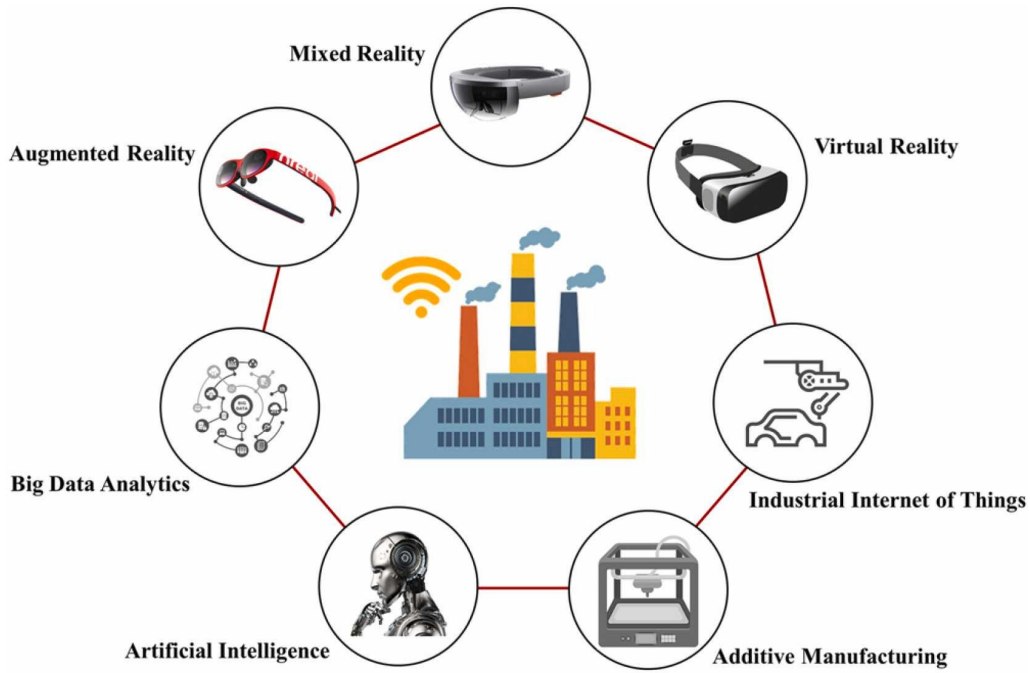


Figure 2.1: Technologies involved in smart manufacturing referred from (Sahoo and Lo, 2022)

To enable cyber-physical integration in manufacturing, one of the front-runners to realize this integration is Digital Twin. According to (Mullen et al., 2022) a general definition of the Digital Twin is defined as “a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity”. However to fit in the scope of modelling and simulation theme of this research, according to (Shao and Kibira, 2018) Digital Twin is defined as “an integrated model that represents, connects, and synchronizes a part of or the whole physical manufacturing system or process, enabled by historical and real-time data from the physical system or process”. They are used in various industries such as production, health, aerospace etc. Where usually used for measurement and analysis of the physical counterparts. Due to their potential in manufacturing and production industries, they enable the users to observe, predict and optimize the systems in which they are used (Shao et al., 2023). Figure 2.3 depicts the working of Digital Twin and their role in providing suggestive action for the physical counterpart.

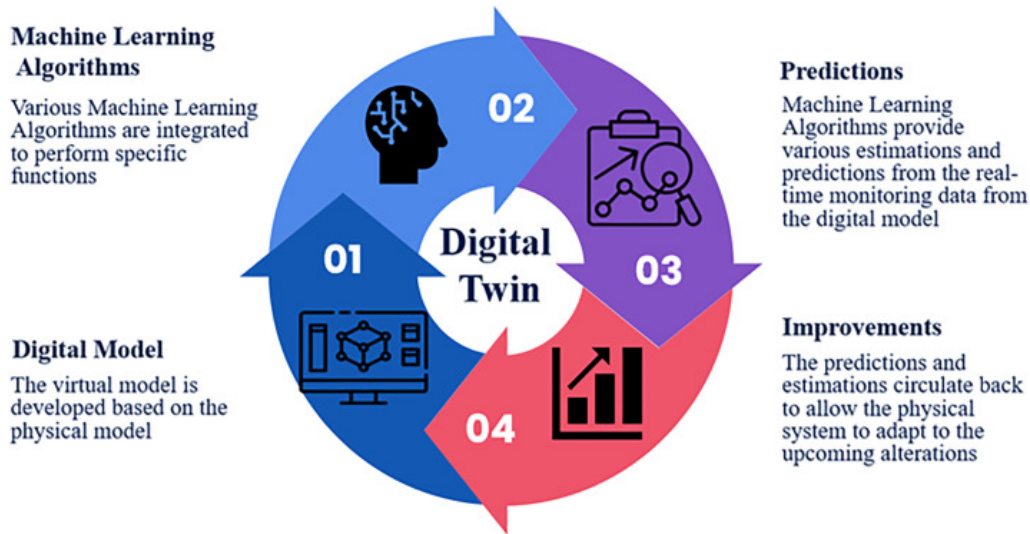


Figure 2.2: Function of Digital Twin referred from Semeraro et al., 2023

According to (Madni et al., 2019) there exist maturity levels in Digital Twin, as establishing a Digital Twin it is important to assess the current state of the system that is to be digitized. Identifying the current state helps in advancing to the next step to improving a system's capabilities and functions (Atreya and Sridhar, 2019). The four stages of maturity and sophistication are shown in Figure 2.3:

1. Pre-Digital Twin, which is used to alleviate technological risks and unearth problems in the early stages of engineering
2. Digital Twin, which is a twin of the physical model and used to study the behaviour and simulate what-if scenarios of the physical counterpart.
3. Adaptive Digital Twin is a Digital Twin which offers an adaptive user interface that is useful in decision-making, real-time planning and support etc.
4. Intelligent Digital Twin is the highest form of Digital Twin that has all the capabilities of adaptive Digital Twin and has unsupervised learning that is used in monitoring and analyzing; health data, performance data etc.

Level	Model Sophistication	Physical Twin	Data Acquisition from Physical Twin	Machine Learning (Operator Preferences)	Machine Learning (System/Environment)
1 Pre-Digital Twin	virtual system model with emphasis on technology/technical-risk mitigation	does not exist	Not applicable	No	No
2 Digital Twin	virtual system model of the physical twin	exists	performance, health status, maintenance; batch updates	No	No
3 Adaptive Digital Twin	virtual system model of the physical twin with adaptive UI	exists	performance, health status, maintenance; real-time updates	Yes	No
4 Intelligent Digital Twin	virtual system model of the physical twin with adaptive UI and reinforcement learning	exists	performance, health status, maintenance, environment; both batch/real-time updates	Yes	Yes

Figure 2.3: Maturity Levels of Digital Twin referred from Madni et al., 2019

2.2 DES and its integration with Digital Twin

The rapid developments in Industry 4.0 have led to the requirements in simulation such as effectiveness, flexibility, cost-effective solutions, etc (Sharma, 2015). These requirements have led to a rise in the number of simulation software, which in turn use different simulation concepts for their modelling. Discrete Event Simulation is one such modelling approach, where the system is modelled as a discrete sequence of events in time. It can also be labelled as a stochastic modelling approach. DES form of simulation tries to capture the realism of a system in terms of its performance and behaviour. According to (Keshari and Sharma, 2019) this approach of modelling uses discrete time steps created by state changes. In the real world, DES abilities are as follows (Gunal, 2019).

- Performance prediction in systems
- Observing and analysing the interaction of various components in a system.
- Experimentation of different scenarios by varying parameters or components of a system.
- Providing users with advanced analytics of system configuration.
- Providing users with support during decision-making support.

Due to this DES has a number of applications in industries such as healthcare, manufacturing, military and etc (Turner and Garn, 2022). With the advancements done to procure accurate, real-time and large amounts of data. It is possible to build simulation models that mimic the production systems that exist in real life. These simulation models can be used to aid the stakeholders and managers in different phases such as planning, designing, testing or optimizing. These abilities displayed

by simulation models can be correlated to the concept of a Digital Twin. According to (Grieves and Vickers, 2017) which states that these virtual representations can be used to design, test and validate various actions before implementing on their physical counterparts. DES and Digital Twin share similar characteristics. However, their combined utilization where a digitised version of a system or model is produced with the ability to monitor and control it based on real-time data is limited. One of the reasons is, DES software currently works on process-based scheduling rather than real-time scheduling. However, as technology advances the DES software functionalities keep improving and expanding, so a real-time scheduling feature may be developed soon. (Agalianos et al., 2020).

2.3 Lifelong learning materials

When it comes to the definition of lifelong learning, there isn't one standard definition to it. There are multiple interpretations of it. One of them is *"Lifelong learning is the lifewide, voluntary and self-motivated pursuit of knowledge for not only personal but professional reasons as well. It does not only enhance social inclusion, active citizenship and individual development but also increases competitiveness and employability."* from (Ates and Alsal, 2012). But the ideology of lifelong learning is the same where it focuses on developing one's self, changing the way one obtains knowledge can be a failure or success and that's where lifelong learning comes into play. Lifelong learning changes and improves the learning standard for engineers and this in turn will help the students be well-prepared when moving into a global market (Zakaria et al., 2022).

Based on (Echegoyen et al., 2022) lifelong learning intends to investigate how general-purpose systems can make use of previously learned information to speed up the learning of new data distributions or enhance outcomes by making use of previously learned information. Lifelong materials never end, always change and adapt to newer concepts. Lifelong learning should help people to engage in critical thinking, employ a variety of creative thinking techniques, and modify their approaches in light of the ever-changing environment (Alt et al., 2023). Lifelong learning materials can be used in areas like institutions, workshops, and skill coaching. One efficient way to develop lifelong learning materials in industries is by developing them around the workers by providing training programmes and conducting workshops for sustainable and organized performance (Shahzad et al., 2023). Using lifelong learning in an industrial space expands the ideology of the employee and makes the employee more aware and promotes more creative ideas for the employee which can further be used to develop one's personal or professional skills.

2.4 Simulation education

From (Juric et al., 2004) simulation education follows similar general objectives of learning which enable the students to

- Learn the content
- Enable creative thinking
- Improve problem-solving capabilities
- Improve overall competence and professionalism

However these objectives are not limited, it also encourages the students to reflect upon the learning material and provide feedback with regard to their own experiences which further improves the quality of the learning material. Simulation education is well received when written around real-life encounters and practice such that it can be related to the industry and the reality of it can be accepted (Juric et al., 2004). The next following sections describes the necessity of performing software benchmarking before developing the lifelong learning materials.

2.4.1 Why software benchmarking?

In this day and age with the advancements in production systems, the requirement of making it sustainable is ever so in demand. The cornerstone for designing such systems is simulation. Over the last few years simulations have gained traction in the field of manufacturing and production as newer, complex and sustainable systems can be designed, observed and validated. There are various advantages of simulation and they are as follows: reduced investment cost, minimization of waste, improvement in efficiency, risk detection and sustainable use of resources (Hosseinpour and Hajihosseini, 2009). Now that the effects and benefits of simulation have been discussed, the need to select a good simulation software is equally important. One main reason to benchmark software is to assess which of the software aligns with the value to stakeholders and the user.

Industries that use software without prior testing and validation delay the schedule. This would put the industry in a backlog with waitlists piling up and customer dissatisfaction growing. Software used by users should be able to use the software with relative ease. But for an industry to use DES software can't be just an easy software to use. It should meet the requirements of the stakeholders and the project management as well (Ebert and Brinkkemper, 2014). Situations like this is where benchmarking comes into relevance. Benchmarking should be performed with different software and finding a middle ground where it's acceptable to the stakeholders, and the management and usable by the users.

Software testing and benchmarking serve as a way for organizations and companies to make the best decision while selecting the ideal software as it presents the stakeholders with qualitative and quantitative information about a product. There are a number of methodologies and techniques in software benchmarking and testing, also a number of reasons to conduct the tests. In this thesis, benchmarking is done to support and justify the software migration done in the course MPR271.

This thesis will focus on five categories for benchmarking that assess the software which is mentioned in Section 3.3.3. The following section describes the guidelines that are established and necessary for developing lifelong learning material in this thesis. referred

2.4.2 Constructive alignment

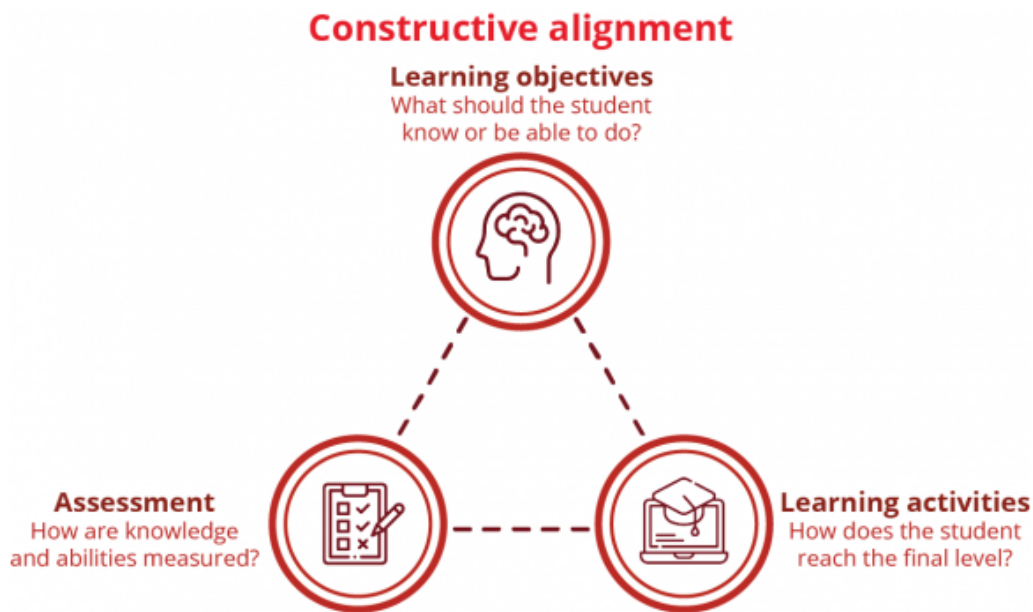


Figure 2.4: Grapical description of constructive alignment. Figure referred from <https://www.ru.nl/en/lecturers/designing-education/integrating-learning-objectives>

From (Loughlin and Lindberg-Sand, 2022 & Skoogh et al., 2012) The aim of constructive alignment is to connect the learning objectives, learning activities and assessments judiciously. For a material/course to be considered having a good standard should contain effective learning objectives. These learning objectives should be developed with the right dynamic verbs so that they can assist the teacher in teaching the material. A good set of learning objectives can also be used to improve the cognitive capability of the student and assist the teacher in relating it for grading (Skoogh et al., 2012). the For this project, the learning objectives and learning activities have been developed with the help of Bloom's taxonomy. Learning activities complement LOs by helping set certain activities that improve the skill of the student and gradually improve the student's skill to achieve learning the learning objective. The assessments should coincide with the learning objectives so that it has some value. The assessments can be in the form of questions, tasks, and objective-based tests (Loughlin and Lindberg-Sand, 2022 & Skoogh et al., 2012). Assessments can be of real-world problems that promote critical thinking in students and can prepare them to take on the global market (Zakaria et al., 2022).

The learning objectives could also be set in a way that can assess this.

2.4.3 Blooms taxonomy

Bloom's taxonomy is used to aid the constructive alignment of this project. According to Larsen et al., 2022 Bloom's taxonomy helps students by giving guidance on how to understand a concept better (Crowe et al., 2008). Bloom's taxonomy helps in setting standards and objectives for a course. Courses are curated by developing the learning objectives, these learning objectives need to be worded in a way that a student reading it should be able to understand and use it. Bloom's taxonomy is used as a language to describe the learning goals for the students (Titova et al., 2023). The cognitive process helps in retaining information in the memory and retrieving it whenever necessary. The cognitive domain of bloom's taxonomy as shown in figure 2.5 helps retain the memory's information by simple verbs and nouns.

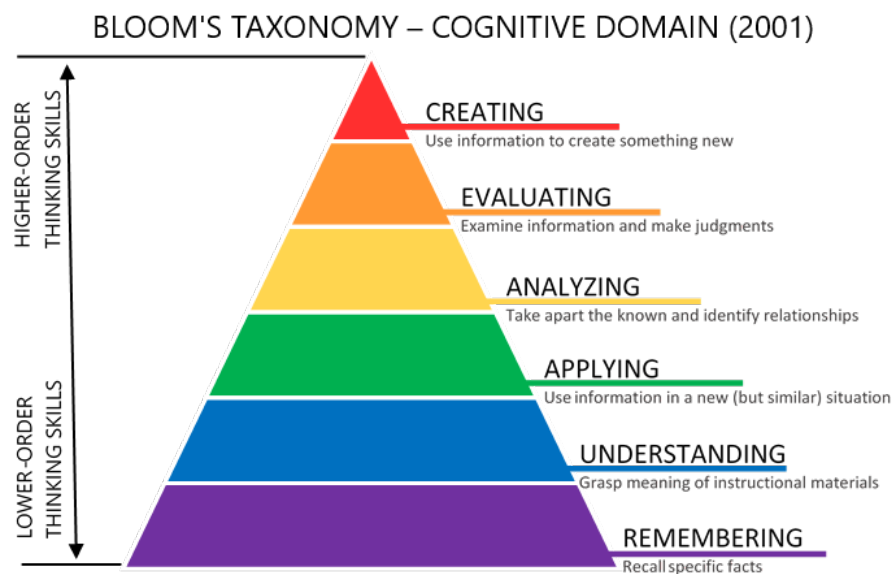


Figure 2.5: Graphical description of bloom's taxonomy. Figure refereed from <https://citt.ufl.edu/resources/the-learning-process/designing-the-learning-experience/blooms-taxonomy/>

The six steps of the blooms taxonomy are shown in figure 2.5 in descending order. When starting with bloom one should start with the *Remember* and make the way up to *Creating*. Let's look into what the six categories mean, the categories have been referred from (Momen et al., 2023).

- Remembering: Focuses on remembering and memorizing certain information.
- Understanding: This is when a student expresses a degree of acknowledgement when going through a concept or material.
- Applying: It's when a student takes in the concept and has the capability to use the information in different circumstances.

- Analyzing: The capability of a student to break down said given information, link it between different concepts and analyse it critically.
- Evaluating: At this stage, the student can make out the differences and defend their discovery.
- Creating: The student has mastered the concept and has the capability to create something new out of it. Regardless if it's an abstract form or a complete version of it.

The course that follows bloom's taxonomy should start with materials that slowly introduce each phase of bloom along with the period of the course. This makes sure that students get enough time to understand the concepts that are being taught and can grasp each step towards mastering the course.

Remember	Understand	Apply	Analyze	Evaluate	Create
define	explain	solve	analyze	reframe	design
identify	describe	apply	compare	criticize	compose
describe	interpret	illustrate	classify	evaluate	create
label	paraphrase	modify	contrast	order	plan
list	summarize	use	distinguish	appraise	combine
name	classify	calculate	infer	judge	formulate
state	compare	change	separate	support	invent
match	differentiate	choose	explain	compare	hypothesize
recognize	discuss	demonstrate	select	decide	substitute
select	distinguish	discover	categorize	discriminate	write
examine	extend	experiment	connect	recommend	compile
locate	predict	relate	differentiate	summarize	construct
memorize	associate	show	divide	assess	develop
quote	contrast	sketch	order	choose	generalize
recall	convert	complete	prioritize	convince	integrate
reproduce	demonstrate	construct	survey	defend	modify
tabulate	estimate	dramatize	calculate	estimate	organize
tell	express	interpret	conclude	grade	prepare
copy	identify	manipulate	correlate	measure	produce
discover	indicate	paint	deduce	predict	rearrange
duplicate	infer	prepare	devise	rank	rewrite
enumerate	relate	teach	diagram	score	adapt
listen	restate	act	dissect	select	anticipate
observe	select	collect	estimate	test	arrange
omit	translate	compute	evaluate	argue	assemble
read	ask	explain	experiment	conclude	choose
recite	cite	list	focus	consider	collaborate
record	discover	operate	illustrate	critique	facilitate
repeat	generalize	practice	organize	debate	imagine
retell	group	simulate	outline	distinguish	intervene
visualize	illustrate	transfer	plan	editorialize	make
	judge	write	question	justify	manage

Remember	Understand	Apply	Analyze	Evaluate	Create
	observe		test	persuade	originate
	order			rate	propose
	report			weigh	simulate
	represent				solve
	research				support
	review				test
	rewrite				validate
	show				
	trace				

Table 2.1: Action words used for Bloom’s taxonomy for each stage. The words were referred from {<https://www.miamioh.edu/cte/assessment/writing-student-learning-outcomes/blooms-action-verbs/index.html>.}

Bloom’s taxonomy helps in giving the right verbal tone for creating the learning objectives/goals. The learning objectives developed for the lab materials were assisted by blooms taxonomy. The verbs used in the learning objectives were based on the six levels of blooms taxonomy. It helps in developing professional and cognitive skills along with extensive technical skills (Sharunova et al., 2022). The lab materials were developed in a way where the complexity is lower initially and the complexity level increases progressively for each lab material. This helps in developing good cognitive skills. For using each stage of bloom’s taxonomy there are certain action words that should be used while developing learning objectives. For this project, the learning objectives were developed by using the action words from Table 2.1.

3

Methodology

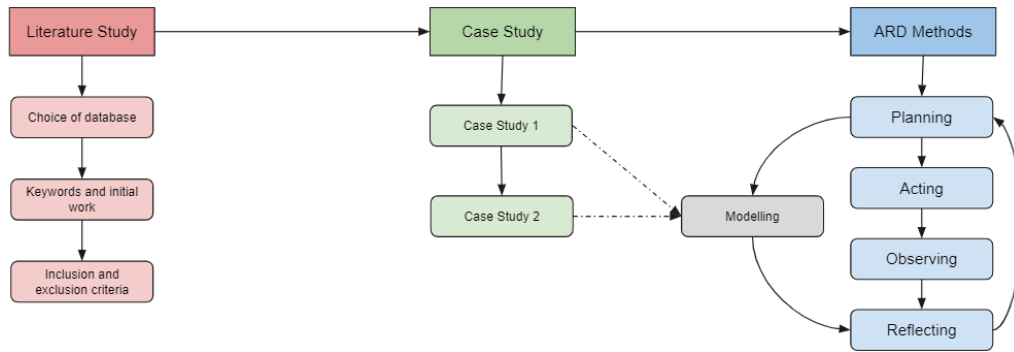


Figure 3.1: The flow of methodology

3.1 Literature Study

From Green, 2010 literature review plays an integral role in any research, therefore it is conducted at the start of a research project. It familiarises researchers with up-to-date knowledge about the topic, which serves as a checkpoint for researchers not to replicate the findings and trends that have already been performed in that field. Also, it informs the researchers of any conflicts and gaps in the literature that present themselves as topics that need additional research. In this research project, the literature study is concerned with the three objectives from section 1.2. This is done by aligning and concising the search terms, keywords and choice of the database with the objectives of the project.

3.1.1 Choice of database

The database tools that were used to search the articles were Scopus, science direct and google scholar. Scopus was used mainly due to its large collection of articles, different functions of searching for articles and the quality of articles. Google Scholar and science direct were also used in case the articles from Scopus did not provide the research with the required data.

3.1.2 Keywords and initial work

The keywords for this research were initially identified from the two research questions mentioned in 1.4. The keywords obtained from the research questions were Digital Twin, Digital Twin competence and learning materials. Synonyms related to these concepts were used to obtain articles. With these keywords, the initial study was conducted. To further strengthen the foundation of the literature study synonyms we used, for example, Digital Twin, and Simulation. The keywords and synonyms were initially used individually to broaden the scope of searching papers and research articles. To narrow down the search, keywords and synonyms were combined and searched like “Digital Twin AND Simulation” in Scopus. As the search progressed newer keywords such as “Smart manufacturing, Lifelong learning, Bloom’s Taxonomy, Discrete event simulation, Software benchmarking” were added.

Digital Twin	Smart manufacturing
Digital Twin competences	Bloom’s Taxonomy
Simulation	Discrete Event Simulation
Learning materials	Software benchmarking

Table 3.1: Keywords used in the Initial study

The table 3.1 mentions the initial keywords that were reviewed at the beginning of the research. For the initial literature work, three articles were studied based on each keyword.

After conducting the initial study more data was required to support the initial study and further progress into the study. Information on the integration of Digital Twin and Discrete Event Simulation, Design for lifelong learning, and benchmarking for simulation software. However, Information on benchmarking strategies for simulation software was found lacking thus keywords like "Software architecture" and "Software design" were used to broaden and strengthen the quality of the literature study. More papers were taken from ResearchGate on topics such as Discrete event simulation applications, Simulation education etc. For example (1) discusses the improvement of simulation education when it is done through web-based discrete event simulation models. Research papers like these give a better understanding of how this project will be carried out in terms of creating good quality simulation learning materials.

DES and DT intergration	DES application
Design for lifelong learning	Software design
Software architecture	Simulation education

Table 3.2: Keywords used in the Initial study

3.1.3 Inclusion and exclusion criteria

In this research various academic databases that provided access to scientific publications were used. Some of them are Scopus, ScienceDirect, Google Scholar, ResearchGate. For better understanding, mentioned below, are the processes followed to procure accurate, reliable and appropriate documents from the Scopus database for the terms 'Digital Twin' and 'Lifelong Learning Material'. As the term 'Digital Twin' was coined in 2002, it wasn't until 2010 that the practical definition was coined (1). Since then the topic has been constantly evolving, so articles and papers published within the time frame 2010-present were chosen to stay up to date with recent developments. Any articles that were published prior to 2010 were excluded. For ease of understanding the articles, journals, and reports published in English were used and articles published in other languages were excluded. The articles searched had to contain full-text, as this would provide more information on the article and additional references rather than articles that just contain the abstract and aren't transparent.

Initially, the search started with using the term Digital Twin combined with the three established exclusion criterias. As Digital Twin in itself is a wide topic and can be used in various fields the results were 11,588 document results. To relate the search to the research the keyword Digital Twin was added to the search, the number of results concise to 5,882 document results. As this research mainly focuses on Discrete Event SIMulation it was used as a keyword to further concise the results, this narrowed the document results to 65. For the term lifelong learning materials, it is difficult to estimate when the term was coined since the concept has existed for a very long time. But to stay relevant to the topic the time frame 2010-present produced 614 document results. The exclusion criteria next used was documents published only in English. Which showed 559 document results, to narrow down the results the keyword was limited to Lifelong Learning limiting the results to 137 document results. The final number of documents for each term indicates the number of documents from which the research was conducted in scopus for the relevant terms.

Criteria	Inclusion	Exclusion
Year of publication	2010-2023	Articles and reports published before 2010.
Sources	Academic database- Scopus, ScienceDirect, Google Scholar and ResearchDirect. Non-academic database- Government reports, web-pages	-
Language	English	Exclusion of non-English studies.
Research scope	Articles that contain the keywords like Digital Twin , Simulation, Lifelong Learning Material etc.	Articles that don't contain any of the keywords.
Text availability	Full text availability	Articles that don't grant complete access and Articles that only provide an abstract of the entire information.

Table 3.3: Exclusion/Inclusion criteria

3.2 Case Study

The case study is divided into two subsections. The first case study will deal with benchmarking of DES software and the second case study will look into the comparisons of educational material used in institutions and industries.

3.2.1 Case study 1

This Case study aligns with the second objective (*"Formulate a pedagogic design for the learning material on the guidelines of constructive alignment."*) from section 1.2 as benchmarking is required to choose the software upon which the learning materials are developed on. This case study looks into the benchmarking of DES software primarily (Automod and Plantsim for this project). DES software is used for different purposes and is used based on the company's specifications and preferences (Dias et al., 2016). Usually, industries use multiple DES software for different projects. Without categorization or having a list of what to look into, benchmarking DES software will be difficult (Dias et al., 2016). Thus a list of criteria will be where the benchmarking will be based on. The benchmarking will be split into two stages where the first stage will be creating a criteria list and the second stage will be where a set of scores will be provided for each criterion and the result is evaluated and analysed.

3.2.2 Case study 2

This Case study aligns with the second objective (*"Formulate a pedagogic design for the learning material on the guidelines of constructive alignment."*) from Section 1.2

as the pilot study of the learning material is developed with the guidelines of constructive alignment for the institutions. This case study discusses the comparison of educational learning materials to the learning materials used in the industries. A comparison of learning materials used in the institution and the industries is a good way to shed light on what the students from the institution miss out on when learning topics that are related to Digital Twin.

The educational learning materials will be developed as lab materials for the students in the course "*Simulation of Production Systems*". For the educational materials, three lab materials based on the learning objectives will be developed. The learning objectives will be developed by a focus group which is explained in ARD methods. These lab materials will be used by the students. The feedback on the lab materials will be discussed in the Results and Discussion section.

For the industrial learning materials, an interview will be performed with a couple of industries where the objective of the interview is to learn how the industry views Digital Twin, the method of teaching and the learning materials used to train its employees. The interview will be a semi-structured interview where it'll focus on three main sectors:- Introduction of the employee, the view on Digital Twin and the learning materials and DES software used.

3.3 ARD Methods

In this section, the chosen methods answer all three objectives of the research project as mentioned in section 1.2. In the Understanding and Planning phase of the method, the objectives are extracted and redesigned using bloom's taxonomy. In the Acting phase, the pilot study is developed on the guidelines of constructive alignment. In the Observing and Reflecting phases, the pilot study is evaluated and an improved version is developed which promotes lifelong learning.

Action research design is derived from the Design science research approach, which is a problem-solving paradigm that seeks to improve knowledge (Brocke et al., 2020). ARD allows the development and modification of IT artefacts through organizational influence. ARD emphasizes the active participation and collaboration from End users and Stakeholders throughout the lifecycle of IT artefact (Haj-Bolouri et al., 2017). ARD methodology adapted to this thesis will contain four stages as mentioned below.

3.3.1 Extraction of Learning Objectives from the existing course

In this step, the learning objectives of the existing course were extracted. This step was crucial in making the new learning objectives because even though the DES software is changed from Automod to Plantsim, the learning objectives shouldn't

change completely but rather add new ones to the existing ones or modify the old ones.

3.3.2 Understanding

To understand what learning objectives and learning activities should be present in the lab materials two steps were taken into consideration where the first step was to learn about Bloom's Taxonomy and the second step was to create these learning objectives and learning activities.

3.3.2.1 New and updated Learning Objectives

A total of two learning objectives were referred from the previous course and a total of 51 learning outcomes were developed. The learning objectives were chosen by having a focus group with an expert from Siemens and with the examiner. A focus group was chosen for developing the learning objectives because it helps in sharing the data and gathering more information (expectations of students and the university's expectations from the course) as more people are involved in it. This would also help in creating a more unbiased opinion on generating new ideas and policies (Breen, 2006). In this case, it is for the learning objectives.

3.3.3 Planning

Problem formulation and planning. This stage included working with the focus group that comprised the stakeholders from Chalmers and Siemens. Where the important LOs from the prior version of the course are ported and new LOs established and updated. A plan was generated, for three deliverables to be delivered every week to a stakeholder for trial. An overall finalizing date was procured. In this phase the first stage of case study where what should be included in the category list for benchmarking will be planned out. The benchmarking category has been listed in Table 3.4. The second stage of this case study will be allocating a set of scores to the benchmarked categories. The second case study discusses the learning materials used in the institution to the materials used in the industries.

Keywords	Categories
DES AND Software	Flexibility Usability Robustness
Benchmarking	Documents in database

Table 3.4: Benchmarking categories

3.3.3.1 Flexibility

According to Mens, 2006, the flexibility of the software is the quality that software engineers prefer. When it comes to industries, engineers look into how flexible software is and how each software element can be utilized. As the industry is evolving

the functionality of the machines is evolving as well. The DES software should also be flexible with this evolution. Some industries consider the flexibility of software based on the programming level/coding language of DES software. Just cause a certain software has high flexibility doesn't mean it's automatically good. Software having high flexibility means it includes a high volume of programming, though in certain situations it can be good, the main issue comes in the debugging, which consumes a lot of time and can put a lot of stress on the simulation engineer. This project will look into the flexibility of the DES software and rather than giving it a score it'll be discussed which DES software has the higher flexibility and which has lower flexibility.

3.3.3.2 Usability

Grassi et al., 2015 describes DES software in general helps in solving design and management problems in the field of manufacturing. Usability of software assesses whether the software has adequate tools and necessities that could aid the user (Bruun and Stage, 2012). Tools and necessities like a well-defined help function, software accessible in multiple languages, warning/alert system and other types of functions and tools. The usability of software encompasses the human-system interaction (Juristo et al., 2007). This category will determine how usable software is to the user. When it comes to the usability of software one should be able to learn the software with ease. The software shouldn't be time-consuming to learn as it defeats the purpose of it being easily usable by its users. Juristo et al., 2007 explains that the usability of software should include ease of use, ease to learn and ease to debug. The effects of the usability of software are to increase the productivity of the users and increase the potential of the users as well.

The usability of the DES software Automod and Plantsim will be determined through a series of interviews for this project. The interview will be performed on two different groups of students who have taken the same course at Chalmers (MPR271), with one group having performed the course with Automod and the latter being Plant sim. This is done to procure real-time data for comparisons. The questions will be developed on the parameters of functionality, robustness, efficiency, understandability and consistency. The questions prepared for the interview were defined based on the ideas of Juristo et al., 2007

- How well does the software satisfy the core functional purpose?
- How long did it take to learn the basics of the software?
- How well does the software perform around errors and failures? (debugging)
- How well does the software perform under minimal time and resources?
- How well can the software's functions and features be understood?
- How well is the software consistent in terms of its User-Interface, performance etc?

3.3.3.3 Robustness

According to (Shahrokni and Feldt, 2013) robustness is the extent to which a software can perform its function with invalid/incorrect inputs. The software should

also perform under strenuous conditions without fail. Robustness of software deals with the health condition of the software which makes it easier to use for the users. For an industry to use the software it should perform without any hassle and with minimum failures. Having strong robustness in software puts less strain on the users and thus makes the users perform efficiently and effectively. Though every software has a breaking point where it fails at a certain point, it should have an acceptable level of failure where it can be used in industries without any issues. The robustness of software can be tested in multiple ways but for this project, it'll follow a version of benchmarking method from (Shahrokni and Feldt, 2013) called CRASH (which stands for Catastrophic, Restart, Abort, Silent, Hindering). The way this benchmarking will be carried out is by gathering feedback from the new and old students that have taken the course Simulation in Production System (MPR271).

- Catastrophic looks into how often the software crashes and if the DES can handle multitasking.
- Restart deals with DES software hanging while performing a task and requiring to restart of the software.
- Abort occurs when tasks or processes are aborted.
- Silent occurs when no error code is returned when it is expected to return one.
- Hindering is when a simulation is executed and a wrong error code is returned.

3.3.3.4 Portability

Software portability is defined as the usability of the software in different environments without needing reconfiguration (Heroes, 2023). Under this category, the software is evaluated on the ability to be transferred to different hardware or software environments and is benchmarked on the range from high portability to low portability. ISO 29119 confirms portability when these four attributes are fulfilled. Compatibility, Installability, Interoperability and localization (Ali and Yue, 2015). Compatibility - It is an attribute where multiple software is able to coexist in the same system, without interfering with each other's functions and configurations. This attribute is deemed necessary as advancements in software have led to the birth of multifunctional complex systems and integrations. Which can lead to errors originating from one software affecting other programs as well (- *ISO/IEC/IEEE International Standard - Software and systems engineering –Software testing –Part 1:General concepts*, 2022).

Installability - It is an attribute where software can be effectively installed, uninstalled and upgraded as the user intends. This degree of ease to achieve successful installation and made operational in the target environment, also when uninstalling is important to make sure that the target environment reverts back to its stable former state defines by its' measure (Lenhard et al., 2013) (Ali and Yue, 2015).

Interoperability - It is an attribute which it measures the ability of the software to communicate, transfer data and execute functions with other software and assets. For software to be able to communicate, the data to read and write must be of common formats (- *ISO/IEC/IEEE International Standard - Software and systems engineering –Software testing –Part 1:General concepts*, 2022) (Ali and Yue, 2015).

Localization - It is defined as if the software can be understood by using the common language of the region in which it is used (Ali and Yue, 2015). It is not only lim-

ited to the linguistic requirement but also the cultural and technical requirements of the region of use. The degree of measure is to ensure that the software's definitions, names and units are not misinterpreted, mistranslated and misread ("What is software localization?", n.d.).

3.3.3.5 Popularity

In this category, the results procured by (Dias et al., 2016) have been used. A study was conducted on the market's 19 relevant commercial simulation tools, based on their 'popularity'. Popularity in this context meant the presence of different sources, which neither assures parameters such as the quality of a tool or a tool that serves a better purpose. But rather most used, which can be positively linked to the previous parameters. The presence of the DES software was measured in the following categories.

- Presence in Winter Simulation Conference scientific publications.
- Documents in digital databases, and libraries. Such as Scopus, google scholar etc.
- Presence in social networks. Such as youtube, Facebook, forums in the software websites and other public forum websites.
- Presence in Reviews, surveys and comparison studies.
- Presence in Google search results.
- Presence in Search trends in the last 5 years.

3.3.3.6 Learning materials used in institutions

This phase deals with understanding what learning materials a student needs on DES and developing three lab materials. These three lab materials will be provided to the students for three consecutive weeks.

3.3.3.7 Learning materials used in industries

The skill of an employee can be divided into hard skills and soft skills (Ibrahim et al., 2017). Hard skills are the skills that are related to technical and administrative skills. An employee that has good hard skills will be good at technical work. Soft skills are the skills that are associated with one's personal qualities, habits etc. Soft skills determine how an employee interacts in the workspace and communicates with other employees. For an employee to be considered a good employee according to the industrial standard should possess both hard and soft skills. But for this project, as it deals with developing learning materials, it'll focus mainly on how to improve the hard skills of the employees.

This part of the project will look into how learning materials are currently being used in a couple of industries in Gothenburg, Sweden. One of the industries is Siemens digital industries software. A semi-structured interview will be conducted which will focus on three topics: Introduction, Digital Twin, and learning materials and DES.

The introduction topic will introduce the employee to their day-to-day activities.

Digital Twin looks into what the employee definition of the Digital Twin is and what the industries' perspective of the Digital Twin is. As Digital Twin is a vast topic and doesn't have a certain definition to it, it's always good to know what one's definition of a Digital Twin is. This gives a good base to determine the learning materials on Digital Twin for the employees. This topic also discusses on how students should be prepared with the knowledge of Digital Twin so that it closes the knowledge gap between industries and institutions. The next topic looks into the current learning materials used in the industries and the type of DES softwares used in the industry. This topic explores the type of learning materials, what kind of training is provided to the employees to learn the DES software, and How they can keep up with the current trend and updates.

3.3.4 Acting

In this stage building, intervention and evaluation cycles were used. Using the LOs, bloom's taxonomy and other developed exercise materials, we developed materials tailor-made for the course which would serve as building blocks to enable the user to be able to complete the final project. Simultaneously, we collaborated with the stakeholder to conduct mock-up trials of the developed materials for the lab. This was an agile approach as this provided us with precise and quick feedback enabling us to make necessary changes to improve the overall quality and quantity well before the finalizing date. In this phase, the category list will be developed for the benchmarking of the DES software.

3.3.5 Observing

In this stage, the developed lab materials were put into their first trial and their effects were observed. The focus groups were the students undertaking the course MPR271, this stage took over a course of three weeks. During the 3rd week of the course, a Mid-term evaluation meeting was conducted, this served as a focus group from which the evaluation of the developed materials was done.

3.3.6 Reflecting

Reflecting is a crucial part of any project, according to (Nobel., 2014) taking time to solely focus on reflecting improves performance. This is also applicable in projects, as it allows the improvement of the pilot study (Vaccarino et al., 2006). In this stage, the first type of feedback procured is institutional feedback. Three methods are used to procure the feedback: a Midway meeting, observing the students using the pilot study material during the lab sessions, and the feedback from a survey conducted at the end of the course. The other type of feedback is industrial feedback. For this feedback, two industrial experts will be interviewed. The interview questions will be framed in a semi-structured manner. The interview will be on the topics of Digital Twin, learning materials, and DES. The feedback from the institution, industry, and self-reflection will be used in tandem to make improvements to the revised version of the pilot study. These improvements will be revisited to see if it aligns with the objectives of the research and the stakeholder's vision.

4

Results

4.1 Designing the learning objectives

The development of the pilot study began with reading and analysing the previous year's learning objectives as the instructions given were to not diverge away from previous year's learning objectives. A focus group meeting was conducted where the Program Director of Production Engineering Dr Anders Skoogh and an Implementation consultant from Siemens PLM, Gothenburg, Marcus Andersson, the following section is the result from the meeting.

From the focus group, a total of five learning objectives and 52 learning activities were developed. A total of 2 learning objectives with 31 learning activities were used in three of the lab materials. All the learning objectives were not included because it was decided that it was better for students to figure out the rest and implement them in their final project.

The learning objectives and learning activities are mentioned in table 4.1.

4. Results

Defintion	LO/LA	Lab material	Stage of bloom's taxonomy
Open the PlantSim software and get familiar with the UI	LA	1	Remembering
Access PlantSim help guide and use the information to learn new aspects of model building	LA	1	Remembering
Identify saving, exporting, and managing model files (e.g. pack-and-go)	LA	1	Understanding
Configure objects to manage the behaviour of model entities	LA	1	Understanding
Demonstrate cycle times in an object	LA	1	Understanding
Demonstrate buffer sizes	LA	1	Understanding
Demonstrate set-up times and loading times	LA	1	Understanding
Estimate model resource failure (MTBF, MTTR)	LA	1	Understanding
Understand and apply object-based programming in SimTalk	LA	1	Understanding
Construct a simple model from scratch	LA	1	Applying
Simulate sources and drains to manage products in and out of the model	LA	1	Applying
Practice creating an input scheme in the source	LA	1	Applying
Use a workstation	LA	1	Applying
Construct and use a conveyor	LA	1	Applying
Practice writing code/logic in SimTalk using methods	LA	1	Applying
Apply exit strategies	LA	1	Applying
Select a simulation end-time in the event controller	LA	1	Analyzing
Test and run a single scenario	LA	1	Analyzing
Summarize and present data from the simulation model	LA	1,2,3	Evaluating
Evaluate the bottleneck analysis	LA	1	Evaluating
Estimate a product failure/scrap rate	LA	2	Understanding
Apply a worker	LA	2	Applying
Apply a workerpool	LA	2	Applying
Apply a broker	LA	2	Applying
Simulate different worker types/roles	LA	2	Applying
Test manual material handling with operator movements	LA	2	Analyzing
Plan and model an assembly station to combine different components/products/fixtures	LA	2	Analyzing
Illustrate graphical changes to products, including dynamically through a simulation run	LA	2,3	Analyzing
Use parallel station and batching	LA	3	Applying
Plan and run a warm-up analysis	LA	3	Analyzing
Illustrate graphs for the objects	LA	3	Analyzing
Create a simulation model representing a complex production system using a professional DES software package and established modelling techniques	LO	1,2,3	Creating
Plan, design, and perform experiments to improve a production system based on a DES	LO	1,2,3	Creating

Table 4.1: List of learning objectives

4.2 Designing the learning materials

Before designing the learning materials it is important to choose the right DES software as mentioned in 2.4.1. The following results of benchmarking categories between AutoMod and PlantSim are mentioned in section 4.4. The next section is the result of the pilot study that was designed and developed.

4.2.1 Pilot Study

Some of the important aspects of the pilot study are shown in the following figures.

Learning objectives

LO3: Create a simulation model representing a complex production system using a professional DES software package and established modelling techniques.

- LO3.1. Open the PlantSim software and get familiar with the UI.
- LO3.1.1 Access toolbox.
- LO3.1.2 Shortcuts/hotkeys.
- LO3.2. Access PlantSim help guide and use the information to learn new aspects of model building.
- LO3.3. Identify saving, exporting, and managing model files (e.g. pack-and-go).
- LO3.4. Construct a simple model from scratch.
- LO3.5. Simulate sources and drains to manage products in and out of the model
- LO3.6. Practice creating an input scheme in the source
- LO3.7. Use a workstation
- LO3.8. Configure objects to manage the behaviour of model entities
- LO3.9. Demonstrate cycle times in an object
- LO3.10. Demonstrate buffer sizes
- LO3.11. Demonstrate set-up times and loading times
- LO3.12. Estimate model resource failure (MTBF, MTTR)
- LO3.13. Construct and use a conveyor
- LO3.14. Understand and apply object-based programming in SimTalk.
- LO3.15. Practice writing code/logic in SimTalk using methods
- LO3.15. Apply exit strategies.

LO5: Plan, design, and perform experiments to improve a production system based on a DES model.

- LO5.1. Select a simulation end-time in the event controller
- LO5.2. Test and run a single scenario
- LO5.5. Summarize and present data from the simulation model
- LO5.6. Evaluate the bottleneck analysis.

Figure 4.1: Learning objectives developed with the actions words from Bloom's Taxonomy

Figure 4.1 is a snippet of the Learning objectives used in one of the Lab materials. Learning objectives have to be established through Bloom's taxonomy and constructive alignment. These learning objectives help the student build their knowledge and also improve their cognitive ability.

Introduction

Plant Simulation is a discrete-event simulation (DES) software by Siemens PLM Software. Plant Simulation allows the user to create or replicate object-oriented and hierarchical simulation models of various production and logistics systems. It can be used to analyze and rectify problems and inefficiencies in the simulation models.

The premise of the lab is to model a production system that comprises stations, resources and workers. Lastly, experiment with worker behaviour and achieve competence in these areas.

To pass this lab session:

- Work through the instructions and answer the question presented in the Task.
- Upload the answers to the tasks with an isometric view of the model in PDF on Canvas.

Figure 4.2: Introduction to the lab materials

Figure 4.2 is the introduction of the lab material. It has to be included while designing learning material as they help in understanding the aim. It also gives a brief description and the students know what to expect in the forthcoming context.

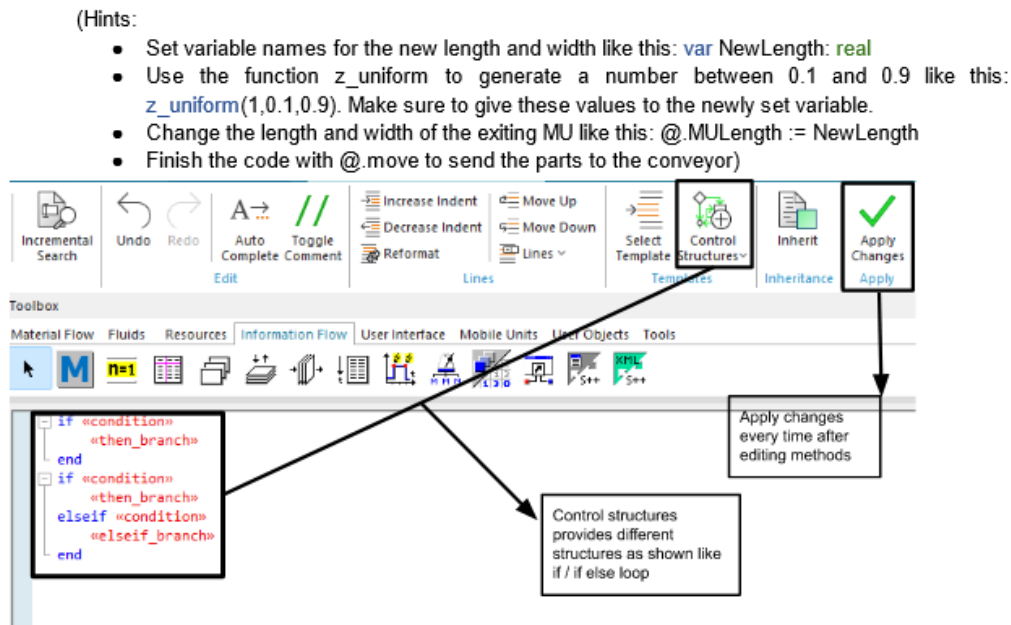


Figure 9. Method window

Figure 4.3: Hints/Instructions that's been provided in the form of an image to visualise and learn

Figure 4.3 shows the instructions/hints used in the lab materials. The figure shows hints on how to use SimTalk, it also shows how to use the tools for the SimTalk function. Instructions are required in learning materials as they guide the users in completing the learning materials. The instructions should be designed in a sequence

such that the users are able to understand and perform the activities in succession to achieve the goal. This also in turn improves the cognitive ability of the user.

Task 1. Create a simple production system and run a bottleneck analysis.

In this task, you have to create a simple model by attaching a source to a station (Station 1) and connecting the station to a conveyor (Conveyor 1). The conveyor will be divided into two other conveyors (Assuming station 1 sends out two different products) (SmallConveyor and BigConveyor respectively). These divided conveyors will be connected to two buffers which are connected to two stations (Station 2 and Station 3). After getting processed from station 2 and station 3 the products will go into "Drain 1" and "Drain 2". When objects are placed it won't show the caption for the object. In order to show these captions **Right click on the object → Edit 3D Properties → Captions → Name/label activated**. Another method is to select the object and press **CTRL + 3** the same Edit 3D Properties would pop up and follow the same instructions. To make the conveyor curve as shown in Figure 8, click on conveyor → anchor it on the spot where you want the conveyor to being → hold control and move the mouse up or down to curve the conveyor.

Create a model like the one in figure 8. Edit the objects respectively and input the following data.

- The *Source* should produce one *Part* every 5 minutes (HINT: Interval Const and 5.00) The amount should be set to 60, the source should produce 60 parts only.
- *Station 1* has a processing time of 5 minutes.
- *Station 2* has a processing time of 8-10 minutes and a setup time of 5-6 minutes (both uniformly distributed). The setup should be done for every *Part*. (Hint: look at the setup tab of the machine and the checkbox "Set-up after").
- *Station 3* has a processing time of 8 minutes and a setup time of 3-4 minutes (both uniformly distributed). With an availability of 70% and an MTTR of 1 minute (Hint: look at the failure tab of the machine)
- *Buffer 1* has a capacity of 5 and *Buffer 2* has a capacity of 20.
- You should change the simulation time to 8 hours (Double click the EventController to reach the settings and edit End) and run through the simulation, making sure it stops after 8 hours (8:00:00.000).

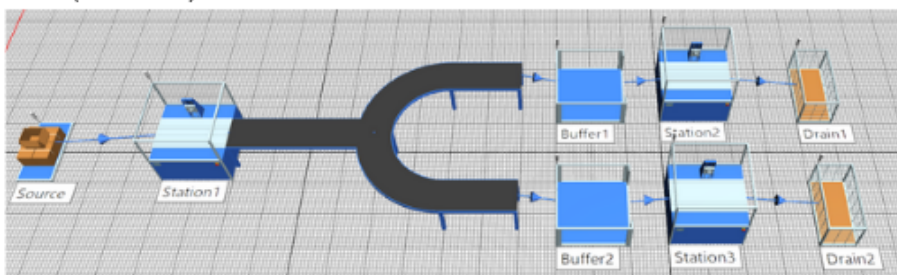


Figure 8.

- We can visualize the machine data through statistics: Find Chart function under the User Interface submenu in the toolbox, drag and drop a chart into the frame. Add the machines you want to visualize to it by dragging and dropping them onto the chart. The chart shows an aggregate of the machine's states during the run. How much part of the total time was spent producing, waiting, blocked, etc?
- You can also use the Bottleneck analyzer, found under the tools tab. After the run is complete, open the BottleneckAnalyser and click the analysis button. You'll see a number of coloured bars over each station.
- Now use the "Open" button in the BottleneckAnalyzer to open the Ranking table. The table contains statistics for each station and aggregates the % of the time it has spent in states over the entire simulation run, for example working, set-up, blocked, and disrupted (broken down).

Figure 4.4: Tasks that have been provided after the instructions to improve the knowledge of the user

Getting familiarized with workers

Let's create a simple model as shown in Figure.12 where only one worker is assigned to work at both stations. The worker has to work at Station 1 and then carry the part to Station 2, process the part and come back to Station 1.

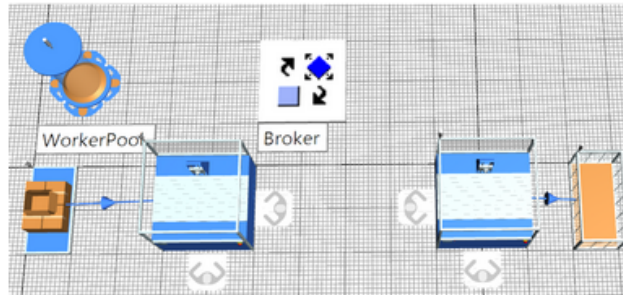


Figure.12. Example layout

- Create a source and connect it to a station
- Add two Workplaces to the station.
- Now create another station that connects to a drain and place two Workplaces in that station.
- Now place a Workerpool and a Broker.
- Click on the first Station go to the "Importer tab" and click on active in the "Processing" tab. In the same importer, tab go to "Transport" and give active. The "Transport" tab will enable the material handling function. Do the same with the second station but activate only the "Processing".
- Now define the services in the stations. Both the stations give "process" as shown in Figure.9. For the first station give "carry" as shown in Figure.11.
- As shown in Figure.8. give "process" to the worker working in the station and "carry" in the workplace for the worker to carry the part from the first station to the other.
- Finally, click on the workerpool as shown in Figure.10. Click on the "Creation Table" and give "carry" under "Additional Services" and in the next column give "process".
- After defining all the services run the simulation.
- Make sure the case sensitivity for "process" and "carry" are the same or else the call function wouldn't work.

Figure 4.5: Subtasks that help in developing additional knowledge

Questions for Task 1

Based on the task performed answer the following questions

1. Identify one bottleneck and describe what type of bottleneck it is?
2. Based on prior experience and knowledge provide some suggestive actions that can be taken to improve the system.
3. Change the simulation time to 24hrs and change the amount of parts produced in the source to -1 (which represents infinity), now run the simulation and find out how many products have been produced (Hint: display function in the user interface section).

Figure 4.6: Questions formulated after the tasks to test the user if they have gained the required learning outcome

Figure 4.4, 4.5, and 4.6 show the task and questions provided after the instructions. The tasks and questions are derived from objectives. These help in challenging the

user's cognitive ability and promote learning in them.

4.3 Evaluating the learning materials

4.3.1 Results on learning materials used in institutions

The following feedback was drawn from discussions with the students of the course. The lab materials were used by the same students to perform the necessary tasks designed in it. The feedback was procured through a mid-way meeting and by observing the challenges and comments during lab hours. The following questions were developed to procure feedback on the lab materials.

- How do you think the lab was? (The grammar, instructions, figures and etc)
- Was it challenging enough to make you ready for the final project?
- Did the hints reduce the challenges of the lab? (Do you think the hints should have been there ?)

The answers the first question procured drew three feedback points, the majority of students stated that the lab was clear when it comes to instructions, also that it could be improved by making it more exploratory where the students encounter trial and error granting them autonomy rather than a constrictive approach. The last feedback point was to give more emphasis on the general explanation given in the material.

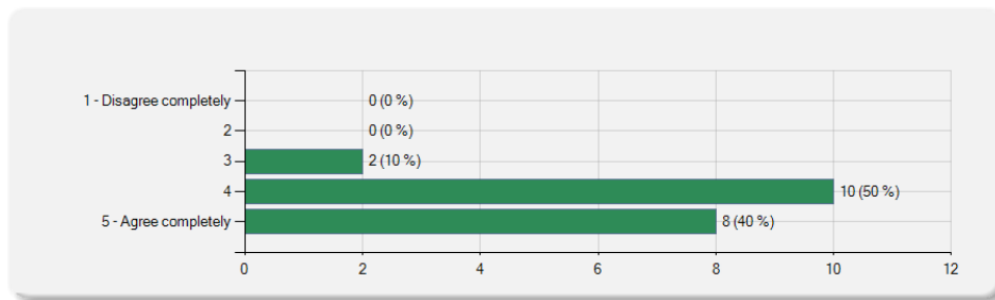
The second question had mixed feedback. Certain students felt there was a lack of challenge and that the challenge felt linear throughout the three lab materials and wanted to progressively increase the difficulty of the labs. While the latter half of the students felt it was challenging when it came to defining certain machine parameters and using certain software and machine aspects like Mean Time Before Failure (MTBF) and SIMTALK.

The last question had unanimous feedback applauding the provided hints stating that it was a good addition to the materials as it helped in progressing through the lab exercises. Also, the students added to their earlier comment about the hints stating that the hints were repetitive but did not present any major concern.

An overall feedback was procured, this gave valuable insight on 4.3.1. From the feedback shown in Figures 4.7, 4.8, 4.9, it can be deduced that the overall acceptance and approval of these lab materials were good.

4. Results

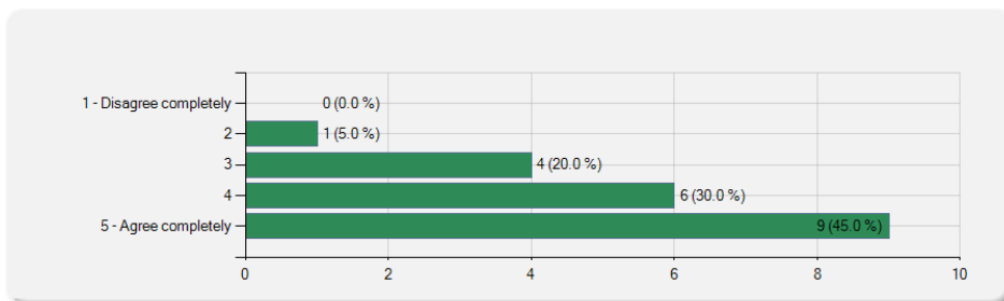
The learning outcomes (see [course syllabus](#)) clearly describe what I was expected to learn in the course



	Mean	Median
The learning outcomes (see course syllabus) clearly describe what I was expected to learn in the course	4.3	4.0

Figure 4.7: Feedback on the learning outcomes of the course Simulation of Production Systems

The course structure (as divided into lectures, exercises, lab sessions, simulations etc.) is appropriate in order to reach the intended learning outcome of the course



	Mean	Median
The course structure (as divided into lectures, exercises, lab sessions, simulations etc.) is appropriate in order to reach the intended learning outcome of the course	4.15	4.00

Figure 4.8: Feedback on how the students have reached the learning expectations of the course Simulation of Production Systems

The assessment (including all compulsory elements, exams, assignments etc.) tested whether I had reached the intended learning outcomes of the course

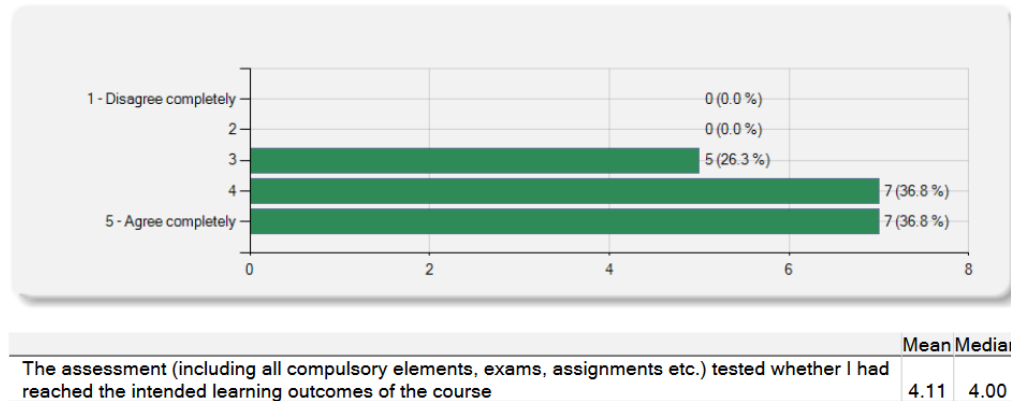


Figure 4.9: Feedback on the assessment of the course Simulation of Production Systems

4.3.2 Results on learning materials used in industries

The section will look into the feedback received by the employees working in industries. The feedback was retrieved by conducting an interview. The interview was performed in a semi-structured manner where a set of questions were developed prior to the interview and additional questions were brought up during the interview. The interview questions were split into three categories where the first category of questions dealt with the introduction of the employee, the second category of questions focuses on Digital Twin and the third category of questions focuses on learning materials and DES. The questions asked during the interview are mentioned below.

Introduction

- Tell us a little about yourself.
- How does a typical workday look like?

Digital Twin

- How does your interpretation differ from the company's interpretation of Digital Twin?
- How can universities prepare their students so they're better apt with knowledge on Digital Twin? (What skills are expected from a simulation engineer?)
- Post-pandemic how has the Industry changed from the inside? Has there been a push towards Digital Twin and smart manufacturing?

Learning materials and DES

- What are the different types of DES used by the simulation engineers in the company?
- As a simulation expert, what are the different parameters that you consider while selecting simulation software?
- When it comes to learning DES software, how are the employees trained? (Duration) (What type of educational material is used for training the employees?)

- What criteria do learning materials have to meet to achieve good-quality results?
- How does one's cognitive skills and technical skills are assessed?

The answers to these questions are mentioned below individually for each industrial employee interviewed.

Answers from Implementation consultant from Siemens PLM, Gothenburg, Marcus Andersson

Introduction

- Name - Marcus Andersson working as an Implementation consultant at Siemens PLM. Works on DES mainly, but also in PLM and Team centre.
- The work consists of daily meetings, which have an agenda to monitor ongoing projects, a great degree of autonomy at work and can choose to work online. A part of the work involves helping with onsite problems of DES and solving questions and queries that occur.

Digital Twin

- Digital Twin is interpreted differently in various parts of the industry, but on a personal level, the general views of it are pretty similar to the company's views. When it comes to Siemens's perspective of what a Digital Twin is, it is quite unified as they work in PLC, hardware and software. Digital Twin technology is both a hindrance and a benefit as they cannot stray away from it. And from a global perspective, the company claims that it is the future of manufacturing and development, which cannot be ignored.
- For simulation engineers looking to join a company, it is imperative that they should possess some knowledge of programming. As real-world problems require complex programming to be able to be solved. As for the institutions, a master-level student needs to have the basic knowledge and understanding of what a DES is and it's functioning. As it's a special event-based modelling system that requires critical thinking to be able to solve it.
- There wasn't much change, but there has always been a ramp-up in the virtual sector. Everything doesn't have to be physical.

Learning materials and DES

- Marcus uses only PlantSim as the DES software but also uses other softwares like Team Centre.
- DES software at its base is the same. The steps that make them different from each other are the usability of the software, documentation (large online library), the community around the software, and ease of use.
- The way Siemens does it is by having engineers conduct workshops and seminars where they conduct a one-day to a one-week training session where they look into DES but other topics as well. The other way of training is by using Siemens Xcelerator Academy as training material.
- Presentability and grammar. The content of the material should contain appropriate challenges to the user and the difficulty get progressively harder and contains more SimTalk programming.
- The skills are assessed by some sort of feedback. Asking the employees about the work and providing feedback on spot helping them improve adapting to

it. The focus is not to have a hard agenda but rather to focus on what's important and work towards it.

Answers by a simulation engineer from an automotive industry in Sweden

Introduction

- Simulation engineer working in an automotive industry in Sweden. The software used by this simulation engineer is PlantSim, IPS Pathplanner, Process Simulate, and Team centre Visual Mockup.
- The first two days of the week usually high workload as it has a lot of meetings discussing what has happened in the previous week. The rest of the days focus on working on simulation and looking into other initiatives.

Digital Twin

- According to the simulation engineer, the Digital Twin is a virtual replica of the physical system, process or embodiment of an industry. Whatever changes made in either one (physical or virtual) should be made in the other as well. This doesn't stick to the product or process but should be for the entire value chain and day-to-day activities. From the company's perspective, it hasn't reached the complete Digital Twin status yet, because a structure and a defined way of working are required. The way of working should be in line with the other stakeholders in the value chain.
- From a simulation perspective as one is working with data, one should have the analytical and technical knowledge on analysing certain processes. Handle certain types of data and interpret a meaningful insight from it. The ability to visualise a process gives the upper hand over those who can't. Thus, students should take up courses in universities that deal with problems in the industry today.
- There is constant talk about Digital Twin and smart manufacturing as the company has got to stay ahead of its competitors and as the industry is changing the company should be able to adapt to how the new data is being processed and stored, how it is handled, and how the processes are being built. When it comes to Digital Twin it's still in its early stages as it involves a lot of stakeholders and their views aligning with other stakeholders. Thus the way of working for Digital Twin would be defined when all stakeholders agree with each other. Transparency, traceability and version control for a smooth process is important when it comes to future-proofing which in turn correlates to smart manufacturing.

Learning materials and DES

- Siemens PlantSim is used as the DES software because the help function is built into the software and the customer support is excellent.
- Internally it depends on who the internal customer is in the organization and what work is carried out and the process needed for software that meets the requirements is chosen. The views of different departments that align with certain software are chosen so that the communication between these departments is smooth and easy. For the company to choose software it looks into the parameters of what it can do, and what capabilities it can deliver in a certain field, how it can visualise like if it has VR capabilities so that a process can be viewed in VR before it is built. The simplicity of software that it provides

over other competing software, though every software has its own complexity and that cannot be changed.

- Initially there wasn't much formal training and the employees learnt it by themselves. But now as the market has grown and to improve the competence of DES training and workshops are being conducted but still on a small scale. The workshop can last from 1-5 days. For PlantSim, materials like Siemens Xcelerator Academy were provided. Employees are trained in such a way that the procedure is outsourced, a supplier trains employees. Later the knowledge is imparted to the rest of the team/department.
- As long as the basics of the materials are clear and one can easily navigate through the material without any issues. If the learning material can deliver information in a way that an employee should be able to do the easiest of the tasks without referring to the material then the material has good quality to it. The material should be able to guide the basic things so that the student doesn't get stuck initially. A training material reaches its highest potential when it gives the basic information and other pieces of information along with a few examples and finally supplements it with a mini project so that the person/employee studying it can master it to a certain degree. Through this mini-project, the employee/student can discover new ideas and learn new hints and clues about the project. What learning materials shouldn't do is flood with too much complex information initially that it fatigues somebody who's trying to learn from it.
- For cognitive skills, it's about visualizing the patterns in the software like pattern recognition in bottlenecks, pattern identification in the data, the capability of understanding the problem statement of the customer's requirements and to building a model that aligns with those requirements. Technical skills are domain knowledge. Domain knowledge is required so that the engineer is capable to assess the situation, analyse it and come up with a solution for it.

4.3.3 Redesigning the learning materials

From the previous section. The feedback from the students, industry experts, stakeholders, additional research and ARD methodology allowed for further analysis and refining of the lab materials. The general suggestions on how to improve the lab materials further are discussed below.

- Introduce a book or article that talks about the basics of SimTalk. Allows for the students who have no prior experience to learn and build knowledge in programming concepts and logic. This also serves the students who have experience in programming as it promotes lifelong learning by refreshing and restoring previously learnt programming concepts and logic.
- A friendly learning environment was established in the lab sessions where the students performed the lab activities and had to raise their hands to get a hold of the Lab Assistants and Industry experts who arrive at the lab stations to solve their doubts and queries. Since the labs were not on successive days this caused the students to perform the activities on their own and procure doubts and queries which were not solved until the next lab session. To further

improve active learning and collaboration between students and teachers, a spreadsheet could be created such that the questions could be asked and the teachers could take a look and provide solutions.

- Small and quick recaps of previous lab learning objectives could be introduced at the beginning of the successive labs, such that the student can connect the dots to visualize the bigger picture. Also, progression in terms of complexity and difficulty can be visualized.
- General formatting suggestion is to use bold and italic text to emphasize objects, and important text so that it can capture the reader's attention.
- Addition of extra tasks at the end of each lab material that has no weightage in overall scoring and does not influence the grades during final evaluation. However, these additional tasks only seek to boost critical thinking, improve collaboration and provide a challenge to students seeking to test themselves.

Further on, the pilot study and the reflection of the changes performed can be seen below.

AFTER IMPROVEMENTS

The sections highlighted in yellow in the figures are the improvements/changes reflected in the revised study. The completed revised material can be viewed in A, B, and C.

- We can visualize the machine data through statistics: Find Chart function under the User Interface submenu in the toolbox, drag and drop a chart into the frame. Add the machines you want to visualize to it by dragging and dropping them onto the chart. **Select the "Resource Statistics" in the statistics type window dialog.** The chart shows an aggregate of the machine's states during the run. Eg: How much part of the total time was spent producing, waiting, blocked, etc?

Figure 4.10: Improve in directions

Figure 4.10 the highlighted text shows the added instruction on using the help menu. This improves in the understanding stage of the user in using the software.

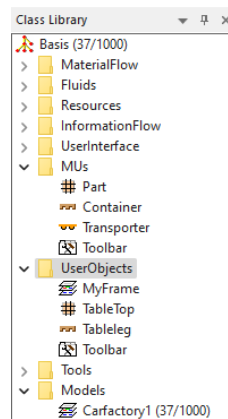


Figure 4.11: Creating MU in UserObjects "TableTop and Tableleg"

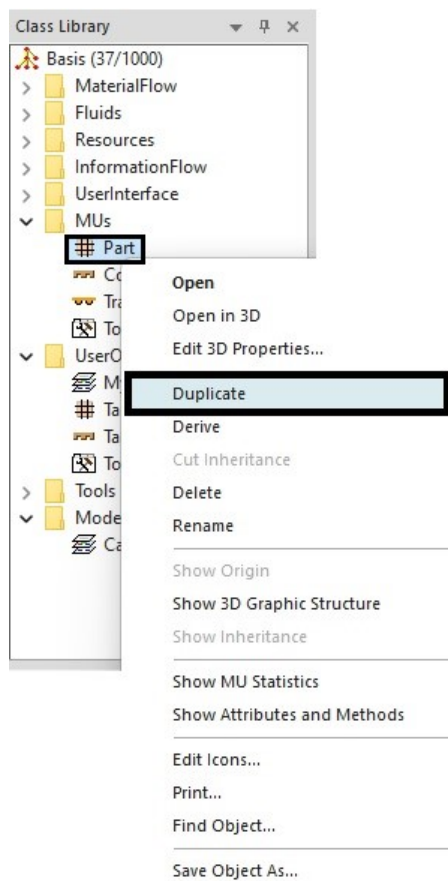


Figure 4.12: Directions on how to create MU parts in UserObjects

4.11 and 4.12 denoted the improvements done in the area of instructions. This was suggested by the industry expert from Siemens. The goal of this improvement is

to provide better instructions in the learning that promote continuity by reducing interruptions.

Extra task (optional)

Getting familiarized with workers

Let's create a simple model as shown in Figure.12 where only one worker is assigned to work at both stations. The **worker** has to work at **Station 1** and then carry the part to **Station 2**, process the part and come back to **Station 1**.

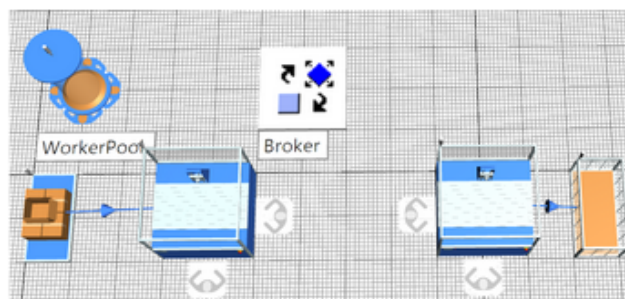


Figure.12. Example layout

- Create a source and connect it to a station
- Add two Workplaces to the station.
- Now create another station that connects to a drain and place two Workplaces in that station.
- Now place a Workerpool and a Broker.
- Click on the first Station go to the "Importer tab" and click on active in the "Processing" tab. In the same importer, tab go to "Transport" and give active. The "Transport" tab will enable the material handling function. Do the same with the second station but activate only the "Processing".
- Now define the services in the stations. Both the stations give "process" as shown in Figure.9. For the first station give "carry" as shown in Figure.11.
- As shown in Figure.8. give "**process**" to the worker working in the station and "**carry**" in the **workplace** for the worker to carry the part from the first station to the other.
- Finally, click on the **workerpool** as shown in Figure.10. Click on the "**Creation Table**" and give "**carry**" under "**Additional Services**" and in the next column give "**process**".
- After defining all the simulation services.
- Make sure the case sensitivity for "**process**" and "**carry**" are the same or else the call function wouldn't work.

Figure 4.13: Extra task on getting familiarized with workers.

Recap of Lab 1 learning objectives

LO3: Create a simulation model representing a complex production system using a professional DES software package and established modelling techniques.

LO3.1. Open the PlantSim software and get familiar with the UI.

LO3.1.1 Access toolbox.

LO3.1.2 Shortcuts/hotkeys.

LO3.2. Access PlantSim help guide and use the information to learn new aspects of model building.

LO3.3. Identify saving, exporting, and managing model files (e.g. pack-and-go).

LO3.4. Construct a simple model from scratch.

LO3.5. Simulate sources and drains to manage products in and out of the model

LO3.6. Practice creating an input scheme in the source

LO3.7. Use a workstation

LO3.8. Configure objects to manage the behaviour of model entities

LO3.9. Demonstrate cycle times in an object

LO3.10. Demonstrate buffer sizes

LO3.11. Demonstrate set-up times and loading times

LO3.12. Estimate model resource failure (MTBF, MTTR)

LO3.13. Construct and use a conveyor

LO3.14. Understand and apply object-based programming in SimTalk.

LO3.15. Practice writing code/logic in SimTalk using methods

LO3.15. Apply exit strategies.

LO5: Plan, design, and perform experiments to improve a production system based on a DES model.

LO5.1. Select a simulation end-time in the event controller

LO5.2. Test and run a single scenario

LO5.5. Summarize and present data from the simulation model

LO5.6. Evaluate the bottleneck analysis.

Figure 4.14: A recap of learning objectives used in the previous lab

From 4.15 shows extra tasks which were added to each learning material such that it provided the users with a greater challenge than the main tasks which boosts critical thinking and cognitive development.

Extra Tasks:

- Extra tasks have been provided for those looking to challenge themselves.
- They have no weightage in overall scoring and do not influence the grades in any way.

Figure 4.15: An introduction to what these extra tasks are for.

Figure 4.16 shows an additional task that was added to the already existing task. This task helps prep students for the final project. This also helps in building domain

knowledge and confidence to solve the final project.

Task 2 Introduction

Modeling a small production system

In this task, you have to model a cutting and grinding section of a section of a factory. The factory produces gym equipment, but this production line produces weight plates of three kinds. The initial raw material is cut into a mix of the three kinds of weight plates. All the plates are 440mm in diameter but vary in thickness which is proportional to their weights. 1.5 cm weighs 5 kg, 3 cm weighs 10 kg and 6 cm weighs 20 kg.

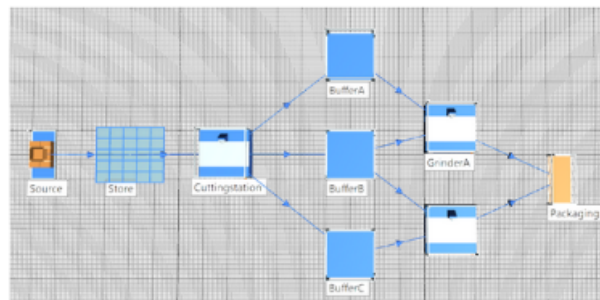


Figure.6. Overview of the first stage to the final project

From Figure.6. The *source* will send raw materials to a store with a capacity of 20 products per day. From the *store* the products are sent to the *cutting station*. The *cutting station* will cut the part into three different sizes 1.5, 3 and 6 cm (Part A,B,C) respectively. After cutting the parts shall be sent to its respective *buffers*. Part A to buffer A, part B to buffer B, and part C to buffer C. From the buffers, the parts go into *grinding*. Part A and B should go to Grinder A and Part B and C should go to Grinder B. After grinding all parts get sent into a *single drain* which will be used as *packaging*. (Hint: use methods to cut the parts and send it to the buffer with exit control strategy.)

Page Break

Data

- The length of the *raw material* is 32cm which is cut into 1.5, 3 and 6 cm respectively.
- *Store* has a capacity of 20 products.
- The *cutting machine* has a processing time of 160 seconds and a setup time is triangular distributed with min 11, mode 14, and max 25 seconds.
- *Buffer Big, Medium and Small* have a capacity of 5.
- The processing time for both the *grinders* are 200 seconds and the setup time is 280 seconds normally distributed.

Questions to answer for Task 2

1. What is the total number of weight plates produced by the section of the factory in 30 days?
2. Find the number of Part A, Part B and Part C produced for 100 raw materials.
3. Design the cutting method logic in such a way that the scrap rate remains constant for every raw material cut.

Extra questions for Task 2

1. The factory plans to use an onsite recycling strategy, they intend to use the scrap leftover from cutting and introduce it back into the system through recycling and use it to make products. How many products of Part A, Part B and Part C can make scrap leftover from cutting 1500 raw materials ?

Figure 4.16: The complete overlook of Task 2 in Lab 3 that was developed on the idea of how to start the final project.

The complete improvements for the labs can be viewed in Appendix A, B, and C.

The refinement of the lab materials hopes to bridge the gap between the institution's learning and the expectations of the industry.

4.4 Results on benchmarking categories

4.4.1 Flexibility

For both the programmes the coding is done in its own proprietary language which is *AutoMod Language* for AutoMod and *Simtalk* for Plantsim. From the articles researched and examples looked into, AutoMod has a high level of programming. That means even simple objects need to be coded before implementing it into the model. Instructions on how to build a conveyor, other functions and examples were referred from Muller, 2017. Let's take a conveyor as an object and compare it between AutoMod and Plantsim on how they're created in each simulation software.

To create a conveyor in AutoMod, three components need to be defined that are sections, transfers, and stations. Where sections describe the dimensions and speed of the conveyor, transfers are how the stations are connected to other stations or different conveyors and stations are the stations that are placed near the conveyors that feed or take in the load. The initial step would be to define the conveyor step and the next would be drawing the conveyor to a specific measurement where it'll be required for one to draw it on the grid. The steps mentioned here contain multiple subfunctions on to define the specifications of the conveyor. The same goes with other functions and objects as well in AutoMod where the user has to define the specifications manually on prompt-up boxes and code them.

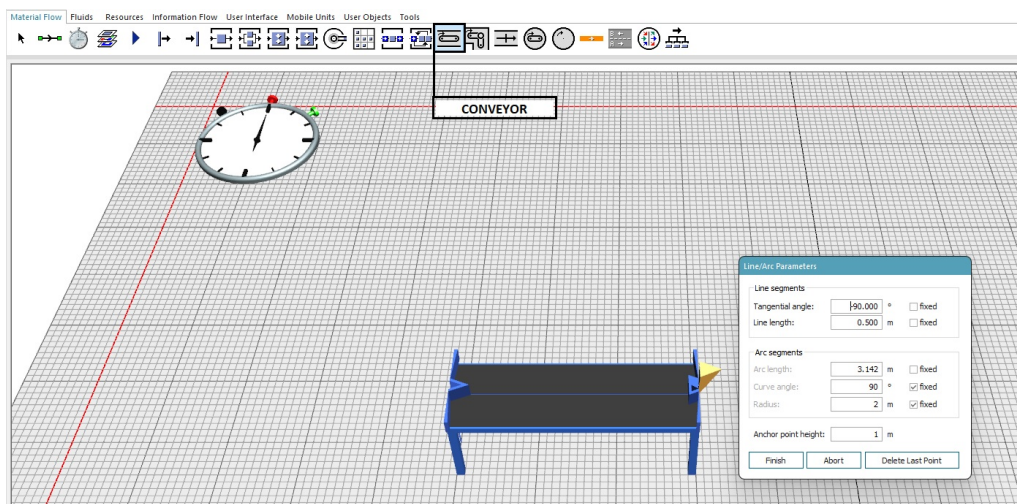


Figure 4.17: Creating conveyor on Plantsim

For Plantsim the conveyor can be dragged and dropped from the toolbox as shown in figure 4.17. The user also has the freedom to specifications but it's not as critical as AutoMod. There are icons for objects which can be dragged and dropped onto the frame and specifications can be mentioned in the specific object window.

4.4.2 Usability

To determine the usability of both the software, 20 students have been taken and the questions from section 3.3.3.2 was asked in Google form. Of the 20 students, 10 of them are currently studying PlantSim and the rest 10 have already completed the course Simulation in Production system which taught AutoMod. The ranking for these criteria is from 1-10, where 1 is the lowest and 10 is the highest. For the question "How long did it take to learn the bases of the software", it is from the least amount of time taken 1 to the longest amount of time taken 10. The results for these questions are below in table 4.2, 4.3, and 4.4.

What software did you use?	How well does the software satisfy the e core functional purpose?	How long did it take to learn the basics of the software?
Automod	6	8
Automod	9	7
Automod	8	5
Automod	8	6
Automod	8	10
Automod	7	8
Automod	9	7
Automod	6	8
Automod	8	10
Automod	7	9
Automod	8	8
Plantsim	9	5
Plantsim	8	10
Plantsim	9	2
Plantsim	9	3
Plantsim	9	2
Plantsim	10	3
Plantsim	8	2
Plantsim	8	2
Plantsim	9	4
Plantsim	9	3
Plantsim	9	5

Table 4.2: Feedback for usability table 1

What software did you use?	How well does the software perform around errors and failures? (debugging)	How well does the software perform under minimal time and resources?
Automod	4	5
Automod	7	6
Automod	5	7
Automod	5	5
Automod	3	5
Automod	5	4
Automod	5	6
Automod	4	5
Automod	6	3
Automod	4	4
Automod	5	1
Plantsim	8	9
Plantsim	8	8
Plantsim	7	8
Plantsim	7	8
Plantsim	6	6
Plantsim	8	6
Plantsim	5	5
Plantsim	8	8
Plantsim	6	7
Plantsim	6	7
Plantsim	6	6

Table 4.3: Feedback for usability table 2

4. Results

What software did you use?	How well can the software's functions and features be understood?	How well is the software consistent in terms of its User-Interface, performance etc?
Automod	4	3
Automod	7	9
Automod	9	8
Automod	3	8
Automod	4	5
Automod	5	2
Automod	2	2
Automod	4	4
Automod	6	6
Automod	7	2
Automod	3	5
Plantsim	10	10
Plantsim	9	8
Plantsim	9	10
Plantsim	9	10
Plantsim	8	8
Plantsim	9	9
Plantsim	10	8
Plantsim	8	9
Plantsim	10	9
Plantsim	7	8
Plantsim	10	9

Table 4.4: Feedback for usability table 3

4.4.3 Robustness

With the CRASH points mentioned in 3.3.3.3, the points have been given from High - Low, where high occurs often, low occurs rarely, and medium.

AutoMod

Catastrophic - Medium

Restart - Medium

Abort - Medium

Silent - Low

Hindering - Low

PlantSim

Catastrophic - Low

Restart - Low

Abort - Low

Silent - Low

Hindering - Low

4.4.4 Portability

From Figure 4.18, the following results for compatibility can be deduced. In terms of the compatibility attribute, both of the DES software are able to coexist in the same environment without interference. In terms of the Installability attribute, both software can be installed, uninstalled and upgraded effectively. In terms of the interoperability attribute, the software can communicate, transfer and execute functions with other software, this is seen as they can use data from spreadsheet packages and CAD drawings from CAD software packages. However, in the localization attribute, Plant Simulation is available in Chinese, German, English, Japanese, Hungarian and Russian. AutoMod is available only in English. Since Plant Simulation offers a more diverse choice of languages than AutoMod, it scores a point while AutoMod remains scoreless.

ATTRIBUTES	COMPATIBILITY	INSTALLABILITY	INTEROPERABILITY	LOCALIZATION
DES Software				
Plant Simulation	✓	✓	✓	✓
AutoMod	✓	✓	✓	✗

Figure 4.18: Comparison table of the DES software vs Portability attributes

4.4.5 Popularity

DES Tools	WSC	DOCS	REVIEWS	SOCIAL	WWW	Growth	tot. (WSC docs social WWW)	Rank 2016
Arena	10	10	10	10	9	10	9,9	1
ProModel	10	9	9	5	9	5	7,6	2
FlexSim	6	7	7	9	8	6	7,2	3
Simul8	6	7	9	7	6	8	7,23	4
WITNESS	8	8	9	7	8	4	7,2	5
ExtendSim	7	8	8	4	5	5	6,2	6
Simio	6	6	4	5	8	9	6,1	7
Plant Simulation	1	6	7	6	7	8	6,1	8
AnyLogic	8	8	8	2	5	7	5,92	9
SIMPROCESS	9	10	4	1	6	4	5,0	10
AutoMod	9	6	7	1	4	4	4,83	11
Micro Saint	4	5	5	0	10	4	4,8	12
QUEST (Delmia)	3	6	4	3	8	4	4,8	13
Enterprise Dynamics	5	4	7	4	4	6	4,8	14
ProcessModel	4	5	1	4	10	3	4,7	15
SimCAD Pro	3	2	5	3	3	5	3,7	16
GPSS World	7	6	2	0	3	4	3,18	17
SLX + Proof 3D	7	3	3	1	3	3	2,9	18
ShowFlow	3	2	5	0	5	0	2,4	19

Figure 4.19: Scoring distribution list referred from (Dias et al., 2016)

From Figure 4.19 the following results were deduced in which the individual categories scores range from 0-10. In the category of WSC, Plant simulation shows the least presence with a score of 1 and AutoMod procures a score of 9 showing that it has a larger presence. In the category of documents in digital databases, which included amazon, google scholar etc. both DES software have procured a

4. Results

decent score of 6 showing that they have a slightly above-average presence. In the parameter of selected reviews, 27 parameters were used to assess the software. Both DES software have procured a decent score of 7 showing that they have an above-average presence. In the parameter of the social network, the results were procured from youtube, LinkedIn, Facebook etc; Plant simulation scored 6 which indicated slightly above average presence and AutoMod had the least presence with a score of 1. The scoring distribution ranges from 0-10. With 0 being the least to a maximum achievable score of 10. The parameter for google search results Plant Simulation outscores AutoMod, 7:4 and the parameter search trends indicated towards the growth in recent years, in which Plant Simulation again outscores AutoMod, 8:4. Now to concisely the results procured from the categories, the Figure 4.20 Indicates the overall scoring distribution. It can be deduced that Plant Simulation's overall score of 6.1 outscores AutoMod's overall score of 4.8 And from a popularity ranking perspective that translates to Rank 8 and Rank 11.

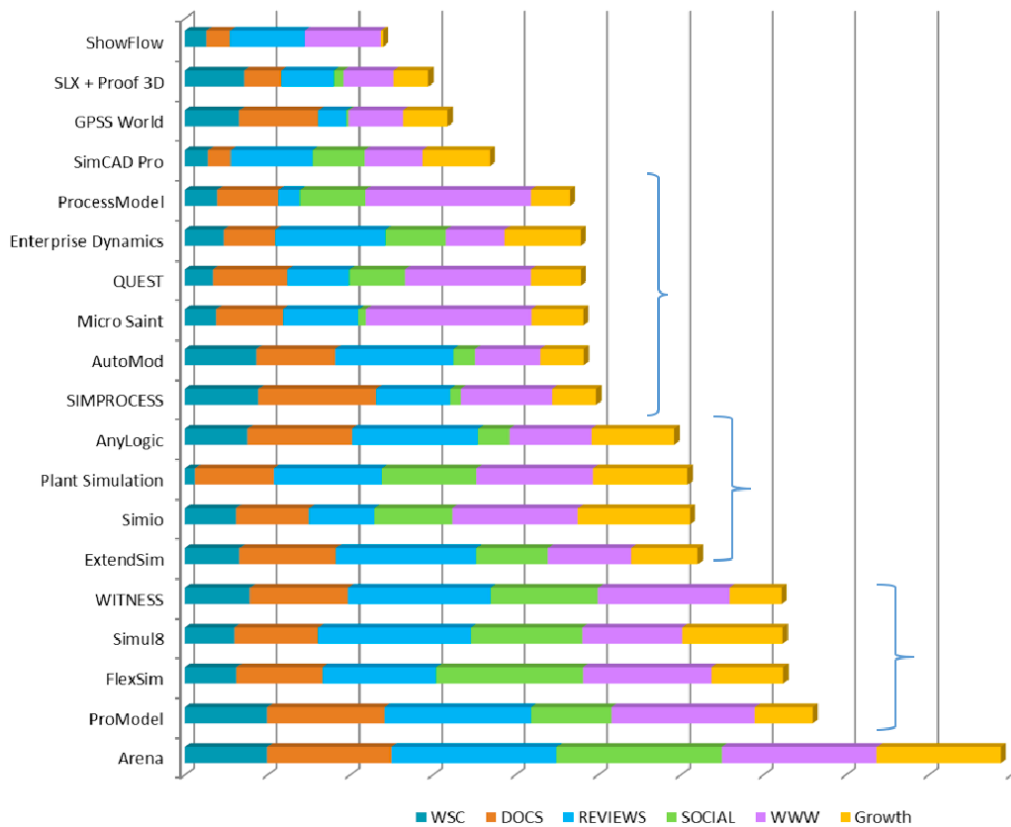


Figure 4.20: Comparison table of the DES software vs Portability attributes referred from (Dias et al., 2016)

5

Discussion

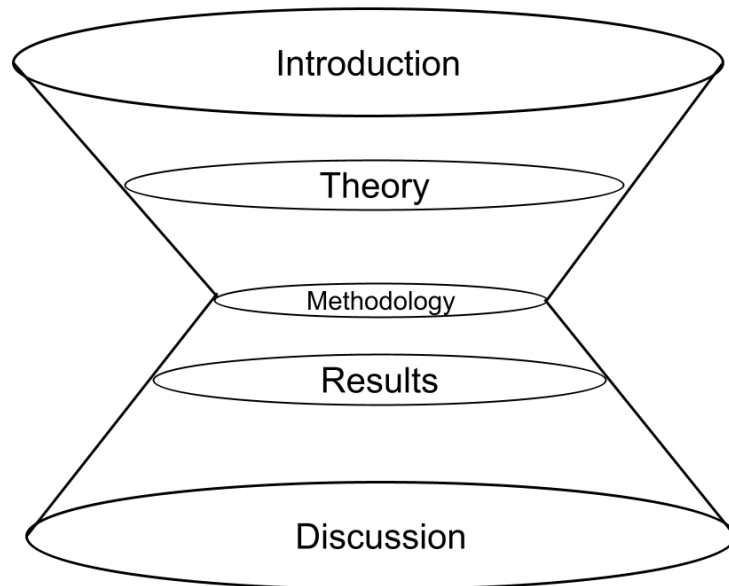


Figure 5.1: Information flow

From figure 5.1 the tunnel represents the level of information mentioned/discussed about the project. The introduction introduces a wide range of information in the project where it talks about Digital Twin. Digital Twin is a wide spectrum it narrows down to developing lifelong learning materials to enable growth in digital twin competence. Next below comes theory where it wouldn't be detailed as the introduction because it focuses on Digital Twin which narrows down to the lifelong learning materials, it focused on what a learning material is, how it helps in developing learning efficiently making students understand the concept easily and implementing that knowledge in real life scenarios. This lifelong learning material comes under "Simulation Education" as discussed in Chapter 2. The next step is the methodology where according to (Brocke et al., 2020) and (Haj-Bolouri et al., 2017)

ARD methodology was used as it aligns with the research. In this stage different stages in the ARD methodology were in tandem with the creation to the deployment stages of the learning material. The next stage contains the result section which deals with obtaining the answers for both the software benchmarking, and learning materials used in institutions and industries. The last stage contains the discussion chapter where it is expanded as it connects both the methodology and result sections. After making the necessary connections and changes, it finally connects to the introduction section by improving Digital Twin competence through lifelong learning materials.

5.1 Discussing and answering Research Questions

The reasoning behind the formulation of the research questions is as follows, the aim of the thesis was dissected into two sections. In which the principle of the first section is to improve Digital Twin competencies. The principle of the latter group is to develop lifelong learning materials.

In the first section, the question *"What are the guidelines for designing and developing effective objectives and learning materials ?"* was developed with an emphasis on the learning objectives and learning materials. Referring to the sections 2.3, 2.4.2, and 2.4.3 the importance of designing learning objectives such that they help in achieving the desired outcome and also improving the cognitive ability of the user by following certain guidelines of Bloom's Taxonomy and Constructive alignment.

In the second section, the question *"What are the specific experiences and aids that enrich learners seeking competence in the field of Digital Twin ?"* was developed with an emphasis on the design and validation of the learning materials for Digital Twin competence. As lifelong learning materials go through multiple iterations of refinement as it passes from user to user, their interpretations and definitions vary. However, for the competencies of Digital Twin, this variation needs to be minimised such that it is easy to design, validate and measure the competencies.

5.2 Discussion on the results of Learning Objectives

This discussion focuses on the first objective from section 1.2. The initial learning objectives were constructed by conducting a focus group as mentioned in section 3.3.2.1. But to develop the learning objectives in a way that helps the student build their knowledge and also improve their cognitive ability Bloom's taxonomy (Momen et al., 2023) and constructive alignment (Skoogh et al., 2012) were used

as mentioned in 2.4.3 and 2.4.2. With the help of action words from table 2.1 the learning objectives were developed which were shown in the result section 4.1. The developed learning objectives ensured there was a progressive increase in knowledge by observing during the lab sessions and gathering feedback during the midway meeting.

5.3 Discussion on the results of development and evaluation of learning materials

This discussion focuses on the second and third objectives from section 1.2. After developing learning objectives in the previous step. It is important to choose the right software before starting to develop the learning material as mentioned in 2.4.1. The following section is a discussion on the categories of benchmarking and the discussion on the overall result of benchmarking.

5.3.1 Discussion on benchmarking categories

5.3.1.1 Flexibility

From the results section 4.4.1 and the instructions provided on how to use AutoMod from (Muller, 2017), looking into this two software it's safe to assume that AutoMod is more flexible than PlantSim. Although both serve the same function the definition of the object happens first in AutoMod before placing it in the grid. This gives the user to define the minute details initially rather than placing them in the frame and then defining the specifications. In the overall benchmarking scoring table AutoMod scores one point while PlantSim doesn't score any point for flexibility.

5.3.1.2 Usability

For the question "How well does the software satisfy the core functional purpose?" the scoring distribution is as follows: AutoMod scored an average of 7.6 and PlantSim scored an average of 8.8. From these average results, PlantSim satisfies the core functions slightly better than AutoMod.

For the question "How long did it take to learn the basics of the software?" AutoMod scored an average of 7.8 to PlantSim 3.6. Compared to both, PlantSim takes lesser time to learn the basics of the software than AutoMod.

For the question "How well does the software perform around errors and failures? (debugging)", AutoMod scores an average of 4.8 and PlantSim an average of 6.9. PlantSim offers users a better way to navigate through errors than AutoMod.

For the question "How well does the software perform under minimal time and resources?", AutoMod scores 5 and PlantSim scores 7.2. Under minimal time and resources, it can be seen that PlantSim outperforms AutoMod.

For the question "How well can the software's functions and features be understood?", AutoMod scores an average of 5.1 to PlantSim 8.9. It can be seen that users using AutoMod find it more difficult to understand the functions and features than PlantSim.

For the last question "How well is the software consistent in terms of its User-Interface, performance etc?" AutoMod scores an average of 4.9 to PlantSim 8.9. In terms of User-Interface and performance, PlantSim is more consistent than AutoMod by the users.

The following result can be deduced from the scores obtained, that PlantSim has better usability than AutoMod.

5.3.1.3 Robustness

From the comparison shown in 4.4.3 it can be seen that errors from the CRASH system the method referred from (Shahrokni and Feldt, 2013) occur less in PlantSim than in Automod. Though the difference is still minuscule that difference will be enough to see which software is more robust than the other.

5.3.1.4 Portability

Drawing conclusions from comparison figure 4.18, ISO 29119, (Ali and Yue, 2015), (- *ISO/IEC/IEEE International Standard - Software and systems engineering – Software testing –Part 1:General concepts*, 2022), (Lenhard et al., 2013), (Ali and Yue, 2015), (- *ISO/IEC/IEEE International Standard - Software and systems engineering –Software testing –Part 1:General concepts*, 2022) and (Ali and Yue, 2015). It can be deduced that both the software showcase compatibility, installability, and interoperability. However, in the localization attribute, PlantSim scores a point whereas AutoMod doesn't. Thus, the overall result is that PlantSim is having higher portability than AutoMod.

5.3.1.5 Popularity

The following result can be deduced from (Dias et al., 2016), the conducted study ranked the software in terms of presence, which also can be linked to the popularity of the tool. Plant simulation has outshined AutoMod in terms of popularity

5.3.1.6 Overall benchmarking discussion

Though this thesis looks into benchmarking of PlantSim and AutoMod it doesn't mean one is better. Usually, industries prefer one simulation over the other depending on multiple factors discussed in the results section and depending on the client's specifications. However, in this research PlantSim fares better than Automod in most of the benchmarking categories so it will be selected as the DES software upon which the lifelong learning materials will be developed.

5.3.2 Discussion on the result of pilot study

After choosing the right software, the formulation and development of the materials began. Using constructive alignment and other resources, the pilot study was procured. After its intended application, the feedback was procured. The discussion of the process is as follows.

5.3.2.1 Learning materials used in institutions

As per the table 4.1 the list of objectives was developed with the stakeholders. The two learning objectives and 31 learning activities were used in these three labs as succession. These learning objectives were divided and three lab materials were produced that were inspired by materials which were developed by Marcus Andersson for another course at the Chalmers University of Technology. Inspirations such as font style, hint placements, and structure were drawn from those materials which greatly enhanced the professionalism of these lab materials.

5.3.2.2 Discussion on the learning materials used in industries

From section 4.3.2, both the employee's views of Digital Twin align with their respective industries. Their views on training students seeking to pursue a career in simulation are that the training should be centred around real-world problems, have a good grasp on basic programming languages and have the good cognitive capability of data recognition and understanding. Their views on the current state of the industry are also similar, in which their respective industries have been working towards industry 4.0 and its technologies. However, the industry expert from Siemens claims that his respective company is making bigger leaps in the virtual sector as they believe that it is the future. In terms of DES software, both industries heavily use PlantSim as their main DES software tool. When asked about the parameters required to select a good DES software, the industry expert from Siemens remains biased about PlantSim since it's their own developed proprietary tool. But the industry expert from the automotive industry is unbiased and expresses that the capabilities and choices of the DES software should align with multiple departments and their opinions. With regards to training the employees, the companies take their employee training seriously by providing them with interactive workshops that enhance competence and skill. When asked about the quality that has to be met in learning materials, the industry experts agreed upon parameters such as quality instructions, good grammar and quality presentation. The automotive industry expert added to this saying the quality of the learning material could be enhanced by adding multiple activities that can be used to build a deliverable project at the end of the session. When asked about assessing cognitive and overall skills, the industry expert from Siemens mentioned that the company has creative ways of procuring feedback and providing help when required. The industry expert from the automotive industry claimed the company assess the employee through problem-solving in projects and in meetings.

5.3.3 Discussion on the revised study material

From the result section 4.3.3 it can be seen how with the feedback from students, and industry experts a revised version of the pilot study was developed. Though there aren't many changes to the overall context of the materials there are certain changes that help the user, use the material easier. Showing the recap of previous learning objectives used in the previous labs as shown in figure 4.14 helps the users revise what they learnt prior to starting a new lab. One change that was improved in a way that challenges the users and also preps them for a bigger/final project is by providing a task in lab 3 (as shown in Figure 4.16) which was the final lab material and after that was the final project. This task helps build the knowledge and confidence to take on the final project. It improves the readiness of the user.

5.4 Discussion on the methodology

The feedback was used in co-relation with the ARD methodology's observing and reflecting stage, where the developed materials underwent reevaluation, and necessary redesign and a refined version has been procured, ready for its next application. The ARD methodology helps in creating the loop for evaluation where a material developed can go through multiple iterations where certain aspects of the material can be improved. These iterations make sure that the material stays relevant to the current industry and stays lifelong. In the vast field of Digital Twin and learning materials, there is a lack of formal structure on how to approach, design and evaluate learning materials related to simulation. When viewed from a broader perspective for this research, the chosen methodology has enabled to achieve the aspirations and goals of the project.

If allowed to do something different in this project, some of the following changes can be made to further improve the methodology. In order to have a stronger ground on the type of methods. Other methods similar to ARD can be explored where the loop of iteration exists but have better forms of evaluation methods. This can go to Bloom's Taxonomy as well. Though the cognitive domain of Bloom's Taxonomy is very reliable when it comes to developing learning objectives it's always good to cross-refer to other types of taxonomies. For users to have more exploratory ways when using the learning materials, the learning materials can be developed with all the learning objectives instead of a select few and give the users the freedom to choose what material is required to learn at that time. This enables positive learning growth among the users. With the formulated learning objectives, the learning materials can be developed into three difficulties (beginners, intermediate, and expert). This will promote a challenging environment for the users where the users can choose any type of difficulty and performs tasks and exercise further hone one's skill. Additional benchmarking categories and software can be used to further increase the validity and accuracy of benchmarking. For users using the learning materials and getting feedback, it's better to have a larger sample size of the focus groups so that the feedback is more detailed and accurate conclusions can be drawn from it.

6

Conclusion

The motivation for this project was to develop lifelong learning materials that could help improve competence in the field of the Digital Twin.

The area of the Digital Twin is a vast spectrum. As an ever-growing field, it is challenging to develop competence without basic knowledge and understanding of the basic concepts. These are required to help ones begin the journey into the world of Digital Twin. To help facilitate and evaluate the learning of any kind, learning materials are developed to accomplish those very goals. A learning material developed with the concepts and knowledge used in the current state of the industry helps the learner steadily improve their skills and these skills can be immediately utilized in the industry allowing them a fast progression in both self-competence and in the field of Digital Twin. A lifelong learning material should not only teach someone the technical aspects of the subject but also help in the development of cognitive skills. Cognitive development can also be improved by involving challenging ideas and exercises in the learning material. Lifelong learning should contribute to both the professional and personal development of a user seeking this form of learning.

The objectives are revisited with the aim to answer them in the following section:

- *Develop requirement-specific learning objectives on the guidelines of bloom's taxonomy.*

To enable lifelong learning, learning objectives should be designed and developed on the desired outcomes. These outcomes are based on the stakeholder's goals and visions. In collaboration with Bloom's taxonomy method, this aids the users to improve both the structure of the learning material and their cognitive ability of the user. Which fine-tunes the process of developing and establishing the goals.

- *Formulate a pedagogic design for the learning material on the guidelines of constructive alignment.*

Before starting to design learning materials, it is important to choose the appropriate software on which the materials are designed. Using the established learning objectives, building, intervention and evaluation cycles of ADR methodology and following the guidelines of constructive alignment, it is possible to develop the pilot study for the learning materials.

- *Evaluating and improving the learning materials to align with the theme of lifelong learning.*

The validation of these materials should be done by performing and observing

their effects in focus groups and during workshops. Feedback should be procured from focus groups, industry experts and stakeholders should be used in tandem with self-reflection and a revised version of the learning materials can be procured that seeks to bridge the knowledge gap between learning materials used in institutions and expectations from industries. This methodology can be followed to design and validate the learning materials that seek to build competence in the field of Digital Twin.

6.1 Future work

Here are a few aspects that can be looked into while further developing this topic.

- Revised learning materials can be tested in the same course to determine and validate the effectiveness of the refinement.
- Benchmarking can be performed with more software, this can improve the quality of the benchmarking.
- Benchmarking categories can include performance metrics such as latency and average response time, inclusion of these metrics can improve the accuracy of benchmarking.
- If software procures similar scores in benchmarking, learning materials could be developed on both and tested focus groups. The feedback could reveal valuable insights into learning materials designed on different software.

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A

Revised Lab 1 material

LAB 1
Simulation of production system
MPR271

Table of contents

Learning objectives	3
Introduction	4
Getting started	4
Working environment	5
Task Introduction	10
Task 1. Create a simple production system and run a bottleneck analysis.	10
Questions for Task 1	11
Extra questions for Task 1	11
Introduction to SimTalk	12
Task 2. Produce a small product and a big product	12
Questions for task 2	13
Extra questions for Task 2	13

Figure A.2: Revised Lab1 Page 2

Learning objectives

LO3: Create a simulation model representing a complex production system using a professional DES software package and established modelling techniques.

- LO3.1. Open the PlantSim software and get familiar with the UI.
- LO3.1.1 Access toolbox.
- LO3.1.2 Shortcuts/hotkeys.
- LO3.2. Access PlantSim help guide and use the information to learn new aspects of model building.
- LO3.3. Identify saving, exporting, and managing model files (e.g. pack-and-go).
- LO3.4. Construct a simple model from scratch.
- LO3.5. Simulate sources and drains to manage products in and out of the model
- LO3.6. Practice creating an input scheme in the source
- LO3.7. Use a workstation
- LO3.8. Configure objects to manage the behaviour of model entities
- LO3.9. Demonstrate cycle times in an object
- LO3.10. Demonstrate buffer sizes
- LO3.11. Demonstrate set-up times and loading times
- LO3.12. Estimate model resource failure (MTBF, MTTR)
- LO3.13. Construct and use a conveyor
- LO3.14. Understand and apply object-based programming in SimTalk.
- LO3.15. Practice writing code/logic in SimTalk using methods
- LO3.15. Apply exit strategies.

LO5: Plan, design, and perform experiments to improve a production system based on a DES model.

- LO5.1. Select a simulation end-time in the event controller
- LO5.2. Test and run a single scenario
- LO5.5. Summarize and present data from the simulation model
- LO5.6. Evaluate the bottleneck analysis.

Figure A.3: Revised Lab1 Page 3

Introduction

Plant Simulation is a discrete-event simulation (DES) software by Siemens PLM Software. Plant Simulation allows the user to create or replicate object-oriented and hierarchical simulation models of various production and logistics systems. It can be used to analyze and rectify problems and inefficiencies in the simulation models.

The premise of the lab is to help you familiarise yourself with the software's graphical user interface while navigating through the various tools and functions. Lastly to perform, observe and experiment on basic DES modelling techniques and achieve competence in these areas.

To pass this lab session:

- Work through the instructions and answer the questions presented in Tasks 1 and 2.
- Upload the answers to the tasks with an isometric view of the model in PDF on Canvas.

Extra Tasks:

- Extra tasks have been provided for those looking to challenge themselves.
- They have no weightage in overall scoring and do not influence the grades in any way.

Getting started

Starting the software

To start the program on a Windows computer, go to the **Start menu** → **Tecnomatix Plant Simulation**.

If asked, answer No for the software update.

When Plant Simulation is started you are greeted by the welcome screen shown in Figure 1. From here you can create new models and open saved ones. It also contains three buttons that can be of use when learning to model.

Figure A.4: Revised Lab1 Page 4



Figure 1. Plant Simulation Start page

The “**Example Models**” in the Figure 1 button allows you to look at different modelling examples. The “**Small Examples**” is very useful as it contains tips and explanations of how to use many of the objects found in Plant Simulation.

The “Videos” in the Figure 1 button brings up an archive with how-to videos and the “**QuickStart**” button will bring up a short tutorial on the basics of creating a model.

Plant Simulation models can be created in both 2D and 3D. If your model contains both a 2D and a 3D view they will be connected so that changes in the 2D space will be reflected in 3D and vice versa.

To make sure that we get both options we must go and edit our preference menu. From the welcome screen press the “**File**” button in the upper left corner. Navigate down to “**Preferences**” and click it. Under the “**File**” tab find the field named “**Preferences**” and check the option “2D and 3D”. Press the **OK** button to close the dialogue window.

Working environment

The graphical user interface (GUI) of Plant Simulation consists of different sections, as shown in Figure 3. The numbered sections are:

1. *Ribbon menu*

The **Ribbon menu** is an interface to allow quick access to general functions and toolbars. The toolbars are grouped in a number of ribbon tabs. The **Ribbon menu** is customisable as per the user's requirements.

2. Class library window

When a new model is created or an existing one is opened in Plant simulation, the model file will load the **Class library** with its available object classes. The **Basis** tree in the **Class Library** will show the number of used and maximum possible objects in the model.

3. Toolbox with shortcut symbols

The **Toolbox** is a container for the different Plant Simulation toolbars that hold the objects of the **Class Library**. The **Toolbox** allows you for easy and fast access to object classes during the modelling. If the **Toolbox** isn't available in the window go to **Window** → **Toolbox**. Click on the **Toolbox** and it'll be visible in the window.

4. Model frame window

When a simulation model is created it is always created with the **Frame**. By default, Plant Simulation will place a Frame under the **Models** folder when you create a new model. You can use this as your main frame.

5. Console window

The **Console** shows information about actions, which **Plant Simulation** executes.

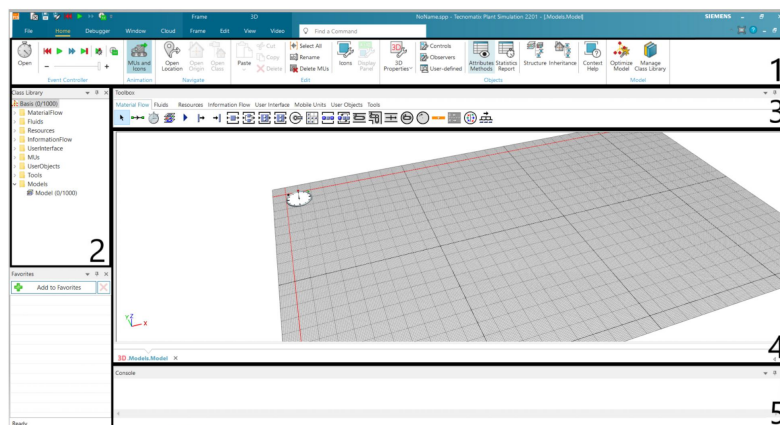


Figure 3. A working environment in Plant Simulation

Before we get started with the actual task, finding help is an essential function. Plant Simulation comes with an extensive help guide detailing most of the functions and objects

found in the software. The help guide can be reached in several different ways. The first is to click **File→Help→Contents/Index**.

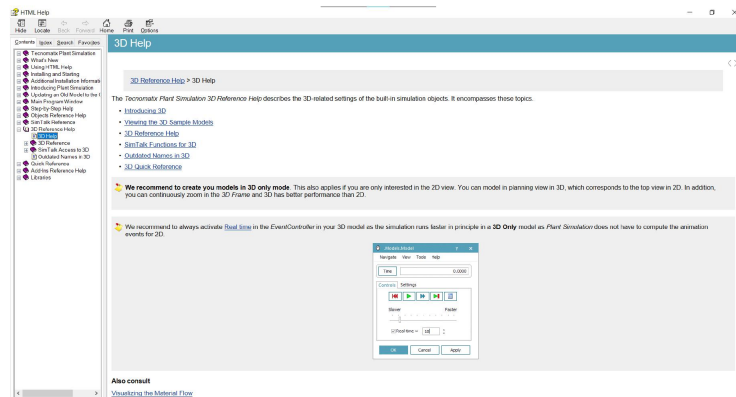


Figure 4. Help window

You can also select an object and press the “F1” key to directly open the help page for that type of object.

Also, every dialogue window contains a query button in the top right corner, (shown as a “?” sign). After pressing this button, you can select any button or field in the dialogue box and briefly describe what it does or what the choices mean. The information also contains the attribute's name connected to said button or field. Figure 5 is an example of the dialogue box. Shortcut keys can be found in the manual “**Control and Shift Keys in Tecnomatix.pdf**”. This PDF can be found online.

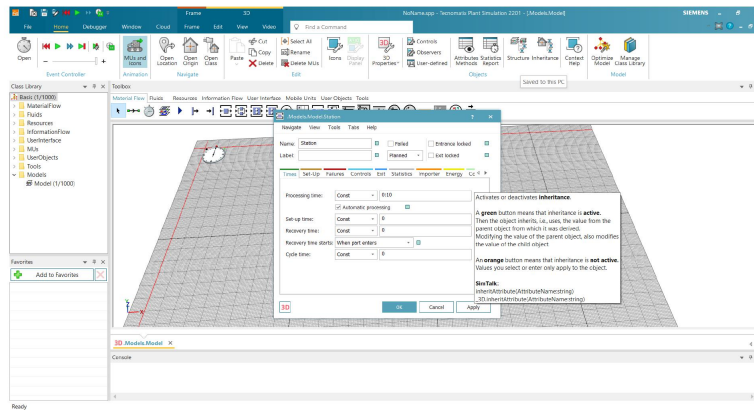


Figure 5. Help dialogue box

On the welcome screen, press the “**Create New Model**” button. Since we changed our preference to both 2D and 3D, we will automatically get both a 2D and 3D window. When the model opens, take a few minutes to familiarise yourself with the user interface. To the left of the screen, you have your **class library**. Here you can find all objects available to use in your model. You should also see the toolbox just below the ribbon bar. The toolbox is another handy way to organise and sort through the different objects available.

The most important object in all models are **Frames**. **Frames** can be described as the window where you do your modelling. A model can contain multiple different **Frames** that may or may not be connected. A **Frame** can also include **sub-frames**, which in turn have more **sub-frames**, and so on.

The second most important object is the **EventController**. The **EventController** is the object that schedules and executes all events in the model and is created automatically with each new model. The **EventController** is also used to control the speed and length of the simulation. The time controls can be reached either by the controls to the far left of the “Home” tab on the ribbon bar or by double-clicking the **EventController** object in the frame. Double-clicking the **EventController** also allows you to change when you want the simulation to “end” and warmup times by changing the values on the “Settings” tab in the event controller.

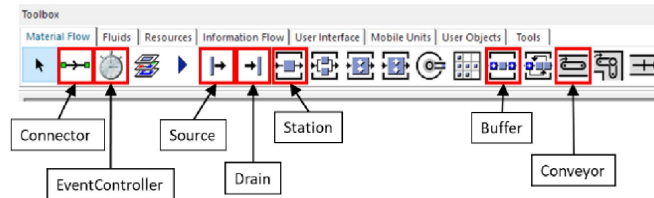


Figure 6. Important objects in the Material Flow tab of the toolbox

To add an object to your model simply click on an object on the toolbar, then click anywhere in the frame. To edit an object in a frame, double-click or right-click and select "open". You can connect two objects together using the **Connector** object. Select the **Connector** and click on the sending object followed by the receiving object. When a material has been processed in the first machine it will then follow the **Connector** to be processed in the second machine. A machine can have several in- and outgoing **Connectors**. In those cases, you usually need to define the entrance and exit strategies, but these will be discussed in later labs.

Material generally enters a model through a **Source** and exits through a **Drain**. Everything that moves in the model is collectively known as **MUs** (shorthand for *Mobile Units*). **MUs** can be classified into three categories: **Parts**, **Containers** and **Transporters**. They can represent everything from screws and boxes to cars and forklifts.

Machines can be represented by several different objects, but the one most often used is the **Station**. Out of the box the **Station** receives a part, processes it for a set time, and sends it to the next object; but it can be configured to do much more if necessary. Lastly, **Buffers** can be used to simulate warehouses and buffer spaces found in a factory.

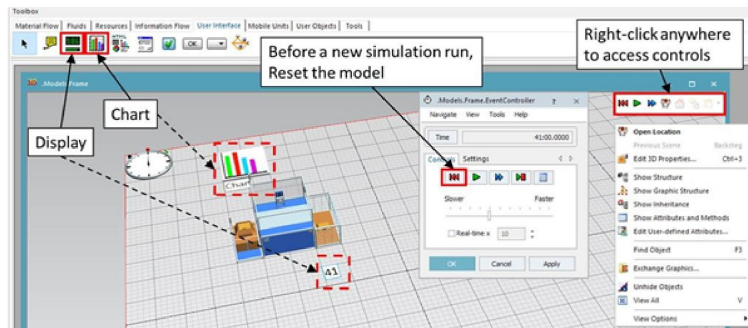


Figure 7. Some more hints and useful objects.

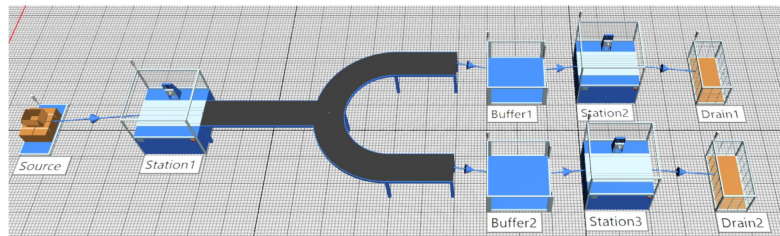
Task Introduction

Task 1. Create a simple production system and run a bottleneck analysis.

In this task, you have to create a simple model by attaching a source to a station (Station 1) and connecting the station to a conveyor (Conveyor 1). The conveyor will be divided into two other conveyors (Assuming station 1 sends out two different products) (SmallConveyor and BigConveyor respectively). These divided conveyors will be connected to two buffers which are connected to two stations (Station 2 and Station 3). After getting processed from station 2 and station 3 the products will go into "Drain 1" and "Drain 2". When objects are placed it won't show the caption for the object. In order to show these captions **Right click on the object → Edit 3D Properties → Captions → Name/label activated**. Another method is to select the object and press **CTRL + 3** the same Edit 3D Properties would pop up and follow the same instructions. To make the conveyor curve as shown in Figure 8, click on the conveyor → anchor it on the spot where you want the conveyor to begin → hold control and move the mouse up or down to curve the conveyor.

Create a model like the one in figure 8. Edit the objects respectively and input the following data.

- The **Source** should produce one **Part** every 5 minutes (HINT: Interval Const and 5:00)The amount should be set to 60, the source should produce 60 parts only.
- **Station 1** has a processing time of 5 minutes.
- **Station 2** has a processing time of 8-10 minutes and a setup time of 5-6 minutes (both uniformly distributed). The setup should be done for every **Part**. (Hint: look at the setup tab of the machine and the checkbox "Set-up after").
- **Station 3** has a processing time of 8 minutes and a setup time of 3-4 minutes (both uniformly distributed). With an availability of 70% and an **MTTR** of 1 minute (Hint: look at the failure tab of the machine)
- **Buffer 1** has a capacity of 5 and **Buffer 2** has a capacity of 20.
- You should change the simulation time to 8 hours (Double click the **EventController** to reach the settings and edit End) and run through the simulation, making sure it stops after 8 hours (8:00:00.000).



10

Figure A.10: Revised Lab1 Page 10

Figure 8.

- We can visualize the machine data through **statistics**: Find **Chart** function under the User Interface submenu in the **toolbox**, drag and drop a chart into the frame. Add the machines you want to visualize to it by dragging and dropping them onto the chart. **Select the "Resource Statistics" in the statistics type window dialog.** The chart shows an aggregate of the machine's states during the run. Ex: How much part of the total time was spent producing, waiting, blocked, etc?
- You can also use the **Bottleneck analyzer**, found under the tools tab. After the run is complete, open the **BottleneckAnalyser** and click the analysis button. You'll see a number of coloured bars over each station.
- Now use the **"Open"** button in the **BottleneckAnalyser** to open the Ranking table. The table contains statistics for each station and aggregates the % of the time it has spent in states over the entire simulation run, for example working, set-up, blocked, and disrupted (broken down).

Questions for Task 1

Based on the task performed answer the following questions

1. Identify one bottleneck and describe what type of bottleneck it is?
2. Based on prior experience and knowledge provide some suggestive actions that can be taken to improve the system.
3. Change the simulation time to 24hrs and change the amount of parts produced in the source to -1 (which represents infinity), now run the simulation and find out how many products have been produced (Hint: display function in the user interface section).

Extra questions for Task 1

1. Find the throughput of the system when The **Source** produces one **Part** every 10-12 minutes and a simulation time of 3 days.
2. Reduce the following parameters to 50% of their values, **Buffer 2** capacity, **Station 3** processing time and setup time. Now using the bottleneck analyser and identify the bottlenecks.

Introduction to SimTalk

SimTalk is the programming language used in Plantsim to model and control the simulation. One of the features of SimTalk is **“Control Structures”**.

Task 2. Produce a small product and a big product

- In this task, you'll have to use the model that was created in Task 1. At station 1 create a method to introduce exit control for **Station 1**. When called it should change the length and width of the part to two different random values between 0.1 and 0.9 m.
- (Hints:
- Set variable names for the new length and width like this: `var NewLength: real`
 - Use the function `z_uniform` to generate a number between 0.1 and 0.9 like this: `z_uniform(1,0.1,0.9)`. Make sure to give these values to the newly set variable.
 - Change the length and width of the exiting **MU** like this: `@.MULength := NewLength`
 - Finish the code with `@.move` to send the parts to the conveyor)

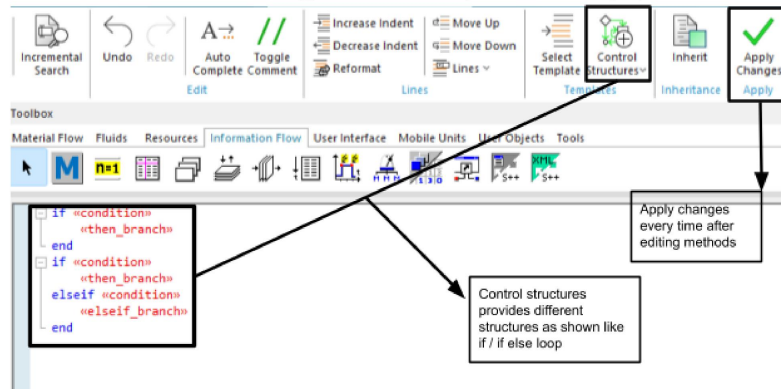


Figure 9. Method window

(As shown in Figure 9, after coding on methods click on “Apply Changes” every time an edit is made.)

- Create another method for “Conveyor” which will serve as an exit control “ConveyorExitCTRL”. It should calculate the area of each **MU** that exits and send them towards the correct Drain. Parts with an area less than 0.35 m² should be sent to the SmallConveyor, all others should be sent to the BigConveyor. (If an exit control for the

conveyor is not provided, then the simulation will stop working after the parts have been produced.)

(Hints:

- Declare a variable of type real.
- Declare a variable of type object.
- Let "PartArea" be real and "PartDestination" is the object.
- Calculate the area of PartArea.
- Make an if-else statement where if the area of a part is smaller than 0.35 m^2 the part will go to the small conveyor and if the area of a part is larger than 0.35 m^2 the part will go to the big conveyor.
- Finish the code with `@.move(PartDestination)` to send it to the conveyor.

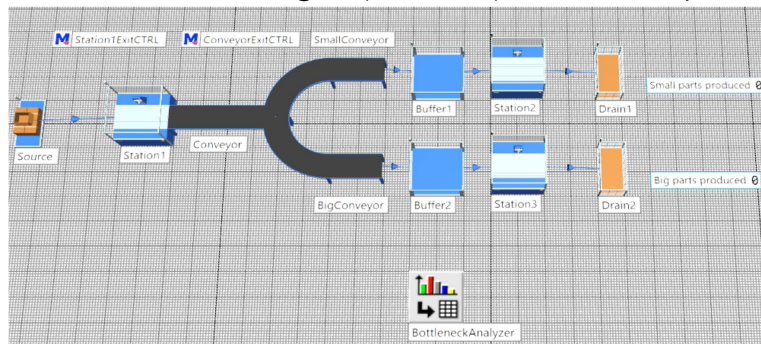


Figure 10.

Questions for task 2

1. For the simulation time of 8 hours, determine the number of small and big parts produced.
2. Determine the simulation time needed to produce 60 products in total.
3. How do you increase/decrease the speed of a conveyor without using methods?

Extra questions for Task 2

1. How can you increase/decrease the speed of a conveyor by using methods?
2. Set the simulation time to -1, make the source to produce in the ratio, 2 big parts for every 1 small part. For a total throughput of 90 products and verify if the drains reflects, 30 small products and 60 big products.

Refer Introduction section for submission requirements and details.

B

Revised Lab 2 material

LAB 2
Simulation of production system
MPR271

Table of contents

Recap of Lab 1 learning objectives	3
Learning objectives	4
Introduction	5
Task Introduction	5
Model production system with workers	5
Data	8
Manufacturing Frame Data	8
Assembly Frame Data	9
Work with the worker(object)	10
Assigning workers	11
Designing services for a worker	12
Designing services for a station	13
Designing services for a workerpool	14
Designing exit services for a station	14
Extra questions 1	15
Getting familiarized with workers	15
Questions for Task	16
Extra questions 2	16

Figure B.2: Revised Lab2 Page 2

Recap of Lab 1 learning objectives

LO3: Create a simulation model representing a complex production system using a professional DES software package and established modelling techniques.

- LO3.1. Open the PlantSim software and get familiar with the UI.
- LO3.1.1 Access toolbox.
- LO3.1.2 Shortcuts/hotkeys.
- LO3.2. Access PlantSim help guide and use the information to learn new aspects of model building.
- LO3.3. Identify saving, exporting, and managing model files (e.g. pack-and-go).
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- LO3.14. Understand and apply object-based programming in SimTalk.
- LO3.15. Practice writing code/logic in SimTalk using methods
- LO3.15. Apply exit strategies.

LO5: Plan, design, and perform experiments to improve a production system based on a DES model.

- LO5.1. Select a simulation end-time in the event controller
- LO5.2. Test and run a single scenario
- LO5.5. Summarize and present data from the simulation model
- LO5.6. Evaluate the bottleneck analysis.

Figure B.3: Revised Lab2 Page 3

Learning objectives

LO3. Create a simulation model representing a complex production system using a professional DES software package and established modelling techniques.

LO3.15. Apply a worker

LO3.16. Apply a workerpool

LO3.17. Apply a broker

LO3.18. Simulate different worker types/roles

LO3.19. Test manual material handling with operator movements

LO3.20. Plan and model an assembly station to combine different components/products/fixtures

LO3.21. Estimate a product failure/scrap rate

LO3.22. illustrate graphical changes to products, including dynamically through a simulation run

LO5. Plan, design, and perform experiments to improve a production system based on a DES model.

LO5.1. Summarize and present data from the simulation model

Introduction

Plant Simulation is a discrete-event simulation (DES) software by Siemens PLM Software. Plant Simulation allows the user to create or replicate object-oriented and hierarchical simulation models of various production and logistics systems. It can be used to analyze and rectify problems and inefficiencies in the simulation models.

The premise of the lab is to model a production system that comprises stations, resources and workers. Lastly, experiment with worker behaviour and achieve competence in these areas.

To pass this lab session:

- Work through the instructions and answer the question presented in the Task.
- Upload the answers to the tasks with an isometric view of the model in PDF on Canvas.

Extra Tasks:

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- They have no weightage in overall scoring and do not influence the grades in any way.

Task Introduction

Model production system with workers

In this task you have to create a furniture plant that produces two variants of tables, Product 1 has 4 legs and Product 2 has 3 legs. The plant has a number of issues with production with the usage of creating a manufacturing section and an assembly section.

The manufacturing section of the frame should consist of two sources, producing two different parts table tops and legs. Workers carry the parts to their respective polishing stations which are manually operated. After this operation has been performed, the products go through buffers that lead to painting and drying machines that are automated. After the products have dried, they are then sent to storage. Figure 1 showcases the manufacturing section.

Figure B.5: Revised Lab2 Page 5

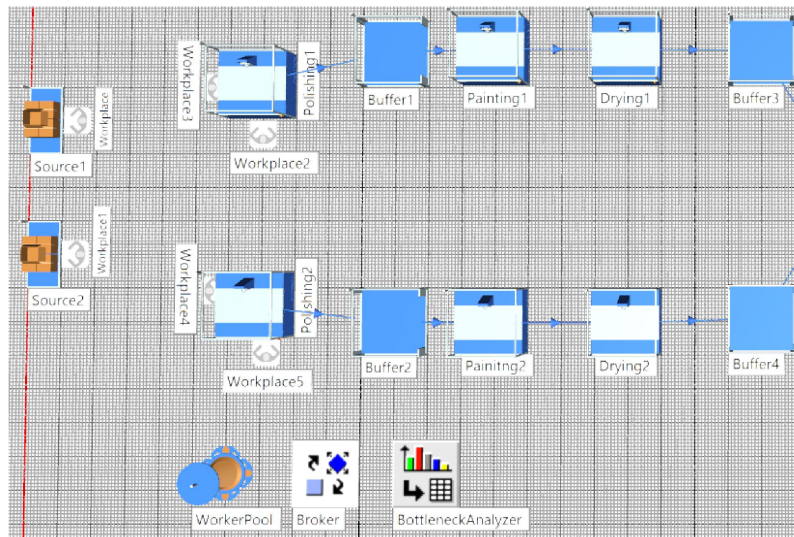


Figure.1. Material flow objects and resources in the manufacturing section.

The assembly section of the frame consists of buffers for each type of product, the workers transport the two types of parts from the storage in the buffers. The company wants to produce two types of products i.e Product 1 has 4 legs and product 2 has 3 legs. The products are assembled in the assembly station that is manually operated. The products pass through a quality gate where inspection is performed and the OK and NOT OK parts are labelled. The NOT OK parts go through the disassembly station which is worker operated, the disassembled parts are then transported to the drain. The OK products are transported to the drain where they are shipped off to a warehouse.

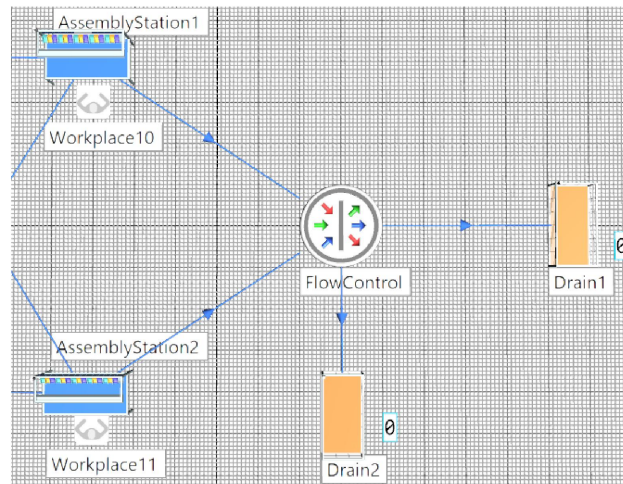


Figure.2. Material flow objects and resources in the assembly section.

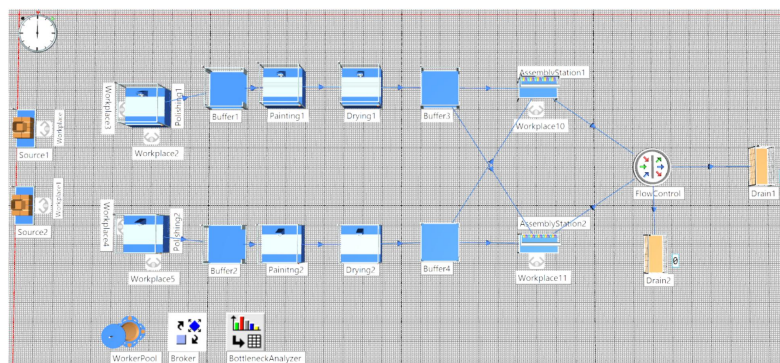


Figure.3.The complete overview of the furniture plant.

Create a model like the one in figure 3. Edit the objects respectively and input the following data.

Data

Manufacturing Frame Data

- *Source1* and *Source2* should produce one *Part* every 5 minutes. The amount should be set to -1. Define 2 different MUs in the class library as shown in Figure 4.1, *Source1* produces *Base* and *Source 2* produces *legs*
- To create new objects, right click on the MU you want to create under MUs as shown in Figure 4. A pop-up will open up and click on duplicate which would create a new object under Userobjects.

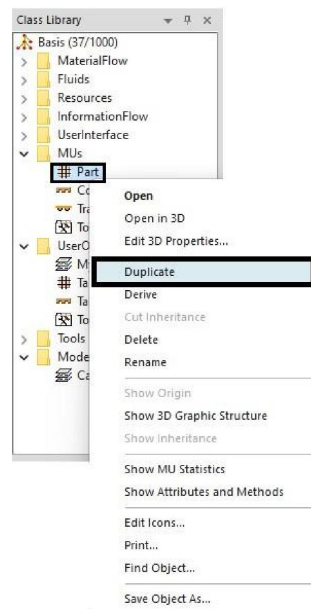


Figure.4.Create new objects

Figure.4.1.Class library

- Assign workers according to Figure 1. *Polishing stations 1 and 2* have a processing time of 2,1,4 minutes (Triangular distribution) and the setup time is 4 minutes. *Station 1* has an availability of 85% with an MTTR of 3 minutes.
- *Buffers 1 and 2* have a capacity of 15.
- *Painting station 1 and 2* have a processing time of 6 minutes with a setup time of 2 minutes.
- *Drying station 1* has a processing time of 200 minutes, *Drying station 2* has a processing time of 40 minutes and both stations have a setup time of 4 minutes.
- Place *Workplaces* according to Figure 3.
- *Buffers 3 and 4* have a capacity of 20.

Assembly Frame Data

- The processing time of *Assembly station 1* and *station 2* is 10 minutes. They have the same setup time of 2-3 minutes. Configure the *Attributes*, the *Assembly table* should be set to *Depends on Main MU* and Click on **Open** and establish the final product with the number of parts, establish **Main MU** and the *MUs* that are assembled on it and the number of MUs that are required to produce the product, *Assembly mode* should be set to **Attach MUs** and **Exiting MU** should be set to **Main MU**. (HINT: there are two different products produced, one type in each station)

.Models.Carfactory1.AssemblyStation1.AssemblyTable			
Base			
	Main MU	MU Name	Number
1	Base	Fixture	4

Figure.5.Attribute menu

- Of the products that pass through the *Flowcontrol* (quality check), 90% of the products pass the check. (HINT: *Percentage*)
- Place *Workplaces* according to Figure 3.

Work with the worker(object)

A worker acts as a person working in the industry. The use of a worker is to simulate working in a station or picking and dropping off parts/items. A worker has to be set up by initially placing a worker pool and broker. These can be accessed from **Toolbox** → **Resources** → **Workplace/worker/Workerpool/Broker** as shown in Figure.6. The **workerpool** defines a breakroom or lounge in the industry. The **broker** sends the worker from the workerpool to the workplace.

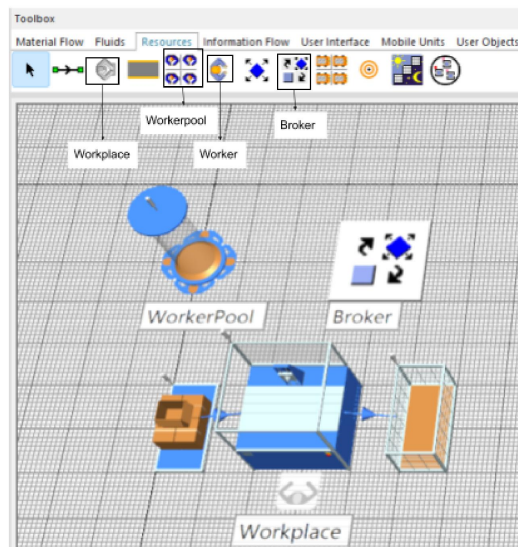


Figure.6. Icons for workerpool, broker and workplace

Assigning workers

A **worker** can be assigned to do processing, setup, failure and material handling. The initial step to assign a **worker** to a station is by clicking on the station that needs a **worker** and going to the "Importer" tab and click "Active" on the processing tab as shown in Figure.7. A **worker** can be defined on what task they can do. For eg. A **worker** can just do processing at a station or the **worker** can work at a station pick up the product and move to another location. To define

services for the **worker** the station, workplace and the **worker** should be defined on what task they should perform.

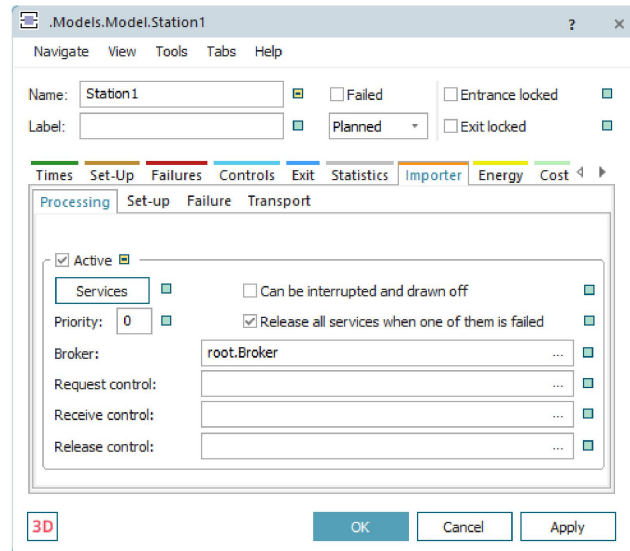


Figure.7. Importer tab for a station to request a worker

Designing services for a worker

Figure.8 shows how to define a workplace, click on the workplace and deactivate the inheritance (small icon near "Supported Services"). Open "Supported Services" and define what task the **worker** wants to perform. A **worker** can perform multiple services but a station can have only one service.

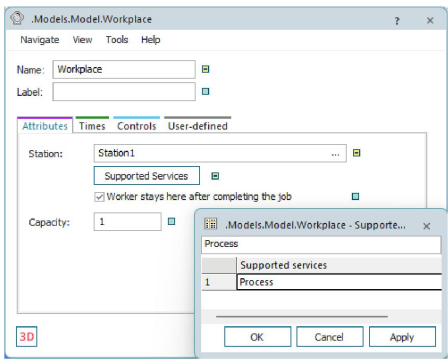


Figure.8. Defining services in the workplace

Designing services for a station

Services for the station can be defined where a **worker** can be called and the defined service can be carried out. As shown in Figure.9. Click on the station and go to the "Importer tab". Turn off the inheritance and click on "Services". From this, a small pop-up comes up where you can define the services that the station needs to perform.

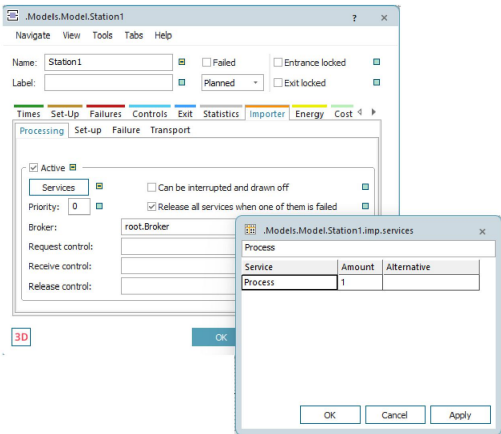


Figure.9.Defining services in the station

Designing services for a workerpool

Services for the **workerpool** are to be defined so the **worker** can go to the designated station when called. To define them click on the **worker** pool and click **Creation Table** and a pop-up tab opens up and the **workers**, the **amount of workers and their services** can be added as shown in Figure.10. Make sure the name of the service that's being defined is the same as in the station and the workplace. The service name is case-sensitive, so make sure the service names have the same case or else PlantSim will consider the two names are two different services.

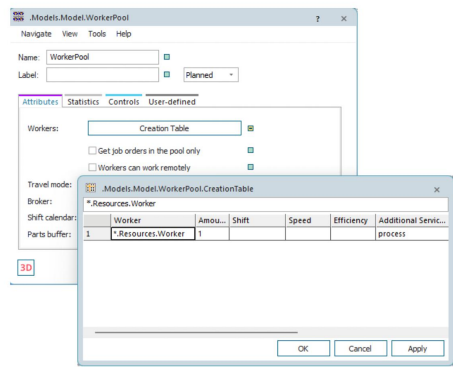


Figure.10. Defining the worker in the workerpool

Designing exit services for a station

To make a **worker** exit the **station** and go to a designated place click on the **Transport** tab in **importer** as shown in Figure.9. Material handling can be performed by going to the **Importer** tab in the **station** and go to the **Transport** tab as shown in Figure.11. Click on **Active** and open **Services**. A pop-up will open where the service for the **worker** to exit the station can be defined. Name the service and click **Apply** to save the changes.

Figure B.13: Revised Lab2 page 13

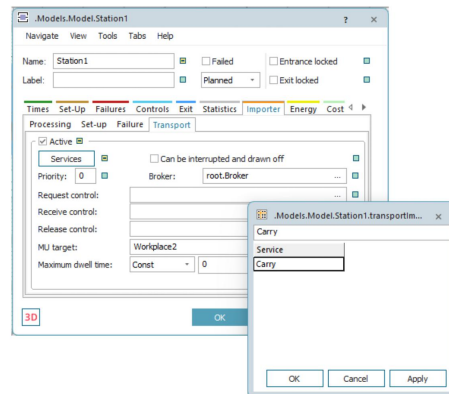


Figure.11. Exit service for a station

Extra task (optional)

Getting familiarized with workers

Let's create a simple model as shown in Figure.12 where only one worker is assigned to work at both stations. The **worker** has to work at **Station 1** and then carry the part to **Station 2**, process the part and come back to **Station 1**.

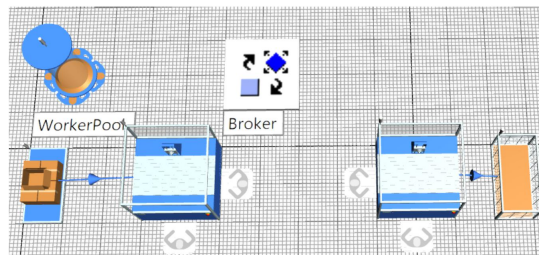


Figure.12. Example layout

- Create a source and connect it to a station
- Add two Workplaces to the station.

- Now create another station that connects to a drain and place two Workplaces in that station.
- Now place a Workerpool and a Broker.
- Click on the first Station go to the "Importer tab" and click on active in the "Processing" tab. In the same importer, tab go to "Transport" and give active. The "Transport" tab will enable the material handling function. Do the same with the second station but activate only the "Processing".
- Now define the services in the stations. Both the stations give "process" as shown in Figure.9. For the first station give "carry" as shown in Figure.11.
- As shown in Figure.8. give "**process**" to the worker working in the station and "**carry**" in the **workplace** for the worker to carry the part from the first station to the other.
- Finally, click on the **workerpool** as shown in Figure.10. Click on the "**Creation Table**" and give "**carry**" under "**Additional Services**" and in the next column give "**process**".
- After defining all the services run the simulation.
- Make sure the case sensitivity for "**process**" and "**carry**" are the same or else the call function wouldn't work.

Questions for Task

1. How many OK parts are produced by the furniture plant in 7 days?
2. Design the worker so that the worker carrying the part from the source also operates the polishing station. Now determine the throughput time to produce 10 products.

Extra questions 2

1. The furniture company wants to make their plant completely automated, design the production system in a way it involves no workers, parts are automatically sent between the machines and every station is automated. Now check the throughputs of both the scenarios and justify if the change is beneficial. (Cost per worker is 2000\$, cost for transport automation is 150000\$ and automated stations cost 50000\$ each). (Hint: use a scenario where the carrying of parts and polishing operators are two different workers.)

Refer Introduction section for submission requirements and details.

C

Revised Lab 3 material

LAB 3

Simulation of production system

MPR271

Table of contents

Table of contents	2
Learning objectives	3
Introduction	4
Task 1 Introduction	4
Model production system with data table	4
Warm up period	6
Data	9
Questions to answer for Task 1	9
Extra questions for Task 1	10
Task 2 Introduction	11
Modeling a small production system	11
Data	12
Questions to answer for Task 2	12
Extra questions for Task 2	12

Figure C.2: Revised Lab3 Page 2

Recap of Lab 2 learning objectives

LO3. Create a simulation model representing a complex production system using a professional DES software package and established modelling techniques.

LO3.15. Apply a worker

LO3.16. Apply a workerpool

LO3.17. Apply a broker

LO3.18. Simulate different worker types/roles

LO3.19. Test manual material handling with operator movements

LO3.20. Plan and model an assembly station to combine different components/products/fixtures

LO3.21. Estimate a product failure/scrap rate

LO3.22. Illustrate graphical changes to products, including dynamically through a simulation run

LO5. Plan, design, and perform experiments to improve a production system based on a DES model.

LO5.1. Summarize and present data from the simulation model

Learning objectives

LO3. Create a simulation model representing a complex production system using a professional DES software package and established modelling techniques.

LO3.23. Use parallel station and batching

LO3.24. Illustrate graphical changes to products, including dynamically through a simulation run

LO5. Plan, design, and perform experiments to improve a production system based on a DES model.

LO5.1. Summarize and present data from the simulation model

LO5.2. Plan and run a warm-up analysis

LO5.3. Illustrate graphs for the objects

Figure C.3: Revised Lab3 Page 3

Introduction

Plant Simulation is a discrete-event simulation (DES) software by Siemens PLM Software. Plant Simulation allows the user to create or replicate object-oriented and hierarchical simulation models of various production and logistics systems. It can be used to analyze and rectify problems and inefficiencies in the simulation models.

The premise of the lab is to model a production system and experiment using data tables and warm up time. Lastly, to use simple *Simtalk 2.0* programming strategies to simplify steps required to produce the desired results.

To pass this lab session:

- Work through the instructions and answer the question presented in the Task.
- For Question 3, write the methods in the same PDF.
- Upload the answers to the tasks with an isometric view of the model in PDF on Canvas.

Extra Tasks:

- Extra tasks have been provided for those looking to challenge themselves.
- They have no weightage in overall scoring and do not influence the grades in any way.

Task 1 Introduction

Model production system with data table

In this task you have to design and model a factory that produces three metal boxes of different sizes. The **Source** produces three boxes of different sizes named Small (White), medium (Red) and large (Blue).

Hint: Create three parts in "**UserObjects**" in the **Class library**. Create a **Data table** and link it to the **Source**. In the **Data table** define the object name in **MU** and give the required frequency. Give the "**MU Selection**" to "**Random**" in the source as shown in Figure.1.

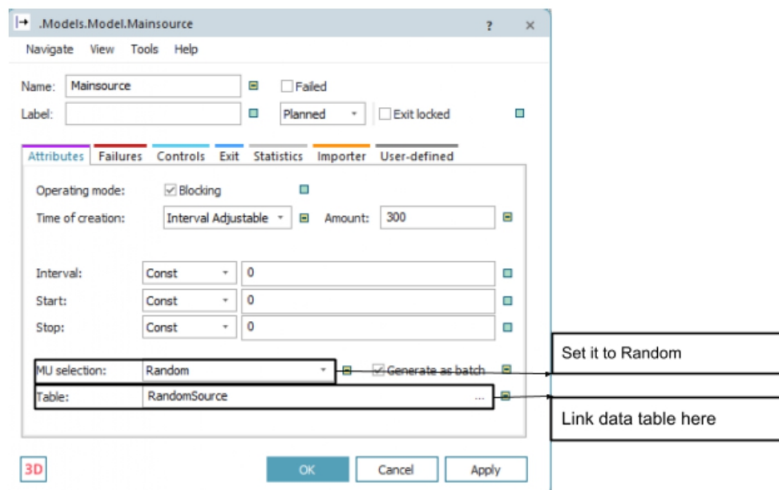


Figure.1. Editing Mainsource

The products go through a flow control where depending on the size of the product they are routed to that particular station.

Hint: Set "**Exit Strategy**" to "**MU Names**" in Flowcontrol to send the product to its respective station. Click on "**Open List**" after selecting MU Names and list the "**Part Name**" and the Successor will be 1,2 and 3 respectively.

There are three sets of station lines, **Station large**, **station medium** and **station small**. In the station line, the products pass through a buffer connected to an internal polishing machine and then to an external polishing machine. After the products are polished they are then sent to a common buffer which is connected to a **Parallel station** in which the embossing process is done as a batch. The products are then sent to another buffer and then to a packaging station where they are packed and labeled. Based on the size of the product they exit out of the flow control through to the respective drain.

Figure C.5: Revised Lab3 Page 5

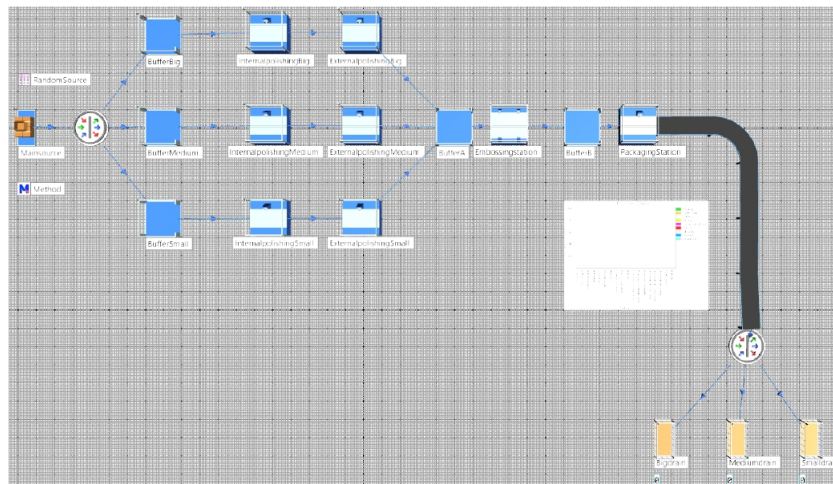


Figure.2.Overview of the production system

Warm up period

Use the **Chart** function to observe stabilization, open the chart and then click on the data tab and the display tab make suitable to changes shown in figure 2 and figure 3

What is warm up time ? Why is it important parameter to be consider in DES ? **OPTIONAL**

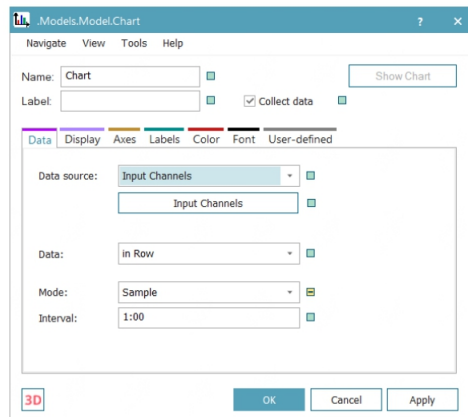


Figure.3.

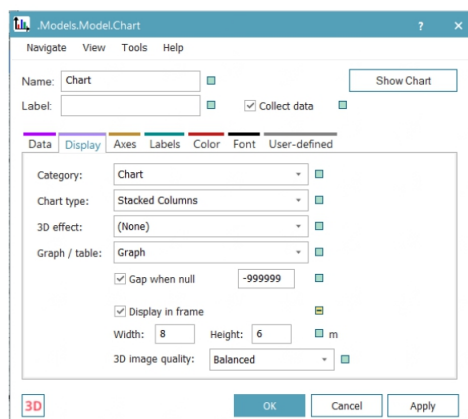


Figure.4.

Now drag stations and resources in the real time chart, run the simulation and observe the statistics in real time.

Set warm up time and use the statistics report

Click on the **Event Controller** and open the **Setting** tab, here the **End** value determines the length of the simulation, set the desired simulation time in **DD:HH:MM:SS**. The warm up time is set in **Statistics** and it is set in **HH:MM:SS**. Once the warm up time is determined click apply and now run the simulation. Figure 4 showcases the Event controller window.

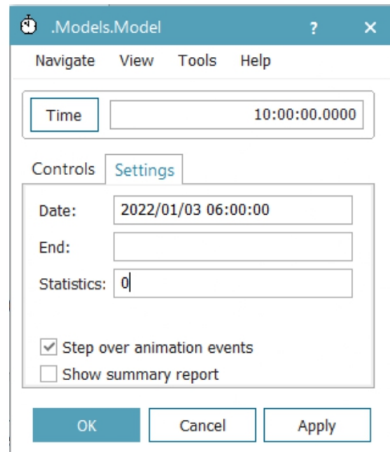


Figure.5.

After the simulation has run for the desired length. Go to the model frame and select the entire factory layout and click on the **Statistics Report** in the Ribbon menu. Here a detailed report on resource and service statistics can be procured.

Data

- The part data is found in Table.1.

Color	Length (m)	Width	Height
White	0.1	0.1	0.5
Red	0.2	0.2	0.5
Blue	0.3	0.3	0.5

Table.1. Part specifications

- **MainSource** produces boxes every 5 minutes and the frequency of production of all sizes is equal (Hint 100/3).
- **Buffer Big, Medium and Small** have a capacity of 5
- **Internal polishing Medium and Small** have a processing time of 7-8 minutes and for **Internal polishing Big** it is 10 minutes with the setup times being 4 minutes for all stations.
- **External polishing Big, Medium and Small** have a processing time of 10 minutes and setup times of 5,1,5 minutes (Hint: Triangular distribution=c,a,b).
- **BufferA** has a capacity of 15.
- **Embossing station** has a processing time of 2 minutes and a set up time of 6-8 minutes.
- **BufferB** has a capacity of 15.
- **Packaging station** has a processing time of 10 minutes and a setup time of 2 minutes.
- Conveyor length 15m.

Questions to answer for Task 1

1. What is the warm up time of this model ?
2. How many products are produced after a **warm up time** of 3 hours and a simulation time of 7 days ?
3. For the source remove the **flowcontrol** and the source sends the three parts to it's three respective stations. (Hint: Link method to the source. Write an "if..elseif.." statement where when the part is a Big part, it would go to the "BufferBig". The statement should start with `if @.class = .UserObjects.PartBig....`)

Extra questions for Task 1

1. From Figure.2., it can be seen that the flow of resources is completely automated. Instead of being automated, use workers to carry the parts. Use five workers in total, where the first three workers pickup products from buffer big, medium and small and drop it at ***internal polishing big, medium and small*** respectively. Those same workers have to polish internally and externally. Two other workers will be at the embossing station and packaging station. These workers should only work for 40 hours a week. (Hint: Use shift calendar for the working hours of the workers.)

Task 2 Introduction

Modeling a small production system

In this task, you have to model a cutting and grinding section of a section of a factory. The factory produces gym equipment, but this production line produces weight plates of three kinds. The initial raw material is cut into a mix of the three kinds of weight plates. All the plates are 440mm in diameter but vary in thickness which is proportional to their weights. 1.5 cm weighs 5 kg, 3 cm weighs 10 kg and 6 cm weighs 20 kg.

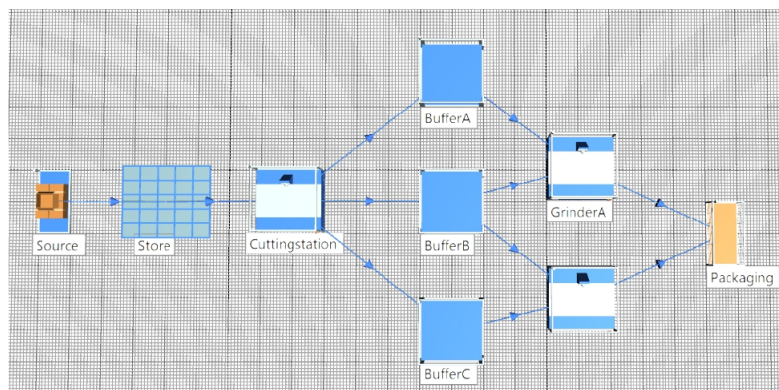


Figure.6. Overview of the first stage to the final project

From Figure.6. The **source** will send raw materials to a store with a capacity of 20 products per day. From the **store** the products are sent to the **cutting station**. The **cutting station** will cut the part into three different sizes 1.5, 3 and 6 cm (Part A,B,C) respectively. After cutting the parts shall be sent to its respective **buffers**. Part A to buffer A, part B to buffer B, and part C to buffer C. From the buffers, the parts go into **grinding**. Part A and B should go to Grinder A and Part B and C should go to Grinder B. After grinding all parts get sent into a **single drain** which will be used as **packaging**. (Hint: use methods to cut the parts and send it to the buffer with exit control strategy.)

Data

- The length of the **raw material** is 32cm which is cut into 1.5, 3 and 6 cm respectively.
- **Store** has a capacity of 20 products.
- The **cutting machine** has a processing time of 160 seconds and a setup time is triangular distributed with min 11, mode 14, and max 25 seconds.
- **Buffer Big, Medium and Small** have a capacity of 5.
- The processing time for both the **grinders** are 200 seconds and the setup time is 280 seconds normally distributed.

Questions to answer for Task 2

1. What is the total number of weight plates produced by the section of the factory in 30 days?
2. Find the number of Part A, Part B and Part C produced for 100 raw materials.
3. Design the cutting method logic in such a way that the scrap rate remains constant for every raw material cut.

Extra questions for Task 2

1. The factory plans to use an onsite recycling strategy, they intend to use the scrap leftover from cutting and introduce it back into the system through recycling and use it to make products. How many products of Part A, Part B and Part C can make scrap leftover from cutting 1500 raw materials ?

Refer Introduction section for submission requirements and details.

Figure C.12: Revised Lab3 Page 12

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