Manufacturing System Modeling & Workers' Behavioral Modeling Using Agent-Based Simulation Approach

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ABSTRACT

One of the most promising application areas of Modeling and Simulation (M&S) is the manufacturing industrial systems for operational research purposes. In this study, I will present the analysis results of a manufacturing system for increasing the number of material output in the factory production taking into account high fidelity behavioral modeling of the workers.

In this production system, metal or composite material parts enter the production lines at a certain interval of time based on a Poisson probability distribution. Then, they are removed from the system after being manually shaped by workers. Additionally, the processing times of parts vary depending on workers' experience, morale and motivation levels and time breaks that they take.

For M&S, the "Discrete Event Simulation" method is used in the process modeling of shaping material parts in the production line by workers, and the "Agent Based Simulation" method is used for the social and behavioral modeling of the workers. Anylogic is used as a simulation tool, which supports both M&S methods.

In the literature review, it has been determined that various manufacturing systems are modeled by using various M&S approaches. However, we found no M&S approach using Agent-Based Simulation to model a worker based production environment taking into account human factors issues such as workers' experience, behaviors, needs, etc.

ABOUT THE AUTHORS

Dr. Mustafa Dinç is a Modeling & Simulation (M&S) specialist. He got his M.Sc. in the field of M&S at NPS, CA, USA in 2001. Then, he got his Ph.D. in the field of Aerospace Engineering at İstanbul Technical University, İstanbul, Turkey in 2013. He has more than 20 years of work experience on Modeling & Simulation (M&S), and project management, additionally three years' experience as a university instructor at Middle East Technical University and Bilkent University respectively in Ankara, Turkey. His main research interest is M&S including Agent-Based Modeling & Simulation, Human Cognitive and Behavioral Modeling, Augmented Reality, Virtual Reality, and Serious Games.

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INTRODUCTION

Over the past few decades, the rapid developments in technology and the fierce competition between the companies have dramatically affected the manufacturing industry. Therefore, new technologies and different methodologies can be applied to an industrial system for improvement and development. However, understanding a system in this domain, providing a control on it, and direct integration of new technologies into the system may cause extra loss of time and income. At this point, it seems that M&S is one of the most effective methods in order to reduce time and cost.

Among the M&S methods, Agent-based Simulation emerges as a key technique for studying the human factors issues especially by the modeling of workers' cognitive and behavioral effects in manufacturing environments. Agent-based Simulation is an artificial intelligence technique that is made of autonomous agents interacting with each other in order to model agent-based systems. Agent-based Simulations are used for modeling complex systems consisting of active entities called agents, which are autonomous, computational entities that can be viewed as perceiving their environment through sensors and acting upon their environment through effectors (Dinc, 2001). Additionally, Agents may be people, households, vehicles, equipment, products, or companies, whatever is relevant to the system. Therefore, these systems can achieve alternative results according to the behavior and reactions of the agents.

In this study, Agent-based Simulation approach is primarily used to model human factors issues such as workers' experience, behaviors, needs etc. in a manufacturing system. Human is an entity that effects on environment and also is affected by environment. Therefore, the amount of processed item output can change according to the employee's experience, skill, morale and motivation. The M&S of the production system without the inclusion of human factors can produce misleading results and also it does not fully represent the real system. For this reason, each employee is separately modelled for giving us more accurate results.

The main goals of this study are

- to make an efficiency analysis of a manufacturing system,
- increasing the number of material output,
- to explore the main effects of Human factors on performance and work efficiency.

This paper is basically structured in three main sections: first, the Agent-based Simulation approach will be summarized. Then, given brief information about the Anylogic software tool, which supports both Agent-based Simulation and Discrete Event Simulation, and technical development of the models is described. Step-by-step, the process model building and evaluation techniques are introduced and illustrated. Finally, conclude the paper with a summary and discussion of the results.

MODELING & SIMULATION AND MANUFACTURING SYSTEMS

Todays' systems are getting more complex and complicated. Therefore, it is necessary to analyze the system, and to change or transform their configuration as an intended direction in order to make systems having complex configurations composed of fields like production, services, social structure, and progress. However, this can bring us extra costs in resources such as time, manpower, and money to carry out methods like continuous trial and error on the actual system. Because of all these reasons, M&S is an emerging technical solution that can be applied to many fields in science and engineering.

Modeling can be described as an example or an imitation of an existing system in the real world in order to analyze and obtain some results from the system. Simulation is an imitation of the operation of the system model within a certain time and space (Dinc, 2001). In short, a simulation model is an effective method that can be used on a real system that already exists to investigate what the results will be by making possible changes, or to design a new system (Axelrod, 1997)

In this manufacturing system, metal or composite material parts enter the system at a certain interval of time based on poisson probability distribution. Then, they are removed from the system after being manually shaped by workers. Additionally, the processing times of parts vary depending on workers' experience, morale and motivation levels and time breaks that they take.

In this study, despite many application areas of M&S methods and technologies, we use both agent-based simulation and discrete event simulation in order to model human factors issues and system process modeling.

Anylogic

Anylogic is an effective simulation software tool that supports the creation of models with different simulation techniques. *Anylogic* with its agent library and various definitions such as creating and destroying dynamic agents, linking them to each other, realization of their communications, provides convenience for users to design "Agent-based Simulations" (Anylogic, 2014).

Anylogic is a software simulation tool, which uses the Java programming language and object-oriented programming approach. There are various sample works carried out for different application areas with this software. There are a number of studies on modeling of many systems such as supply chain management, material handling systems, air defense systems, vehicle scheduling. In addition, while Anylogic supports object-oriented programming, it can use the suitable ready-made libraries and easily supports the 2D (Dimensional) / 3D conceptual model of the created model (Anylogic, 2014).

SYSTEM MODELING & SIMULATION

In this study, labor-intensive production system operating in the field of defense industry is modeled with the help of Anylogic simulation tool. Before modeling the system, we have made observations in the real working environment for one month and collected valuable data about the production system process, working conditions and workers' behaviors. Then, we applied the data to the model that we built.

The production system consists of totally five stations including working area, dining room, tea and coffee station, smoking area, and restrooms. There are three levels of experience of workers, and items enter the system, after being processed by the workers, and exit from the system.

In the system, there are nine workers in total and these nine workers are categorized by three levels of experience:

- 1st level: 3 workers with 10 years of experience or more,
- 2nd level: 3 workers with 5 years of experience or more,
- 3rd level: 3 workers with 1 year of experience or more.

System modeling has been realized with 2D logical model and 3D visualization of manufacturing system is developed by Anylogic 3D Window feature of the program. The 3D visual model of the manufacturing system is shown in Figure 1.

In the conceptual 3D Model of the manufacturing system, according to the numbers given in Figure 1. 1-Temporary Storage Area, 2- Restrooms, 3- Mess Hall, 4- 1st Level Workers' Working Area, 5- 2nd Level Workers' Working Area, 6- 3rd Level Workers' Working Area, 7- Tea and Coffee Station, 8-Outdoor Recreation Area for Smoking are designated.

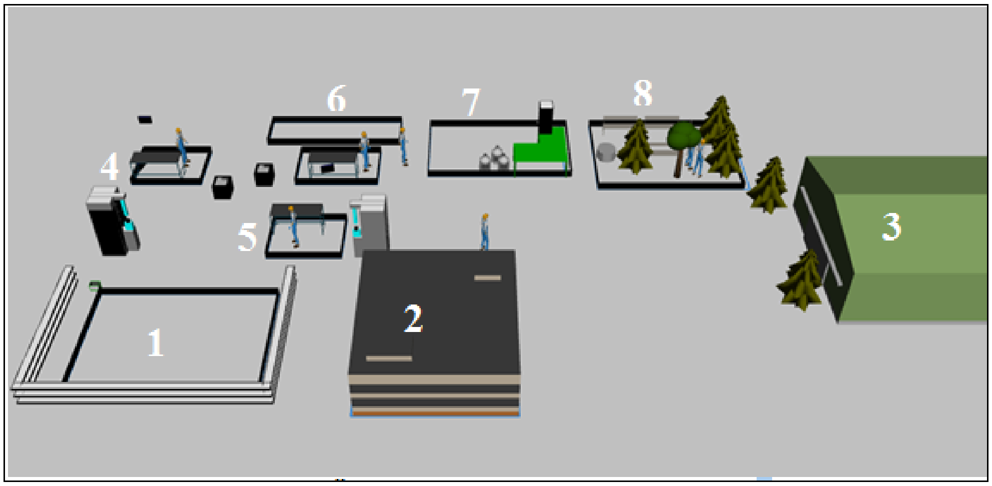


Figure 1. 3D Visualization of Manufacturing Environment

The main goals of the manufacturing system modeling are to analyze behaviors of the employees and find effects on their working performance, and to measure the number of material output. Due to employees' decision-making mechanism and their interaction with the other workers and the working environment, each worker is modeled using Agent-based Simulation approach, and each worker's performance is analyzed that how much time he worked actively or is idle based on his daily shift.

Process model of the manufacturing system is illustrated in Figure 2. According to the model shown in Figure 2, the items flow in the system is modeled using Discrete Event Simulation approach and the items enters to the system in accordance with poisson probability distribution at time intervals [1-5] min. Additionally, working time period in the system is divided into two shifts, which is the same as in the real system, one is in the morning between 0800-1200 and the other is afternoon between 1300-1700, and processing time of the items in the production line is also adjusted according to the daily work shifts. The processing times of items directly depend on workers' actual working times.

For defining employees' performance in the model, the probability values of 0.4194, 0.35, and 0.2306 are assigned to each worker due to his experience level respectively. These probabilities were determined based on collected data during five days of observation in real working environment. Based on this data, the average number of items processed by worker is 360 a day, 151 items out of 360 are formed by the first level of experienced workers, 126 items out of 360 are formed by the second level of experienced workers, and finally 83 items are formed by the third level of experienced workers.

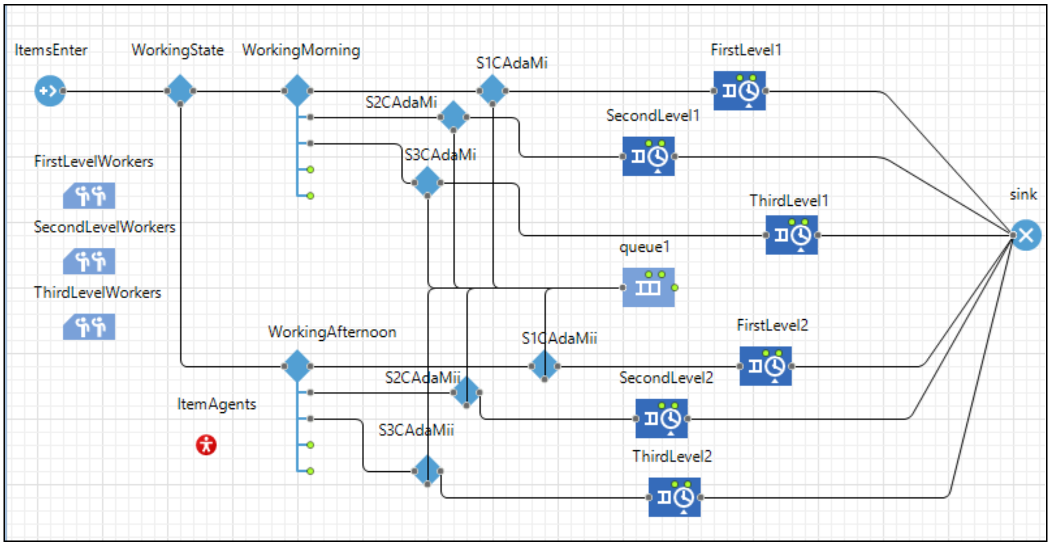


Figure 2. General Process Model of Production System

Manufacturing process basically comprises of three phases. First, unprocessed items enter the system, then they are formed by workers and finally these processed items leave the system. The process time of each item is inversely proportional to workers' experience. That is, first level of experienced worker is formed an item less time than third level of experienced worker is. On the other hand, if any worker does not work and is not in the working area, the items assigned to him are stored in the temporary storage area.

The processing time of an item varies due to daily work shifts and experience level of each worker, and all these times characteristic fits to normal probability distribution based on time data, which was obtained from observations of the duration of 53 processed items that were formed by workers in the real manufacturing system. It is easily seen from Table 1 that the means and standard deviations of normal distributions for processing times vary in the morning and afternoon shifts of workers. That is, the workers' performance decrease in the afternoon comparing to the morning performance.

Table 1. Processing Times of Items Fit to Normal Probability Distribution

	Probability Distribution	
Parts Arrival Time	normal(1.25,0.48) min	
Morning Shift	1st Level of Exp. Worker	normal(5, 1.46) min
	2nd Level of Exp. Worker	normal(6.176, 1.48) min
	3rd Level of Exp. Worker	normal(10.5, 1.12) min
Afternoon Shift	1st Level of Exp. Worker	normal(7.5, 1.12) min
	2nd Level of Exp. Worker	normal(8.95, 1.52) min
	3rd Level of Exp. Worker	normal(12.5, 1.18) min

The Agent-based Simulation design for each worker's behavior is conceptually shown in Figure 3. In Figure 3, first it is determined whether the employees are working in the morning or in the afternoon shift, and then according to their morale and motivation status, they work or take various breaks.

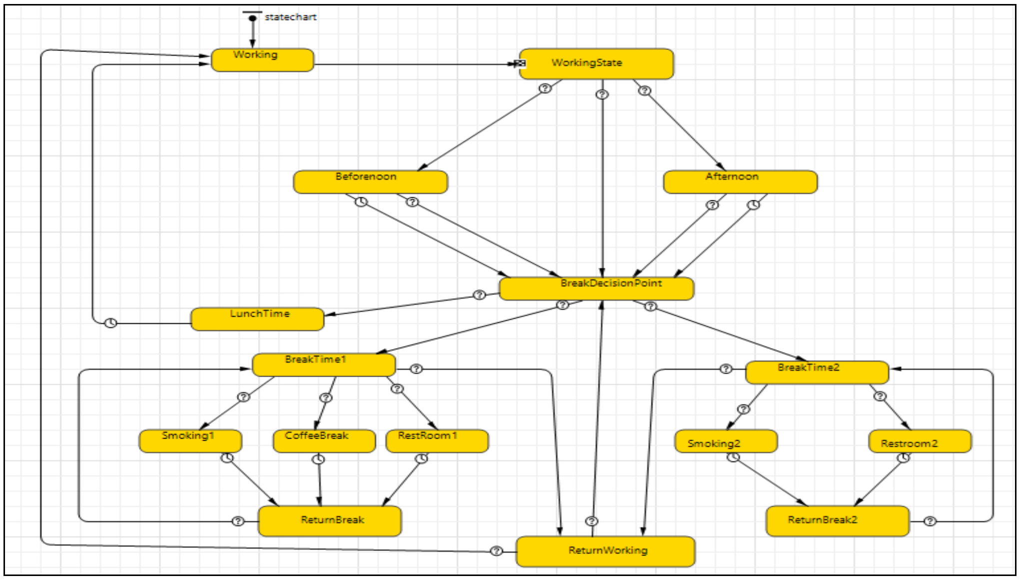


Figure 2. Conceptual Design of Workers' Working and Break States

The decision-making processes of workers are also modeled using the Agent-Based Simulation approach. Workers start to work at 0800 o'clock in the morning. Depending on work shift of the employees, the morale and motivation of the employees are evaluated in three categories. Workers who work for a certain period of time make a choice according to the time frame. These choices are, the fixed official break like 15-minute break be taken between 1000-1015 and 1500-1515, lunch break taken between 1200-1300, and other official breaks be taken between 0800-1700. The choices also change according to the breaks be taken by workers depending on their own personnel needs. Workers are able to take breaks in line with their own initiative to meet the needs of smoking and/or lavatory after working sometimes without interruption.

Smoking or toilet break times are also determined randomly. Employees should meet the cigarette and/or toilet and/or tea needs during 15-minute fixed break. Workers stop working if the 15-minute break time has begun. Break times can be extended according to the decisions of the workers, and after the end of the breaks, they return to the working area. Workers go to the smoking area for the need for smoking, to the lavatory area for the need for toilet, while they are on the break, and they go to the dining area for lunch break. In Table 2, duration of staying of the employees in the work area, and in Table 3, the time used on break, are given.

The morale and motivation of the employees and the state of daily shifts, whether it is in the morning or in the afternoon may cause to changes in the uninterrupted work duration of workers in the working area. The morale and motivation of employees can also lead to changes in the processing time of the items. For example, at the 1st level of experienced workers is the higher possibility to loaf around during work shifts due to the degeneration caused by working of many years.

Table 2. Work Duration Defined as Random Variable

Work Period	**Mood State** / **Experience**	**Good** (minutes)	**Medium** (minutes)	**Bad** (minutes)
Morning Shift	1st Level	random(25-50)	random(25-45)	random(25-35)
	2nd Level	random(30-60)	random(30-50)	random(25-40)
	3rd Level	random(27-55)	random(28-48)	random(23-35)
Afternoon Shift	1st Level	random(25-45)	random(20-35)	random(20-25)
	2nd Level	Random(30-55)	random(25-45)	random(20-40)
	3rd Level	random(28-50)	random(23-38)	random(15-30)

In Table 2, work duration selection of all employees vary in accordance with their mood state, and the daily shifts. As a result of the observations conducted, it was determined that work duration of the employees varied according to their own decisions. It is concluded that the time is randomly assigned. The minimum and maximum values of random variables are based on the observation data.

Table 3. Times Used on Breaks by 1st Level of Experienced Workers

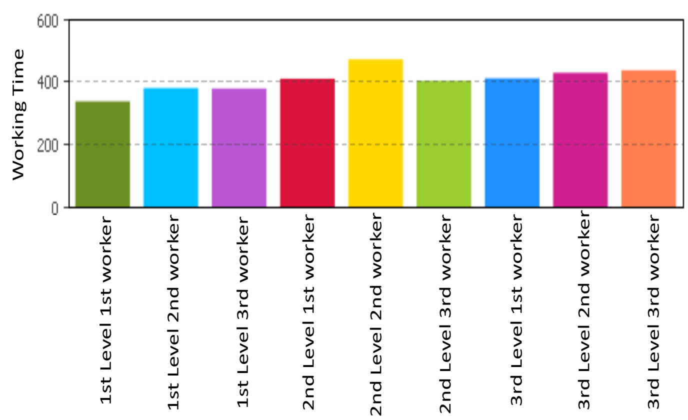
State	**Break Type**	**Break Order**	**Break Time (minutes)**
Working	**Smoking**	After Work	random(5-7)-
		After Toilet	random(4-6)
	Toilet	After Work	random(3-8)
		After Smoking	random(3-4)
On Break	**Toilet**	After Tea	random(4-5)
		After Smoking	random(3-4)
		After Tea + Smoking	random(4-5)
		After Smoking + Tea	random(4-5)
		Only Toilet	random(4-19)
	Smoking	After Tea	random(5-6)
		After Toilet	random(4-5)
		After Tea+Toilet	random(5-6)
		After Toilet+Tea	random(4-5)
		Only Smoking	random(5-15)
	Tea	After Smoking	random(5-6)
		After Toilet	random(5-8)
		After Smoking + Toilet	random(5-6)
		After Toilet + Smoking	random(5-8)
		Only Tea	random(6-21)

For example, the times used by the first level of experienced workers in the breaks are shown in Table 3. According to this table, the state of each worker whether he is at work or on break, the type of break, and the time used in these breaks according to the order of break occurrence are indicated. These break times were obtained from the observation data based on the same logic existing in the choices of the employees for the duration staying in the working area. Similarly, this approach is also valid for the second and third level of experienced workers.

SIMULATION RESULTS

In this chapter a series of simulation results we carried out present the details of our evaluation, including the metrics, the evaluation methodology and the simulation results. The simulation aims to explore the trade-offs, performance and scalability of manufacturing system. The simulation code we developed was very modular in design, allowing for easy scaling to more powerful simulations. It is hoped in near future to extend the simulations to the more realistic cases, and this can easily be accommodated.

In Figures 4 - 5, we present the results obtained from actual simulation runs. Active working times regarding the time percentages of all employees are demonstrated in Figure 4. It can easily be seen from the charts in Figure 4 that first level of experienced workers are actively working lower time than third level of experienced workers are.



Workers	Active Working Time Percentage Before noon	Active Working Time Percentage Afternoon
1st Worker	35.4%	30.1%
2nd Worker	35.56%	34.33%
3rd Worker	31.9%	34.2%
4th Worker	35.3%	29.8%
5th Worker	39.7%	33.5%
6th Worker	38%	30.3%
7th Worker	38.5%	34.2%
8th Worker	37.3%	42.8%
9th Worker	40.0%	34.4%

Figure 4. Active Working Times and Time Percentages of All Workers

In Figure 5, times spent by the first level of experienced worker working in the morning and afternoon shifts for breaks taken during work time, for official breaks, and for lunch break can be seen as a pie chart. While the times spent on the item searches are also included in the working time, the times spent on the road during the breaks are included in the break times.

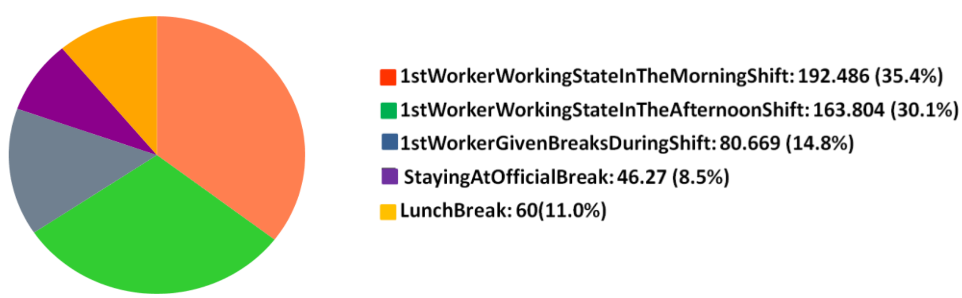


Figure 5. Total Times Spent by 1st Level of Experienced Worker

It can easily be seen from the Figure 5 that the employee's working performance in the morning shift is higher than the working performance in the afternoon, and the breaks given by the employee during the working period constitute 8.5% of the total time, which is higher. Considering that the normal official breaks times are 30 minutes in total, the main reason for exceeding 16 minutes in official break time is that worker return to work late from breaks. Therefore, this situation is compatible with the real system regarding the variability of the mood states of 1^{st} level of experienced employees in the morning and in the afternoon.

A significant aspect of this model is able to demonstrate human factors effects on work efficiency. Namely, employees' product efficiency decreases 2 to 3 items in an hour when we add human factors effect, for example, while one of 1^{st} level of experienced workers can form 11 items an hour without human factors, he is able to form 8 products an hour adding human factors. Similarly, while one of 3^{rd} level of experienced workers can form 5 items in an hour without human factors, he is able to form 3 products in an hour adding human factors.

CONCLUSION

In this study, we develop high fidelity M&S of the manufacturing system by taking into account of human factors effects. For instance, although it was observed that a second level worker in the simulation started to work at high morale at the beginning of work and worked continuously for 55 minutes, after one hour, because of the decrease in his morale and motivation level, continuous work duration observed as 27 minutes. The same worker with the low level of morale, continued to work in the afternoon, until the end of the working period, the active time in the work he remained after each taken break was determined as an average of 22 minutes.

In the analysis of the simulation results, the best working performance among the level of experience groups is identified as the second level of experienced employees. They were followed by the third level of experienced employees, and the least working performance group is the first level of experienced workers. However, it is observed that the first level workers processed the items faster than the other groups despite the less working time. In the performance evaluation, in terms of the number of output items, the first level of experienced workers, with an average of 50 processed items per day, are better than the second group with an average of 42 processed items, and the third group with an average of 28 processed items.

As a result, while the system was being modeled, all factors were taken into consideration, with significant efforts at ensuring model verification and validation. In this way, it is aimed to be able to interfere in the system with alternative realistic solution by accurately determining the problems in the system.

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