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ARENA SIMULATION SOFTWARE AS AN EXAMPLE OF THE DISCRETE EVENT SIMULATOR

The goal of this article is to briefly present Arena Simulation Software as an example of Discrete Event Simulator used for modelling queuing systems. It contains example Case Study and the key factors that may be vital when making a purchasing and implementation decision of the Simulation Software.

1. Introduction

Over the years organizations are implementing Lean to achieve competitive advantage, which is a *"condition which enables a company to operate in a more efficient or otherwise higher-quality manner than the companies it competes with, and which results in benefits accruing to that company."* [1]

Lean production is the philosophy of eliminating all waste in all system processes continuously. The system is the complete set of processes required to produce the product. In Lean Production every action that is taken to improve processes is planned, implemented, and evaluated in terms of the overall goals of the system.

Combining multiple processes into one piece flow should be a primary objective in Lean manufacturing. Merging processes completely eliminates and prevents the build up of inventory and allows for much smoother operations. But it is not always possible.

The main reasons why we are not always able to facilitate single piece flow are:

- There are shared resources that can cause bottlenecks,
- There is equipment with long change-over times,
- The output of a particular process goes to many different follow-up processes.

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[1] InvestorWorlds.com competitive advantage Definition http://www.investorwords.com/998/competitive_advantage.html - accessed on 5 August 2010.

Alternative to single piece flow is batch manufacturing which means *"producing lots or quantities of a product in order to achieve maximum "Economic Order Quantities" (EOQ). Although some products must be batched to maximize use of equipment with long cycle times, often batching is wrongly assumed to be more economical than single piece production for various reasons.*

Often when large "batches" are the preferred operating mode it is due to excessively long or difficult changeover practices. Improving changeover techniques through SMED implementation will generally minimizes lot or "batch" sizes, reduce finished goods inventory on-hand, allow for increased varieties of products that can be made more quickly, and ultimately lead to greater customer responsiveness." [2]

In the situations when we have to link batching with single peace flow we should use one of the inventory control interfaces, such as Kanban systems, supermarkets and FIFO lanes.

Future State Map is one of Lean visual tools that show how a value stream can look after improvements have been implemented. A value stream is all the actions (value added and non-value added) currently required to bring a product through the main flows: from raw material to customer, and the design flow from concept to launch.

Creating a Future State Map that is optimal for our organisation is not an easy task. Data has to be first collected and then analysed. Depending on the complexity of the organisation we may consider using a professional software. A range of simulation methods are used by organisations. The primary approaches are discrete-event simulation, Monte Carlo simulation, system dynamics and agent based simulation [3].

Commonly used to simulate manufacturing environment are Discrete Event Simulators. Discrete-event simulation is used for modelling queuing systems [4]. A system is represented as entities flowing from one activity (effectively a time delay) to another. Activities are separated by queues. The queues result when entities arrive at a faster rate than they can be processed by the next activity. Discrete simulators (such as ProModel, Arena, Extend, and Witness) generally rely on a transaction-flow approach to modelling systems. Models consist of entities (units of traffic), resources (elements that service entities), and control elements (elements that determine the states of the entities and resources). They are not

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[2] ThroughPut Solutions Batch Manufacturing | Lean Manufacturing Glossary http://www.tpslean.com/glossary/batchdef.htm – accessed on 5 August 2010.

[3] S. Robinson, SIMULATION The Practise Of Model Development And Use, Second Edition, Palgrave Macmillan, New York 2014.

[4] W. David Kelton, Randall P. Sadowski, Nancy B. Zupick, Simulation with Arena, Sixth Edition, McGraw-Hill International Edition, New York 2015.

meant to model the movement of continuous material (e.g., water) or represent continuous systems that are represented by differential equations[5].

2. Arena Simulation – Example Case Study

We can use the Arena Simulation Software as a very good example of the Discrete Event Simulators. It will be only a short review to give the general understanding on the matter, based on the example case study presented below.

2.1. Data

Two products AX123 and BX123 have been identified as a high volume, runner, and family products. The parts are identical mirror images as AX 123 is fitted to the left hand side of the vehicle and BX123 is fitted to the right hand side of the vehicle.

The product structure trees shown below (Fig. 1) present the assembly of AX123 and BX123.

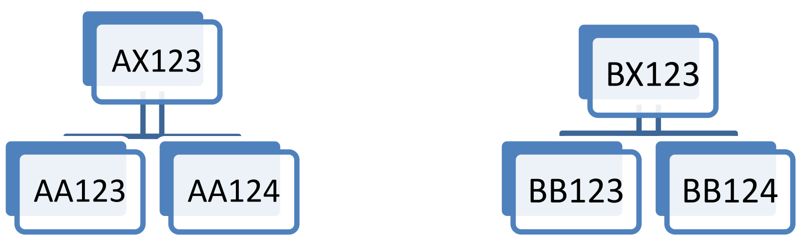


Fig. 1. AX123 and BX123 product structures
Source: own research.

All components are launched in a batch size of 1, but for economic reasons and due to short processing times (press shop) at various stages in the manufacturing process they are batched up and then separated back to single piece flow.

Components AA124 and BB124 are first punched and pressed in the batch size of 10 and then they are separated to the batch size of 1 and send to the assembly area.

Components AA123 and BB 123 are machined twice on a CNC machine. Universal fixtures are used to locate product on the machine base plate, which

[5] GoldSim Technology Group Selecting Simulation Software http://www.goldsim.com/Content.asp?PageID=603 - accessed on 24 March 2010.

helps to reduce set up times. A skilled operator is loading fixtures to the machine, start the automated machining cycle and when operation is completed, he turns the component over, load to the fixture and start the automatic cycle again. After machining the parts are automatically ejected and are batched up to batch size of 5 and sent for painting at a subcontractor. On returning they are separated to a batch size of 1 and are send to the assembly area.
All products are then shipped to stores.
Coventry Automotive Manufacturer resources and their capacity:

No.	Resource	Capacity
1.	Skilled operator	1
2.	CNC machine	2
3.	Fixtures	2
4.	Punch	1
5.	Press (shared resource)	1
6.	Assembly	1

Fig. 2. Resources Capacity
Source: own research.

Arrival Rate

The arrival rate for components AA123 and BB123 is 25 minutes. Every 25 minutes one component is launched- or AA123 or BB123. The same situation is for components AA124 and BB124.

1 component every Expo (25) mins: 50% AA123, 50% BB123

1 component every Expo (25) mins: 50% AA124, 50% BB124

Manufacturing processes Routes and Times

All manufacturing processes routes and times are show below:

Op. No.	AA124	Batch	Time per part (minutes)	AA123	Batch	Time per part (minutes)	AX123 (AA123 + AA124)	Batch	Time per part (minutes)
Op 10	Punch	10	Norm (1,0.2)	CNC	1	Norm (14.2, 0.7)	Assemble	1	Norm (23,1.2)
Op 20	Press	10	Norm (2.0,0.2)	CNC	1	Norm (12.3, 1.2)	Inspect	1	-
Op 30	-	-	-	Paint	5	4 hrs turn around per batch of 5	-	-	-

Fig. 3. Processes Routes and Times for AX 123

Op. No.	BB123	Batch	Time per part (minutes)	BB124	Batch	Time per part (minutes)	BX123 (BB123 + BB124)	Batch	Time per part (minutes)
Op 10	Punch	10	Norm (1,0.2)	CNC	1	Norm (15.5, 0.5)	Assemble	1	Norm (23,1.2)
Op 20	Press	10	Norm (2.0,0.2)	CNC	1	Norm (13.7, 0.9)	Inspect	1	-
Op 30	-	-	-	Paint	5	4 hrs turn around per batch of 5	-	-	-

Fig. 4. Processes Routes and Times for BX 123
Source: own research.

Material transfers from:

- raw material stores to the press shop – 5 mins,
- raw material stores to the CNC machines – 5 mins,
- All other transports or products are negligible.

CNC Fixture loading times:

OPERATION	AA123	BB123
Op 10	2,5 mins	3,5 mins
Op 20	4,8 mins	4,1 mins

Fig. 5. CNC Fixture Loading Times
Source: own research.

2.2. Model Development

Basic Flowchart

First we need to create basic flowchart on which all simulation will be based.

The flow chart below presents the basic manufacturing operations within the example company. As we can notice there are two production lines. First line is for AA123 and BB123 components production; second one is dedicated to AA124 and BB124 components. Both lines are connected before the assembly operation.

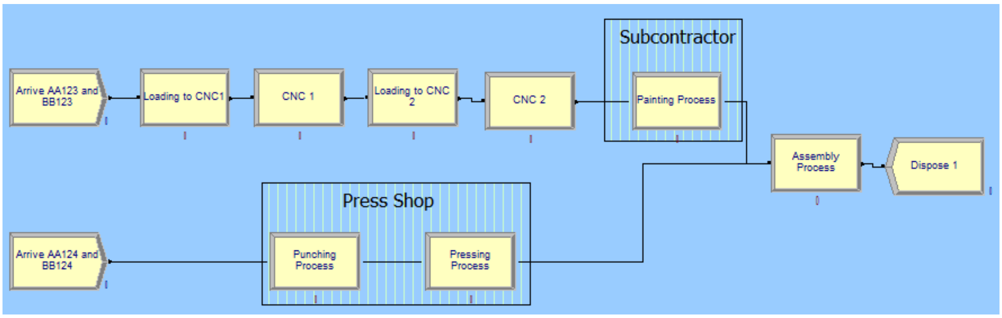


Fig. 6. Basic Flow Chart
Source: own research.

First Line:

AA123 and BB123 components are loaded and machined twice on CNC machines, and then they are sent to subcontractor in the batch size of 5 for painting.

Second Line:

AA124 and BB124 components are first Punched and Pressed at the Press Shop. It is required to create the batch of 10 before proceeding to Press Shop.

Connection:

Before Assembling both lines are link together and matched to particular products. Assembled products AX123 and BX123 are then dispatched.

Initial Simulation Model

Figure 7 and 8 below presents initial simulation model created in Arena simulation Software. Contains manufacturing operations, transportation, matching, batching and separating components. This model is based on basic flow chart shown on Figure 6.

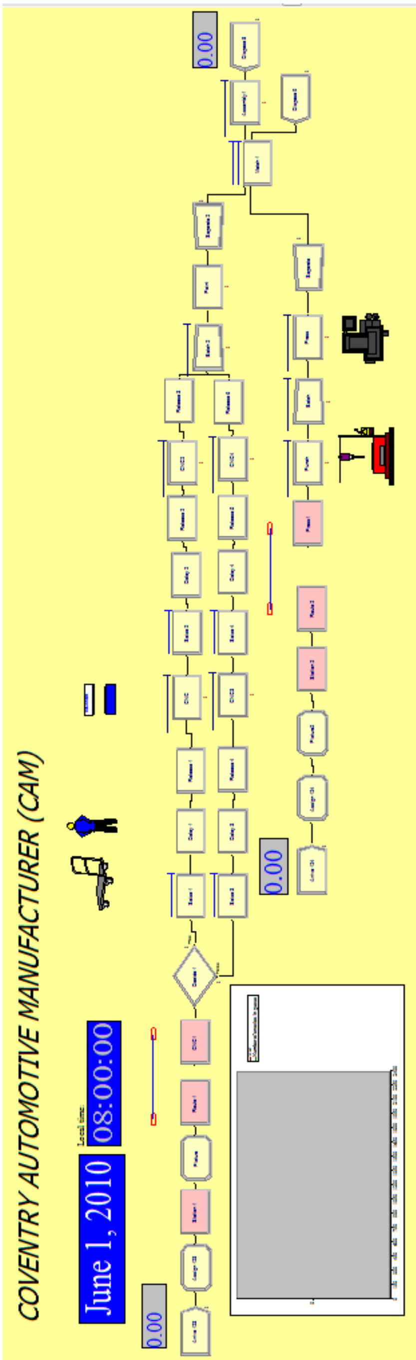


Fig. 7. Initial Arena simulation model
Source: own research.

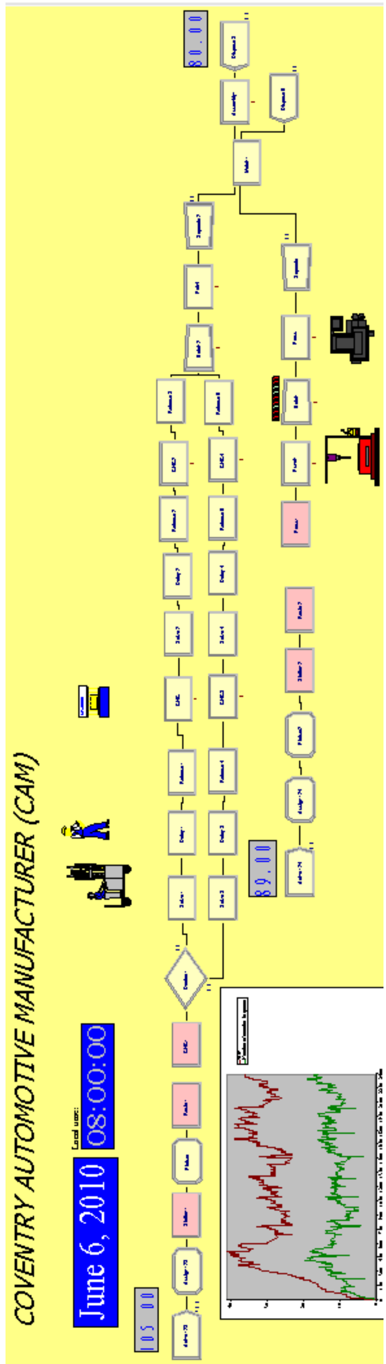


Fig. 8. Initial Arena simulation model – after running
Source: own research.

Below is presented only a very small part of the logic used during programming in Arena Simulation Software.

<u>AA124 and BB124 Components processing</u>

Fig. 9. AA124 and BB124 component processing – part 1
Source: own research.

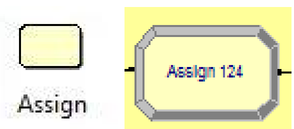
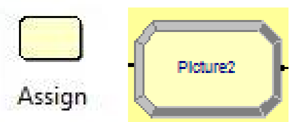
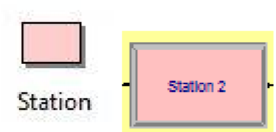
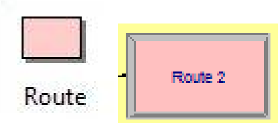
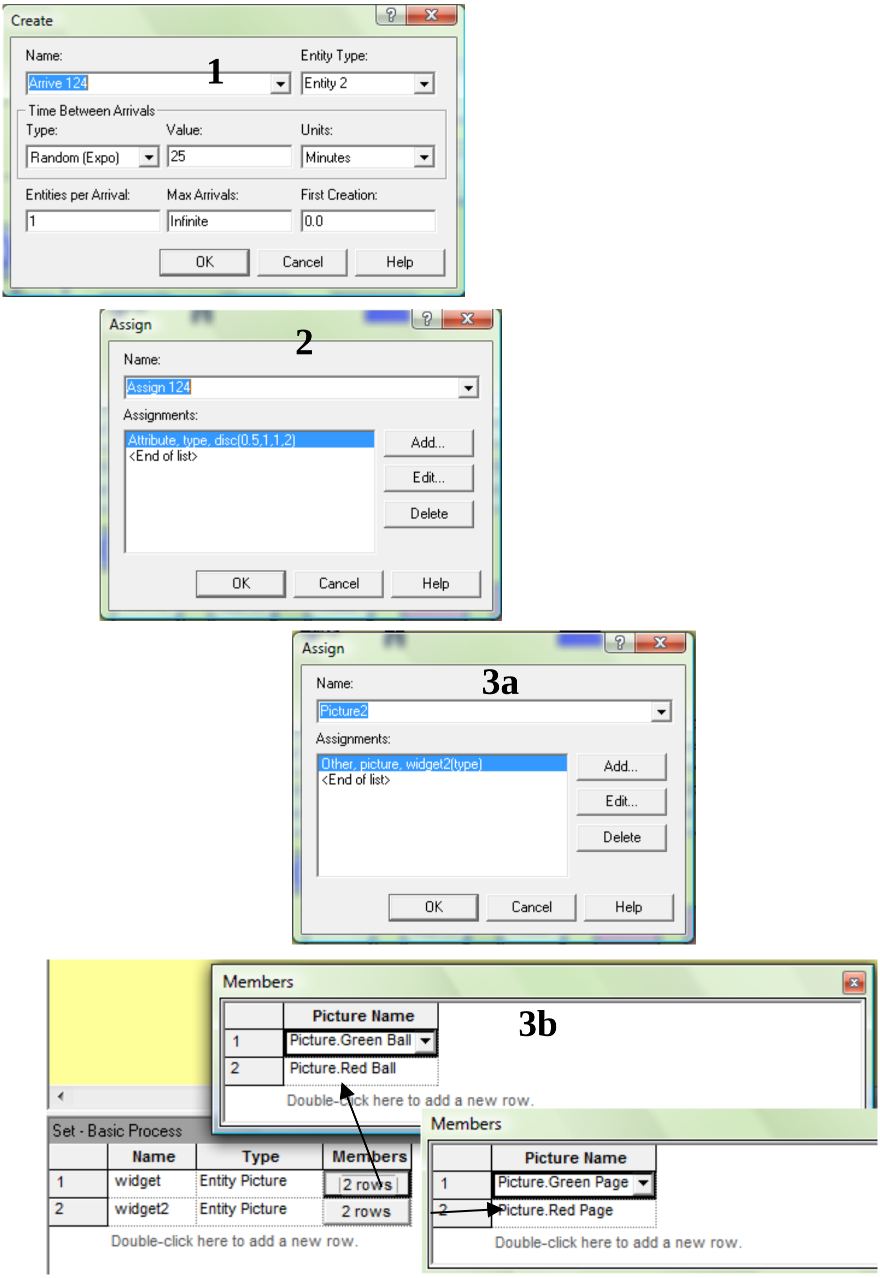
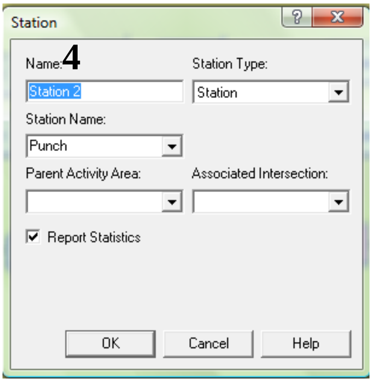
No.	Block type	Name	Comment
1.		Raw materials AA124 & BB124	Launch one component every 25 minutes = Expo(25) minutes
2.		Assign AA124 & BB124	50% of incoming raw materials will be assigned as AA124 products, 50% as BB124. Discrete probability (0.5,1,1,2) was used to express split of products
3.		Picture type	Assigns animation to each product type with a different colour entity moving across the model. SET data block was used to create picture set. (widget2(type)). For AA124 was used green page for BB124 red page.
4.		Station AA124 & BB124	Station Block was needed for animation purpose. Route Block allows setting material transfer time (5 minutes) between raw materials store and the Press Shop. Route block is not physically linked to another block.
5.		Route 2	

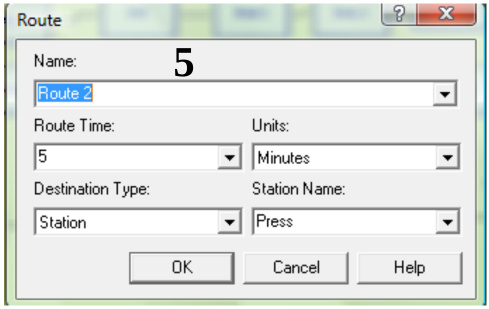
Fig. 10. AA124 and BB124 component processing part 1 – comments
Source: own research.

Cells details are shown below. Number of the block from the table is similar to the picture No.



Source: own research.





Source: own research.

2.3. Results of current conditions

Typical expectations from manufacturing systems are: high utilization, low inventory, short lead times and maximized outputs. That is why in this report we will focus on measuring needed data like: resources utilization, queues, production rate (number inputs to number outputs), lead time and work in progress. Collected data will enable us to create better future state model of manufacturing system in Coventry Automotive Manufacturer company. Detailed analyze of crucial outputs is shown below.

<u>Lead Time</u>

As we can see from The Arena report the average lead time for those manufacturing processes is 1381,8 minutes, which is slightly below 23 hours. With an assumption that Coventry Automotive Manufacturer shift last 8 hours per day that would mean that processing of one complete product takes about 3 working days. Lead Time is way too high and needs to be improved.

Collected Statistics are shown below.

	Average [minutes]	**Minimum [minutes]**	**Maximum [minutes]**	**Observations**
Lead time	1381,8	440.79	2396.1	69

Fig. 11. Lead time statistics
Source: own research.

<u>Queue size</u>

The number of entities in queue in different time intervals is shown below. Data was collected by using “Plot” option in Arena software. As we can see current process doesn’t have proper capacity. Queues are increasing constantly during the manufacturing process.

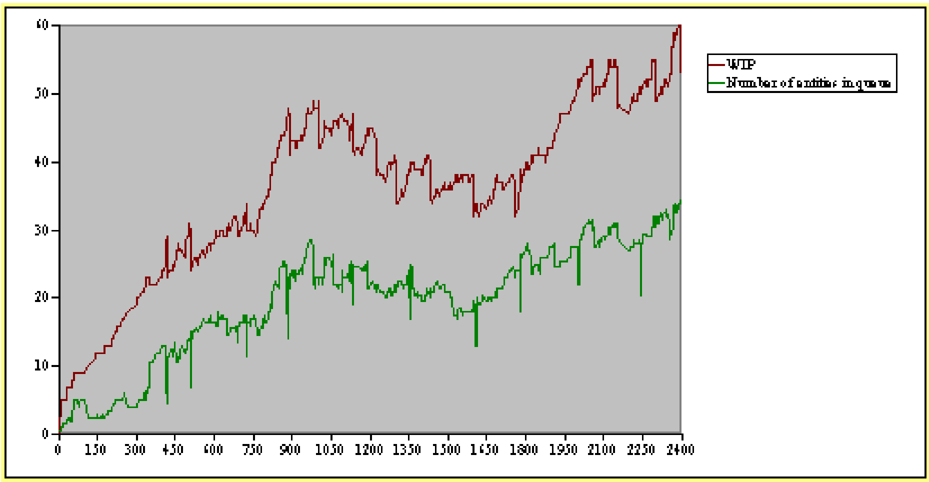


Fig. 12. Number of entities in queues in different time intervals
Source: own research.

Figure underneath illustrates number of waiting components and average time of waiting. The highest queues were observed during seizing processes (Seize 1 and Seize 3), which refer to loading process before CNC machining. High queues are result of limited Fixtures capacity.

Very high level of queues we can also notice during Batching process before press shop and painting, but the highest queues levels are at the end of the manufacturing process while matching BB123 with BB124 and in the final assembly cell. High waiting times is due to the difference between number of operations and cycle times during 123 (painting – turn over time of 4 hrs in a batch size of 5) and 124 (short cycle times) components manufacturing.
Assembly cell has not enough capacity.

No.	Queue	Number waiting	Waiting time [minutes]
AA123/BB123			
1.	Seize 1	***0,18***	***9,61***
2.	CNC machining 1	0	0
3.	Seize 2	0	0,21
4.	CNC machining 2	0	0
5.	Seize 3	***0,15***	***7,81***
6.	CNC machining 3	0	0
7.	Seize 4	0	0,08
8.	CNC machining 4	0	0
9.	Batching 5 (painting)	***1,87***	***55,63***
AA124/BB124			
11.	Batching 10 (press shop)	**4,68**	**106,25**
12.	Punching	0	0
13.	Pressing	0	0.00
Final matching and assembly			
14.	Final matching (AA123 & AA124)	*0,21*	*6,71*
15.	Final matching (BB123 & BB124)	***15,7***	***367,01***
16.	Assembly	***1,59***	***54,38***

Fig.13. Number of products waiting and average waiting time
Source: own research.

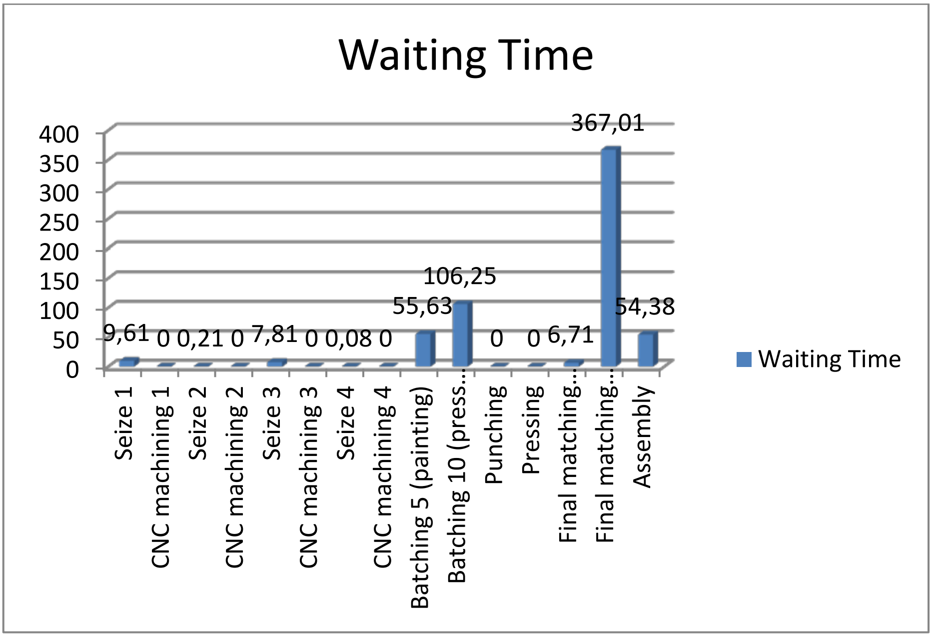


Fig. 14. Number of products waiting
Source: own research.

No.	Resource	Number of products seized	Utilization [%]
1.	Assembly	70	66,45
2.	CNC machine	167	48,01
3.	Fixtures	84	61,18
4.	Press	10	0,86
5.	Punch	10	0,4
6.	Skilled operator	167	25,83

Fig. 15. Number of resources utilization – table
Source: own research.

Resources utilization

Following figures shows resources utilisation depending on number of seized products. None of the resources is fully utilized due to large number of queues before operations. Utilisation rate is very low, but most utilized are assembly resource – 66,45%, Fixtures – 61% and CNC machine 48%. Typical resource utilisation should be about 85%, so future improvements should be implemented.

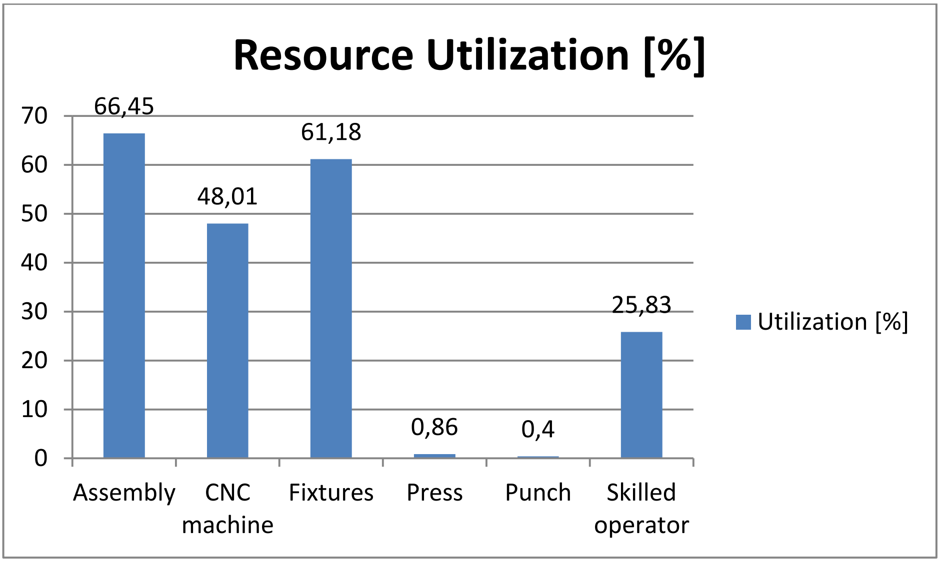


Fig. 16. Number of resources utilization
Source: own research.

Processes

Figure 17 shows processes value added time and waiting times during manufacturing. Most of the processes do not have waiting times. However one of them, namely assembly is having relatively long waiting time of 53,77 minutes. It might be caused by insufficient number of resources in assembly operation.

No.	Process	Value added time [minutes]	Wait time [minutes]	Total time [minutes]
AA123/BB123				
1.	CNC machining 1	14,71	0,00	14,71
2.	CNC machining 2	12,89	0,00	12,89
3.	CNC machining 3	14,87	0,00	14,87
4.	CNC machining 4	12,96	0,00	12,96
5.	Painting	240,00	0,00	240,00

AA124/BB124				
6.	Punching	0,95	0,00	0,95
7.	Pressing	2,05	0,00	2,05
Assembly				
8.	Assembly	***23,07***	***53,77***	***76,84***

Fig. 17. Processes manufacturing times
Source: own research.

Inputs vs. Outputs

Statistics below shows entities that are coming in and out from the manufacturing process. It is easy to notice Work In Progress is on a high level, which indicates long queues inside the manufacturing process. Number in – number out = 53.

	Number In	Number Out
Entity 1 (AA123/BB123)	103	84
Entity 2 (AA124/BB124)	119	85
Final products (AX123/BX123)	222	**169**

Fig. 18. Inputs and outputs
Source: own research.

As we can see Work In Progress is constant increasing during the simulation time.

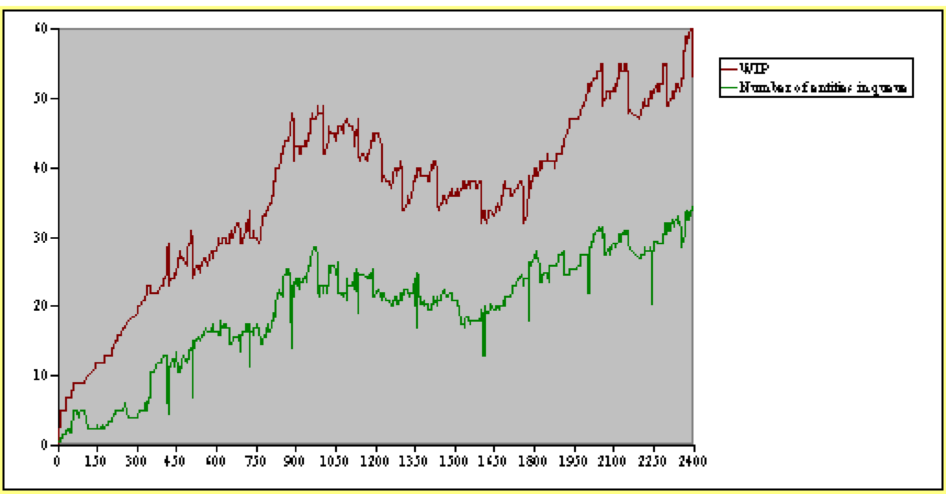


Fig. 19. Work In Progress
Source: own research.

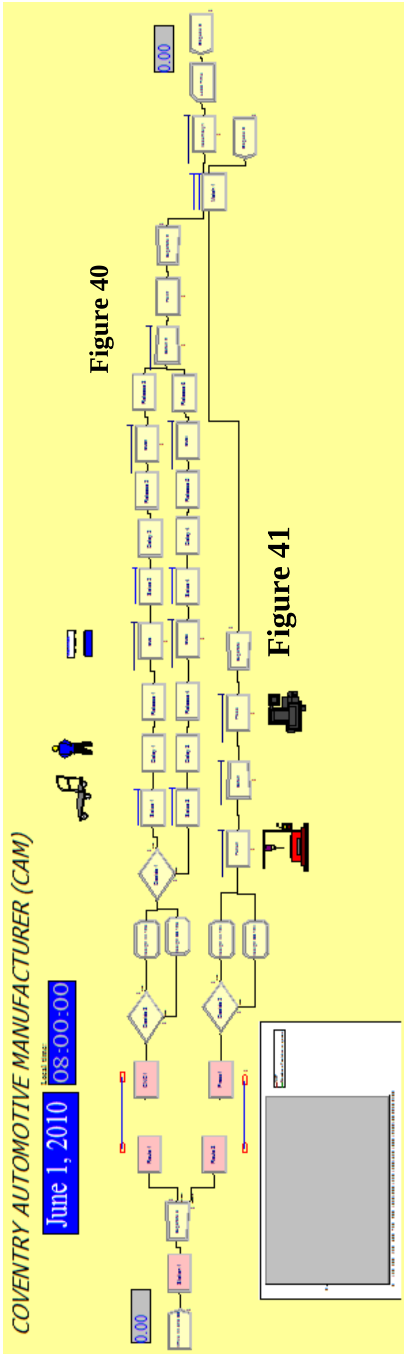


Fig. 20. Improved Arena simulation model
Source: own research.

Due to expected large increase in orders in the near future subcontractors are willing to invest in some new painting technology on side which will enable the components to be painted in a batch size of 1, with a reduced turnaround time of 6 minutes. Future state amendments relates also to:

- Press Shop Batching – batch size reduced from 10 to 5,
- Arrivals – one synchronised launch every 6 minutes.

Future State Simulation Model is very similar to initial Model that is why this part will focus only on differences between these two models.

Main changes are at the beginning of the manufacturing process because there is only one Create block used (one entity type).

Because of that separate block was needed to duplicate incoming entities to the system. They are separate threw decision block and one component is going to CNC machining while the other one is going to press shop area. This action is fully synchronized.

Next step of the process is created by using two decide blocks. Which separate exactly the same number of entity on both – true and false paths.

When entities are separated and synchronized assign blocks assign product types which enables to launch AA123 with AA124 and BB123 with BB124.

Batch size in the Press shop was reduced to 5, while batch size of products going for painting to the subcontractor was reduced to 1. Time of turnaround was also significantly reduced to 6 minutes.

After creating a model we can then experiment on it to make a best possible decision, by changing inputs and analysing outputs such as presented below for queues:

		Initial Model		**Improved Model**		**Experimental Model**	
No.	**Queue**	**Number waiting**	**Waiting time [minutes]**	**Number waiting**	**Waiting time [minutes]**	**Number waiting**	**Waiting time [minutes]**
AA123/BB123							
1.	Seize 1	***0,18***	***9,61***	***12,56***	***193,17***	▲14,87	▼164,49
2.	CNC	0	0	0,00	0,00	▲0,16	▲4,54
3.	Seize 2	0	0,21	**0,02**	**0,59**	▼0,01	▼0,37
4.	CNC 2	0	0	0,00	0,00	▲0,08	▲2,05
5.	Seize 3	***0,15***	***7,81***	***12,34***	***198,93***	▲14,78	▼172,59
6.	CNC 3	0	0	0,00	0,00	▲0,18	▲5,12

7.	Seize 4	0	0,08	0,00	0,00	▲0,01	▲0,24
8.	CNC 4	0	0	0,00	0,00	▲0,06	▲1,79
9.	Batching 5 (painting)	***1,87***	***55,63***	0,00	0,00	0,00	0,00
AA124/BB124							
11.	Batching (press shop)	**4,68**	**106,25**	***1,89***	***11,83***	▼1,81	▼9,60
12.	Punching	0	0	0,00	0,00	0,00	0,00
13.	Pressing	0	0.00	0,00	0.00	0,00	0.00
Final matching and assembly							
14.	Final matching (AA123 & BB123)	*0,21*	*6,71*	0,00	0,00	0,00	0,00
15.	Final matching (AA124 & BB124)	***15,7***	***367,01***	**24,82**	**210,86**	▲30,67	▲190,27
16.	Assembly	***1,59***	***54,38***	**14,66**	**69,43**	▼0,18	▼2,77

Fig. 21. Queues
Source: own research.

Further analyze of the case study can be done, but it is not the purpose of this article. The aim is only to present the analytical possibilities of the simulation tool such us Arena Simulation Software. How we will use it depends only on our needs and our IT knowledge.

This kind of software is very useful if the would like to see how changes will affect the production line in real life without spending money and loosing precious time.

3. Recommendations

According to Kuljis and Paul and Wang and Liao, simulation is and always was a highly specialist application area, with a high degree of difficulty. Simulation beginners often spend a great amount of time to accumulate the knowledge as well as the experience to overcome the technical complexity of simulation, and even for the experienced user, building, running, and analysing a simulation model can be a very time-consuming and error-prone process [6].

That is why it is so important to choose the software that will really help us to solve our problems. To choose the most suitable software for us we should consider key factors that may be vital when making a purchasing and implementation decision, such as:

a) The general type of simulation tool, for example:

- Discrete Event Simulators,
- Agent-Based Simulators,
- Continuous Simulators,
- Hybrid Simulators,

b) Vendor

- How long the vendor exists on the market,
- On-line help and technical support,
- Updates,
- Free demo version,

c) Input

- Importing and Storing data (capability to import files created in a different type of programs like : CAD drawings, Excel tables, ProModel files),
- Simulation objects (resources, objects, components etc.),

d) Output

- Types of reports (Standard or customized),
- File exporting (exporting data, events to a file),
- Interface to other programming language (ability to switch to another programming language for additional info),

e) Animations and graphics

- Icons (are standard icons provided),
- Dynamic animations and graphics,
- 3D simulation,

f) Cost

- General purchase price for each software version,

[6] J. Byrne, C. Heavey, P.J. Byrne, (2010) 'A review of Web-based simulation and supporting tools'. Simulation Modelling Practice and Theory 18, pp. 253-276.

- Cost of additional training,
- Cost of additional features.

The Table below shows comparison of three main simulations software against factors mentioned above:

No.	Factor	Software's ability		
		Simul8	**GoldSim**	**Arena**
1.	**The General type of simulation tool**	Discrete Event Simulator	Continous process Simulator	Discrete Event Simulator
2.	**Vendor**	• Simul8 Corporation founded in 1994	• GoldSim technology can be traced back to 1990	• First release in 1993
		• Training is provided	• GoldSim was first released in 1999	• Arena was acquired by Rockwell Automation in 2000
		• Professional consulting	• Training is provided	• Training provided
		• Free demo videos	• Professional consulting	• Profesional consulting
			• Free demo version	• Free demo version
3.	**Input**	• Importing from Databases	• Imput elements can be linked directly to ODBC-compliant database	• Imput and process analyzer
		• External Distributors	• Importing form MS Office	• unlimited model size: resources entities, modules, erc.
		• Importing from Excel-VB, COM, SDX- FactoryCAD, XML, SQL, BPM and Flowcharting Software, Command Script	• Data, time series and Stochastic elements	• Importing data through VBA
		• Unlimited Objects	• Expressions - mathemathical models	• Importing from AutoCAD, Visio, Excel
		• Processes	• Object and Components images	• Siman Blocks and Elements
		• Components		• Advanced Transfer and Process
				• Visual Basic for Applications
4.	**Output**	• Result manager	• Probabilistic simulation	• Exporting data through VBA
		• Optymization	• Risk, Failure and Vulnerability Analysis	• Advanced logic for modeling pull, Kanban and other advanced systems
		• Summary	• System Reliability and Throughput Analysis	• Crystal Reports with default report templates
		• Profit and Loss Account	• Warranty Claims Modeling and Cost Analysis	• User-defined statistic and expressions
		• Gantt Chart		
		• On screen Charts		
5.	**Animations and graphics**	• Object images	• Object images	• Animation of resources, queues and variables
		• Gant chart view	• 2D Graphic System	• Animation of material handling prosesses an entity travel
		• Animating work centres and storage bins		• 2D/3D graphic system
		• Dynamic Image Browser		
		• Virtual Reality		

6	**Cost**	● Simul8 Standard - $1495	● GoldSim Player - Free	● Basic Version - 1895 $
		● Simul8 Professional - $4995	● GoldSim Academic - Free	More prices available threw indyvidual e-mail requests
		● Simul8 for Education - $1995	● GoldSim QuickStart - $10500	
			● GoldSim Research - $950	
			● GoldSim Pro - $3950	
			● Distributed Processing Module - $1000	
			● Reliability Module - $2000	
			● Contaminant Transport Module - $2000	
			● Radionuclide Transport Module - $9000	
			● Floating Network License - 150% of standard licence fee	

Fig. 22. Simulation software
Source: own research.

4. Summary

The aim of the project was to briefly present Arena Simulation Software as an example of Discrete Event Simulator used for modelling queuing systems.

In real life to create complex manufacturing simulation it is highly recommended to use professional software available on the market. They save our money and time because we can see what effect on the real manufacturing system changes in inputs and outputs will have without spending money on their implementation. Although the software is usually very expensive it is worth trying because our savings usually will be higher that the price of the software.

Unfortunately even the best simulation software will not make the decisions for us. They are just tools that we can use to simulate what suppose to happen in the future. We will get different possibilities and only by analyzing the inputs and outputs we will be able to choose the best option.

References

[1] **1stcourses.com** Pull system concept in lean manufacturing http://www.1stcourses.com/pull.html - accessed on 5 August 2010.

[2] **Byrne J., Heavey C., Byrne P.J.:** *A review of Web-based simulation and supporting tools*. Simulation Modelling Practice and Theory 18, 2010, pp. 253-276.

[3] **EMS Consulting Group, Inc**. Lean Production Control http://www.emsstrategies.com/dd100105article.html – accessed on 5 August 2010.

[4] **Finch B.J.:** Interactive models for operations and supply chain management. Boston: McGraw-Hill/Irwin, 2006.

[5] **FutureState Solutions, Inc.** Flow & FIFO Lanes http://futurestatesolutions.com/FlowandFIFO.aspx – accessed on 5 August 2010.

[6] **GoldSim Technology Group** Selecting Simulation Software http://www.goldsim.com/Content.asp?PageID=603 – accessed on 24 March 2010.

[7] **Gross J.M., Mcinnis R.K.:** Kanban made simple: demystifying and applying Toyota's legendary manufacturing process. New York: AMACOM, 2003.

[8] **Harris R., Harris Ch.,Wilson E.:** *Making materials flow: a lean material-handling guide for operations, production-control, and engineering professionals*. Brookline: Lean Enterprise Institute, 2003.

[9] **InvestorWorlds.com** competitive advantage Definition http://www.investorwords.com/998/competitive_advantage.html – accessed on 5 August 2010.

[10] **King P.L.:** *Lean for the process industries :dealing with complexity*. New York: CRC Press, 2009.

[11] **Kosieradzka A., Krupa A., Sawicka M.:** *The barriers in impleamentation Lean Solutions on the example of food manufacturing company,* [in:] Challenges in enterprise management of today. ed. by Lewandowski J., Jałmużna I., Sekieta M., Lodz, Wydawnictwo Politechniki Łódzkiej, 2009, pp. 67-77.

[12] **Leone G., Rahn R.D.:** Fundamentals of flow manufacturing. Boulder, Colorado: Flow Publishing, 2002.

[13] **Lewandowski J., Jałmużna I.:** *Contemporary problems in managing production and services supporting manufacturing processes*. Lodz, Wydawnictwo Politechniki Łódzkiej, 2009.

[14] **Marc Timothy Smith** Push vs. Pull http://elsmar.com/Pull_Systems/sld010.htm – accessed on 5 August 2010.

[15] **Holweg M.:** *The genealogy of lean production.* Journal of Operations Management 25 pp. 420-437, 2007.

[16] **Melton T.:** *The benefits of lean manufacturing. What Lean Thinking has to Offer the Process Industries.* Chemical Engineering Research and Design 83, pp. 662-273, 2005.

[17] **Robinson S.:** SIMULATION The Practise Of Model Development And Use, Second Edition, Palgrave Macmillan, New York 2014.

[18] **Rother M., Shook J.:** version 1.2 edn. *Learning to see: value stream mapping to create value and eliminate muda.* Brookline: The Lean Enterprise Institute, 1999.

[19] **Systems2win** http://www.systems2win.com/c/vs_inv_symbols.htm – accessed on 5 August 2010.

[20] **ThroughPut Solutions** Batch Manufacturing | Lean Manufacturing Glossary http://www.tpslean.com/glossary/batchdef.htm – accessed on 5 August 2010.

[21] **Tooling University, LLC** Value Stream Mapping: The Future State 305 – Quality Training http://www.toolingu.com/class-900305-value-stream-mapping-the-future-state.html – accessed on 22 August 2010.

[22] **Vision Lean** The main LeanTek applications | Vision-Lean.com http://www.vision-lean.com/leantek-applications/ – accessed on 25 August 2010.

[23] **Vollmann T.E., Berry W.L., Whybark D.C., Jacobs F.R.:** *Manufacturing planning and control for supply chain management*. McGraw-Hill: Boston 2004.

[24] **Kelton W.D., Sadowski R.P., Zupick N.B.:** *Simulation with Arena*, Sixth Edition, McGraw-Hill International Edition, New York 2015.

[25] **Womack J.P. and Jones D.T.:** *Lean Thinking Banish Waste and Create Wealth in Your Corporation*, First ed., New York: Simon & Schuster, 1996.

ARENA SIMULATION SOFTWARE JAKO PRZYKŁAD SYMULATORA ZDARZEŃ DYSKRETNYCH

Streszczenie

Celem artykułu jest prezentacja oprogramowania Arena Simulation Software jako przykład symulatora zdarzeń dyskretnych systemów modelowania wykorzystywanych do kolejkowania. Artykuł zawiera przykładowy case study oraz kluczowe czynniki, które mogą mieć istotne znaczenie przy dokonywaniu zakupów i realizacji decyzji.