BAUHAUS UNIVERSITÄT WEIMAR

SIMULATION METHODS IN ENGINEERING

“SIMULATION OF VISITORS IN THE MENSA

FOR ANALYSING CROWD”

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ACKNOWLEDGEMENT

We would like to thank Prof. Christian Koch for assigning this project on simulation methods, which enabled us to conduct an extensive study and discover a wealth of new information.

We would also like to sincerely thank Mr. Mohamed Said Helmy Alabassiy and Mr. Seyedali Amid for their honest efforts and selfless time. We were able to successfully complete the project with the support of their guidance and thorough coaching each week.

DECLARATION

We the members of group 5 hereby declare that this particular project report titled "Simulation of Visitors in the Mensa for Analysing Crowd" is based on our own work, carried out during the academic summer semester 2023.

We further declare that the results and conclusions provided are the outcome of our research. We further attest to the originality and teamwork of the report that comprises our collective efforts.

We further certify that; the project has not been submitted to any other organization or academic institution. When preparing the entire report, we adhered fully to the university's regulations and requirements. If the material came from another source, that source is acknowledged in the text, and the specifics are noted in the references.

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1. INTRODUCTION

Real-world issues are frequently complex, ambiguous, and impacted by a variety of interconnected events and processes. Simulation modelling are abstract replications of a real system, efficient to map all relevant properties with regard to a certain purpose and are used to investigate the behaviour of the corresponding system. Hence, reduce the complexities driven by the real-world scenarios.

In pedestrian simulation, the system needs to analyse how pedestrians move, interact with the internal and external environment and disperse among the space. While considering pedestrian movement in a particular space, we need to consider factors like entry points, exit points, waiting areas, moving directions, and actions based on certain functions. Based on the events or functions to consider in the simulation, we have followed the below approaches to run the simulation experiment.

- Agent Based Modelling

  In this particular approach, each pedestrian is modelled as an individual agent with specific properties such as speed, delay time, movement preferences, etc. It is represented as a group of agents in which each can interact with its own and outer environment. The agents can perform based on the specified set of rules given and also by the different patterns preferred by the system. It helps in the detailed analysis of the pedestrian flow, behaviour in individuals and as a group.

- Discrete Event Modelling

  It is used to simulate a real-world system that contains a lot of logically different processes that are progressing independently with time. It occurs in a sequence of operations. Each event occurs for a specific amount of time and represents a change of state in the system.

In the project, a combination of both methods is used for the simulation of pedestrian flow. Agents are created that behave as pedestrians, have various properties and are interconnected with the environment. Logical events which occur sequentially are defined in the simulation process to analyse the overall objective of the simulation experiment. These events are implemented with the help of process flow charts that take the input, calculated by considering theoretical distributions.

2. LITERATURE REVIEW

1. Jerry Banks - INTRODUCTION TO SIMULATION

Simulation is the imitation of the operation of a real-world process or system over time. It involves generating an artificial history of the system and observing that history to draw inferences about the real system it represents. Simulation is an essential methodology for solving real-world problems and is used to describe and analyse system behaviour, explore "what if" scenarios, and aid in the design of real systems. It can model both existing systems and conceptual systems, making it a versatile problem-solving tool.

To illustrate simulation, let's consider an example of simulating the operation of a one-teller bank. In this example, customers arrive for service at random intervals between one and ten minutes, and the service time for each customer is between one and six minutes. By simulating the bank operation manually, measures of performance such as the percentage of idle time and average waiting time per customer can be computed. Although this example is limited in scope, it provides insights into system performance. However, for more complex problems or when a larger number of customers and multiple simulation runs are required, using a computer for simulation becomes necessary.

2. Anu Maria - INTRODUCTION TO MODELING AND SIMULATION

Modelling is the process of creating a simplified representation of a system, aiming to capture its essential features. A model serves to predict the impact of system changes and should strike a balance between realism and simplicity. Simulation models, typically developed using simulation software, are mathematical models used for simulation studies. These models can be deterministic or probabilistic, static or dynamic, depending on the characteristics of the system under study. Model validity is crucial, and it is assessed by comparing the output of the model with the actual system output under known conditions.

Simulation, on the other hand, involves operating a model of a system to gain insights into its behaviour and properties. It allows for experimentation and evaluation of system performance under different configurations and over extended periods. Simulation is valuable in system design and optimization, as it can identify potential issues, allocate resources efficiently, and assess the impact of changes. Discrete event simulation, the focus of this tutorial, assumes that the system undergoes instantaneous changes in response to discrete events. It is a simpler form of simulation compared to continuous simulation but finds broad application due to its ease of implementation. Human decision-making plays a crucial role throughout the simulation study, from model development to output analysis and conclusion formulation. While simulation software is important, the expertise of experienced problem formulators and modellers is essential for successful simulation studies.

3. JulienWalzberg, Jean-Marc Frayret, Annika L. Eberle, Alberta Carpenter, Garvin Heath - Agent-basedmodeling and simulation for the circular economy.

This article analyses and discusses the insights gained from applying agent-based modelling and simulation to study the techno-economic and social conditions promoting circularity and sustainability. It analyses the benefits and limitations of this technology and discusses future methodology developments within the circular economy context. Moreover, six limits of the circular economy concept are used to interpret insights from the literature: thermodynamic limits, system boundary limits, limits posed by the physical scale of the economy, limits posed by path dependencies and lock-in, limits of governance and management, and limits of social and cultural definitions. Promising research avenues are to use this methodology with machine learning, industrial ecology methods, and detailed geographic information.

Sustainable development encompasses a broad range of interconnected challenges that extend beyond the economy, including environmental protection, social equity, and cultural preservation. To address these complex issues, a multidisciplinary approach is crucial. Integrated assessment models (IAMs) have emerged as powerful tools for understanding and analysing the complex interactions between various sustainability dimensions. IAMs integrate data and knowledge from diverse fields such as ecology, economics, sociology, and policy analysis, enabling policymakers and researchers to explore the potential impacts of different policies and scenarios on sustainable development. By considering environmental, social, and cultural factors simultaneously, IAMs provide a comprehensive understanding of the trade-offs and synergies involved in decision-making, guiding the development of holistic strategies for a more sustainable future. Moreover, IAMs facilitate stakeholder engagement and participatory processes, ensuring that diverse perspectives are considered and fostering inclusive decision-making for sustainable development initiatives.

Circular economy (CE) is an economic paradigm that spurs material efficiency through reusing and recycling products and transforms waste into wealth. The CE concept promises to contribute to sustainability through the enhanced social connection of the sharing economy, additional value and jobs created within the economy, and the decoupling of economic activities from environmental impacts. According to some estimations, CE could contribute to 85% of the greenhouse gas (GHG) emission reductions needed to limit global warming below 2°C (Circle Economy, 2021). However, several scholars have questioned the relationship between enhanced circularity and sustainability. In a seminal article, Korhonen identifies six challenges that may hinder the CE contribution to environmental global net sustainability: thermodynamic limits, spatial and temporal system boundary limitations, limits posed by physical economic growth and externalities, path dependencies and lock-in, intra- versus inter-organizational strategies and management, and social and cultural definitions of physical flow.

4. **Faza Fawzan Bastarianto, Thomas O. Hancock, Charisma Farheen Choudhury and Ed Manley - Agent-based models in urban transportation: review, challenges, and opportunities.**

Findings from the analysis of agent-based models in urban transportation research revealed the existence of nine distinct clusters representing various research methods and problem interpretations in the field. These clusters highlighted key challenges faced by agent-based modelling approaches, including enhancing computing efficiency, developing unified calibration and validation methods, ensuring reproducibility of work, and incorporating modules or frameworks to accurately replicate the complexities of the transport system and travel behaviour within specific application contexts. The study also examined the historical trend of publications and modelling tools used in agent-based models. The analysis showed a steady rise in publications from 2010 to 2014 and exponential growth from 2015 onwards, attributed to the development of numerous modelling tools and significant increases in computing performance. The most frequently used agent-based simulation framework was MATSim, known for its ability to simulate large-scale models and enable the creation of various urban mobility scenarios. Other popular tools included NetLogo, SimMobility, and AnyLogic, each offering specific features and capabilities for modelling urban transport systems.

In conclusion, this comprehensive review of agent-based models in urban transport research provides valuable insights into the diversity of applications and identifies research gaps and challenges in the field. The findings serve as a valuable resource for researchers and practitioners interested in utilising agent-based models for urban transport planning. The analysis highlights the importance of addressing key challenges such as computing efficiency, calibration and validation methods, reproducibility, and incorporating complex modules to accurately represent the transport system and travel behaviour. The availability of various agent-based modelling tools and frameworks, with their specific features and programming languages, offers researchers flexibility in designing and simulating urban transport scenarios. Overall, this study paves the way for future research directions and advancements in the field of agent-based modelling for urban transportation.

5. **Shuntaro Masuda, Kyle Bahr, Noriyoshi Tsuchiya & Tatsuya Takemori - Agent-based simulation with a data-driven parameterization for evaluation of social acceptance of a geothermal development: a case study in Tsuchiyu, Fukushima, Japan**

The development of geothermal power plants and local geothermal energy initiatives has faced obstacles in Tsuchiyu Onsen, Fukushima prefecture, Japan, despite the abundance of geothermal resources. These obstacles include conflicts with stakeholders such as Onsen owners, which have hindered progress in this area. Tsuchiyu Onsen is a resort area known for its hot springs and natural environment, but it has been struggling with population decline and an ageing population.

6. Brian Heath, Raymond Hill and Frank Ciarallo (2009) - A Survey of Agent-Based Modeling Practices (January 1998 to July 2008)

Emerging from the fields of Complexity, Chaos, Cybernetics, Cellular Automata and Computers, the Agent-Based Modeling (ABM) simulation paradigm began gaining popularity in the 1990s and represents a departure from the more classical simulation approaches such as the discrete-event simulation paradigm. A primary reason for the popularity of ABM and its departure from other simulation paradigms is that ABM can simulate and help examine organised complex systems (OCS). This means the ABM paradigm can represent large systems consisting of many subsystem interactions. These systems are typically characterised as being unpredictable, decentralised and nearly decomposable. Although computer simulation as an analytical tool has been around since the advent of computers, the ability of the ABM paradigm to simulate complex systems has moved into a breadth of fields ranging from engineering to mathematics to social science and economics where sometimes for the first time analysts can utilise simulation to explore these complex systems at a level of detail that was difficult or impossible to previously obtain.

Due to its characteristics and abilities, some claim that ABM represents a revolution in modelling and simulation. However, this statement is based primarily on the potential of ABM rather than the current results. One reason for the lack of meaningful results sometimes emanating from ABM studies, in general, is due to the type of complex systems that ABM is used to simulate and explore. Traditionally these types of systems are difficult to analyse given their non-linear behaviour and size. Nevertheless, there is no reason why analysing these complex systems using ABM should not eventually always produce meaningful, model-based results. Systems that are large and difficult can be understood. History gives many examples of problems that seemed nearly impossible to solve, but when given the proper tools scientists found solutions. For example, at one point we did not understand why an apple fell to the ground from a tree. Newton and others were able to develop theories and tools that helped them not only explain but also predict the behaviour of the falling apple. By extension meaningful results regarding these complex systems will be consistently gained when the proper tools and models are in place, and ABM is, at least for the moment, the most suitable tool for analysing these types of the complex systems.

3. SYSTEM ANALYSIS

Objective

The project seeks to simulate the real-world situation of visitors entering the Mensa (Canteen of Bauhaus-Universität Weimar), where there is a large crowd of people, acting as a barrier to visitors' simple mobility. The simulation model analyses (on both the ground floor and the first floor), and suggests enhancements that can be made to ensure that visitors flow smoothly and use the services efficiently.

Model Development

Visitors can access the ground level and the first floor of the Mensa building. The service and dining area is located on the first floor. Students have the provision for recharging the Thoska card on the ground floor. The Mensa model is depicted in the following figure by taking into account two floors. AnyLogic is employed in the modelling process. The system structure, boundaries, and elements and the layouts of the ground floor and the first floor which are provided are given below.

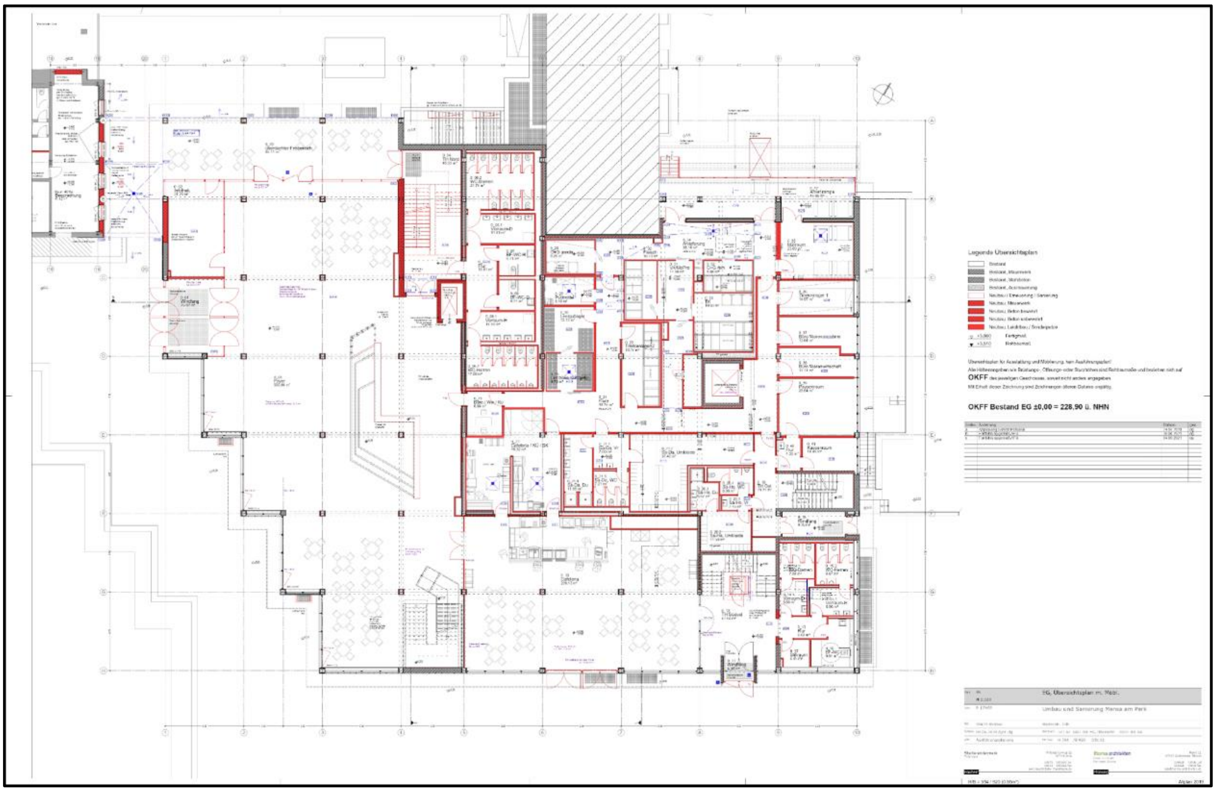

Fig 3.1 Ground Floor Plan

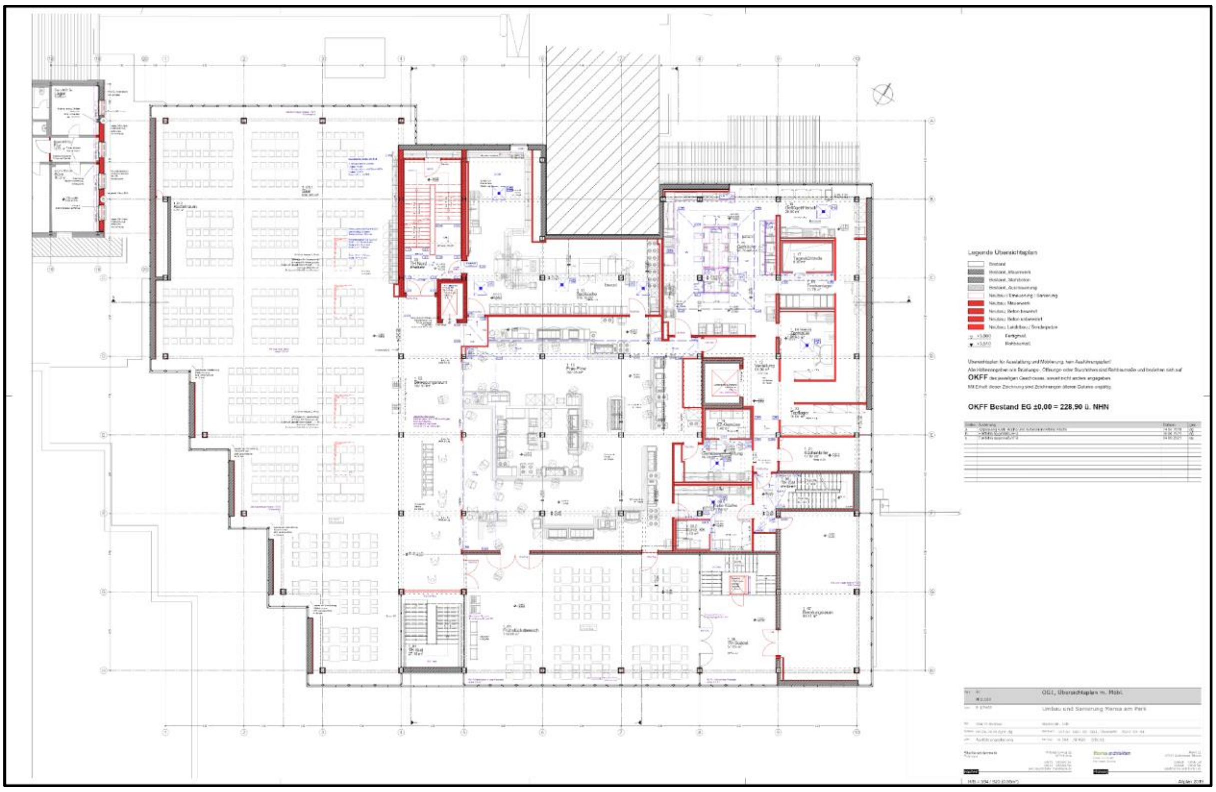

Fig 3.2 First Floor Plan

We have reconstructed the ground floor and first-floor layout in AnyLogic based on the model layout provided in Moodle. To make modelling easier, we scaled down the actual arrangement to create an abstract representation. We have considered the areas that visitors access the most.

The areas which we have considered for the simulation are marked by blue colour line as the boundary and are shown below;

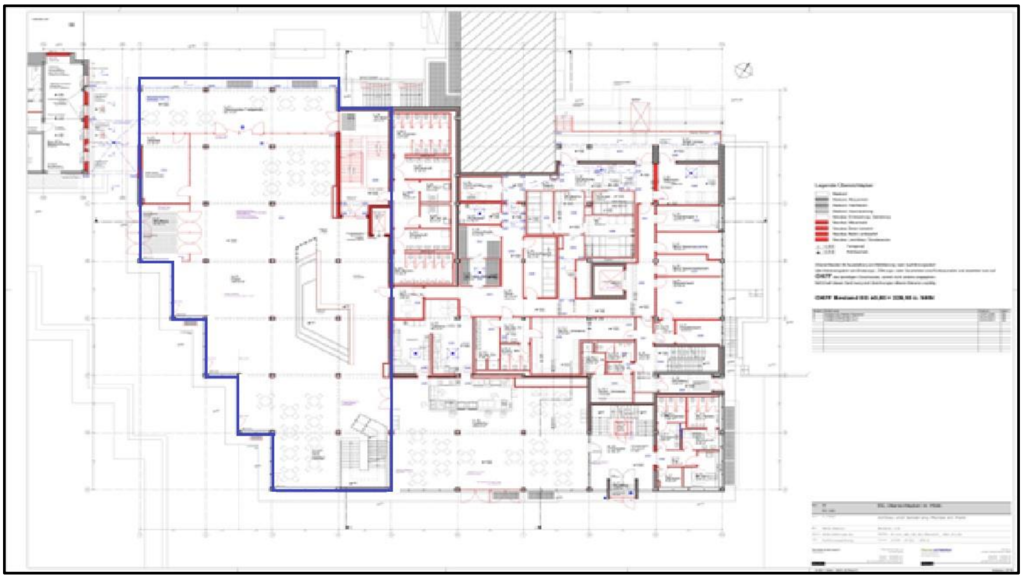

Fig 3.3 Ground Floor Area considered for Simulation

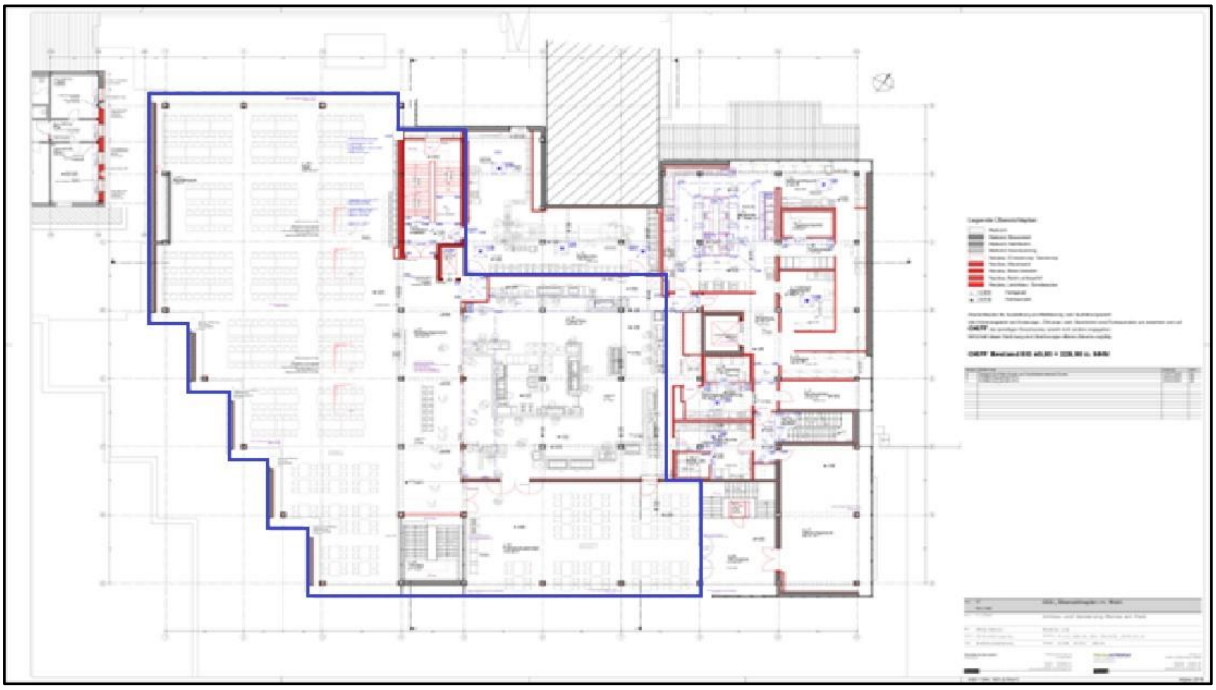

Fig 3.4 First Floor Area considered for Simulation

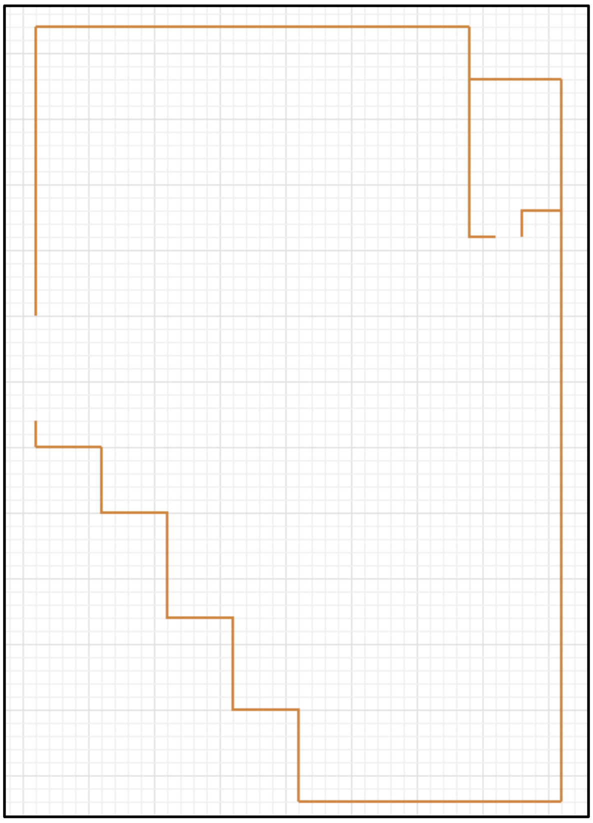

Fig 3.5 Modelling of Ground Floor Walls

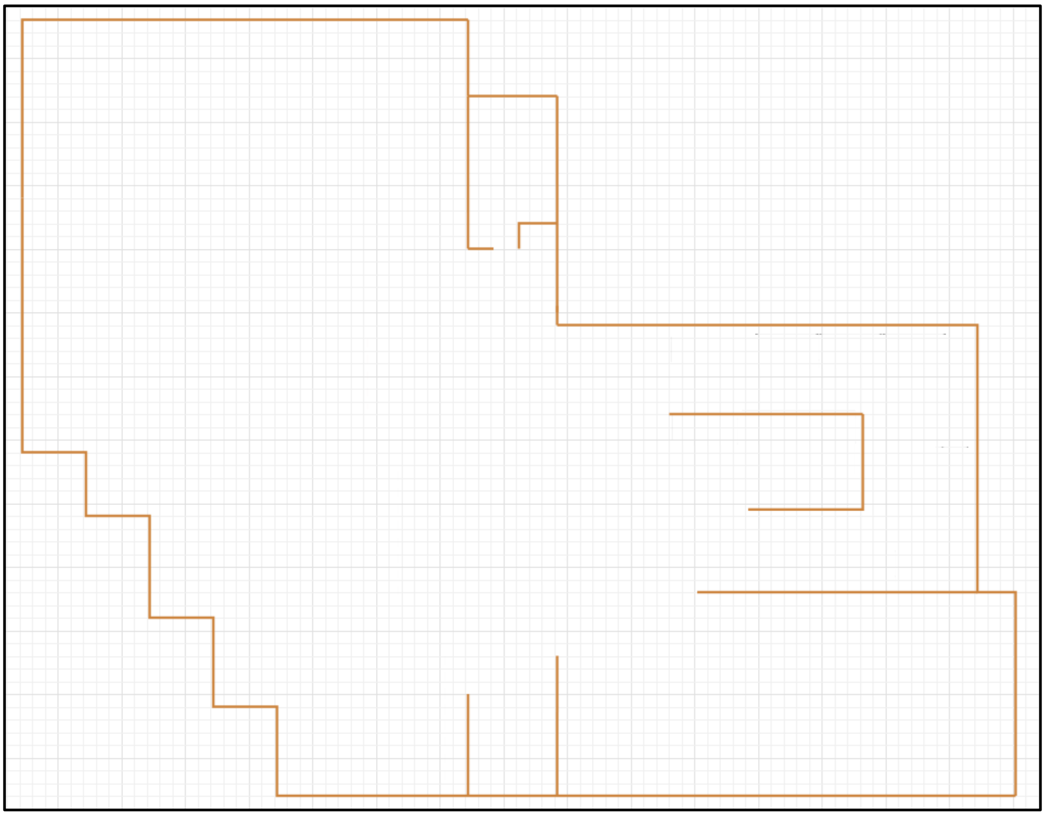

Fig 3.6 Modelling of First Floor Walls

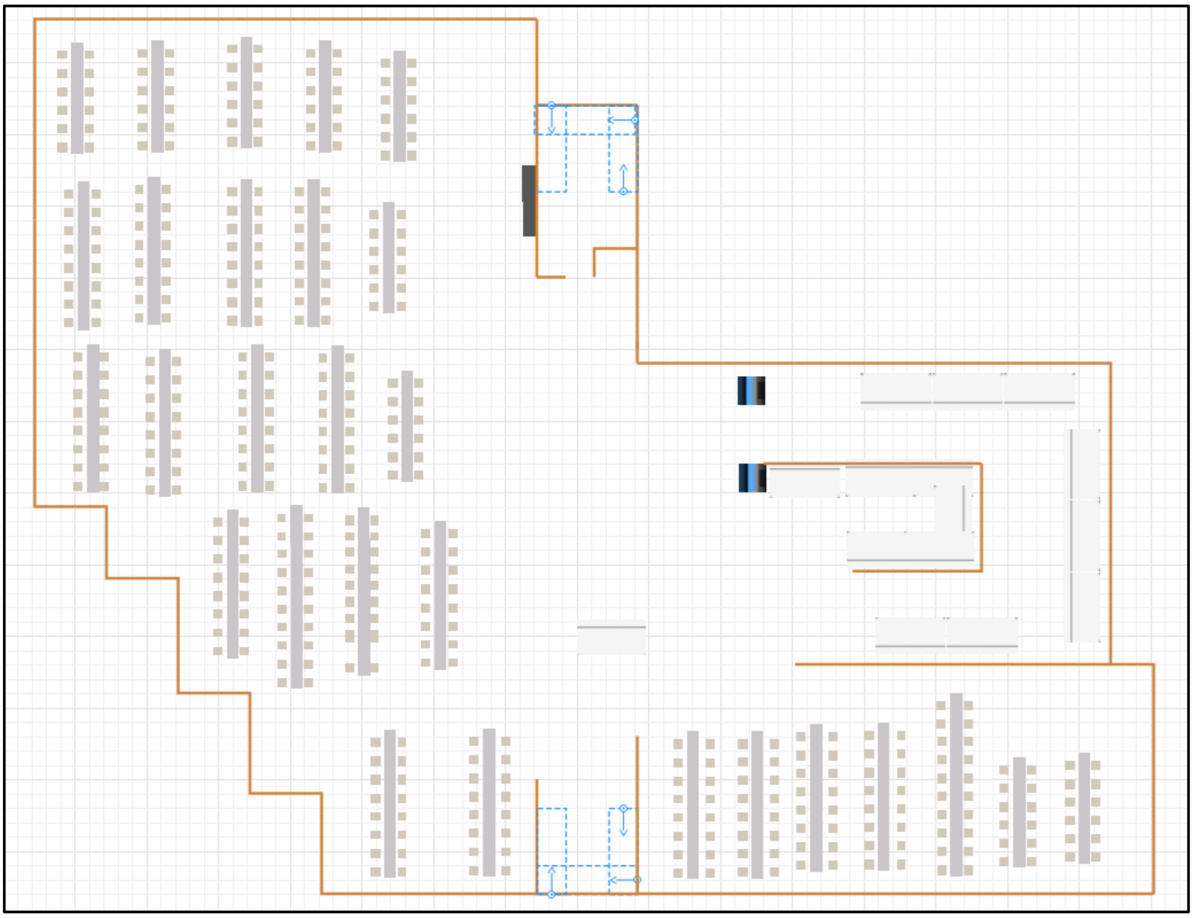

Fig 3.7 Furniture Modelling of First Floor

Ground floor

The ground level is laid out such that we place more emphasis on the areas that are used by visitors most frequently. There are few areas which are restricted to the visitors. Visitors usually enter through the ground floor through the entrance and proceed to the first floor for dining. The areas which are necessary for crowd management are included in the model.

The Thoska charging machines have not been taken into consideration because there is no queue for recharging and the number of people who recharge their Thoska each day varies greatly. The Mensa's regular and daily guests typically recharge for a big amount. Visitors who visit the Mensa less frequently recharge less—almost the same amount as the cost of food. Some people visit Mensa to recharge their thoska cards for their personal use. The disproportionate number of people recharging thoska daily acts as a barrier for calculating the probability of people.

Since there are no long lineups, restrooms are not taken into account in the model. Some people use the washroom before going to the first floor for lunch; others do so after finishing their meal. Therefore, it is quite challenging to determine the percentage of people using the washroom before or after lunch.

Due to the low number of visitors, Infotech is not taken into consideration. Students frequently use this to find out any information.

Since the data was gathered before the cafeteria opened, it has not been taken into account in the simulation process.

First floor

The first level is modelled after the actual layout, taking into account all the areas that guests can access. The kitchen, service area, and dining area make up the majority of the first level. Since visitors are not permitted in the kitchen area, we have taken into account both the dining room and the service area. The beverage area, major food counters, salad area, and cashier counter have all been segregated into separate areas of the service area. The dining area consists of cutlery Service and its disposal and the table area is divided into six service areas based on the orientation of tables and chairs in the dining area. The separated table spaces also help to distribute guests evenly around the dining area.

Stairs

Stairs to the first floor are taken into account in the model. Since there is no option for stairs in AnyLogic, we used the software’s Elevator functionality to implement the steps. One elevator is placed on the ground floor and the other on a newly created level called mid-level.

Mid-level

Mid-level is constructed for the provision of stairs to connect the first floor with the ground floor. For a continuous flow of pedestrians, the movement is connected by a target line in the mid-level.

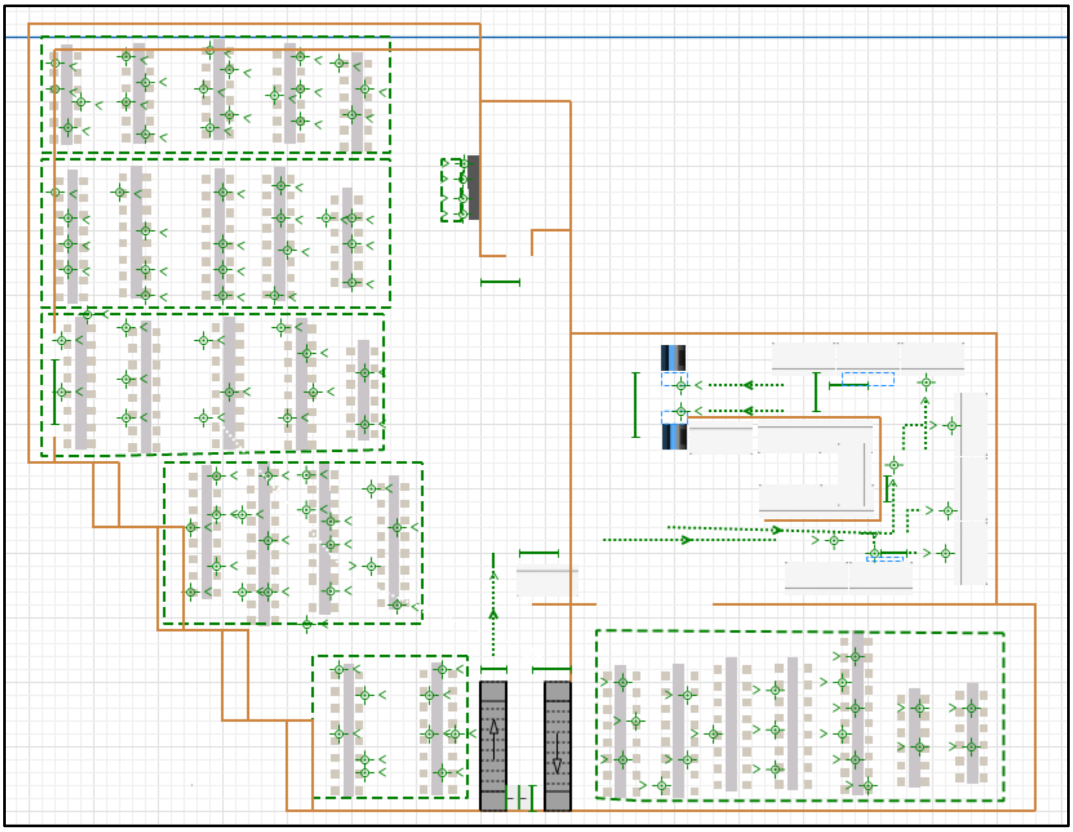

Figure 3.8 Plan with the implementation of stairs

The properties of the elevator are adjusted in such a way that it matches with the movement of pedestrians. We analysed the pedestrian flow through the elevators the and whole space by varying the properties of speed, and pedestrian walking percentage in the Elevator group. Finally, a conclusion by analysing the full flow of pedestrians in both 2D and 3D models with trial and error is made. Elevators are given with an inclination of 30 degrees. The elevators are considered only on the entrance side, the exit of pedestrians is not implemented with elevators. The pedestrian flow is ended on the first floor near the door with a Ped Sink.

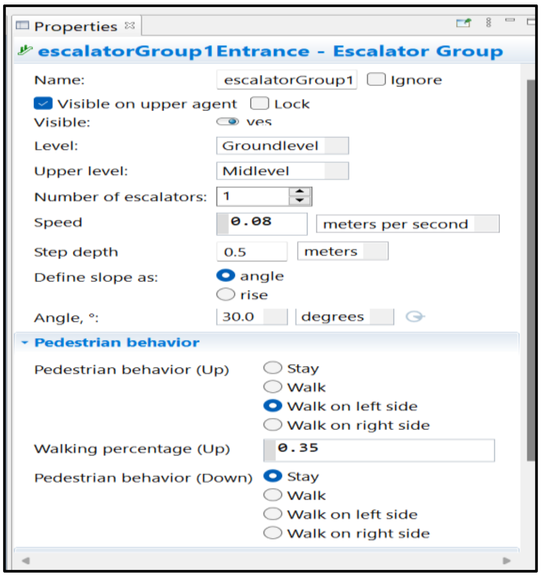

Figure 3.9 Specification of Elevator Group

4. DATA COLLECTION

The project tries to analyse the current Mensa scenario. This is accomplished by acquiring the real-time data, using data modelling in Any Logic, and validating the model with the real scenario. The optimization and improvements based on the simulation experiment results are discussed in the later part of the report.

Collection of data

The data collection phase is crucial for a simplified and efficient simulation operation. The input data that is given determines how accurately the simulation will provide outcomes in a bigger way. Any incorrect input data can result in erroneous simulation and failure. The input data may be collected either manually or with the assistance of electronic devices. We collected the number of visitors entering and leaving the Mensa manually and the time taken for other activities such as serving, billing, etc are taken with the aid of electronic devices. We gathered real-time data in the Mensa from 11 a.m. to 2 p.m. We considered the data on two different days of the week (Monday, June 5, 2023, and Thursday, June 8, 2023). Each group member received an equal share of the work of gathering the data.

Assumptions

There will be various assumptions made in any research or project that has no impact on the functioning of the system. We have assumed a few instances which neither deviate from the main objective of our project nor impact the simulation of the model.

The following assumptions that are made are-

Before departing, every guest that enters the Mensa will eat.
The entry and exit ways are unidirectional.
(A person enters the first floor by taking the right-side staircase and exits by the left-side staircase)
The washroom and elevator utilities are omitted from the model.
The people entering the Mensa after 2 PM are not considered.

The count of the infants are not considered.

Table 4.1 Daily data of visitors at the Mensa

Daily Data		
Date	Total in	Total out
5/6/23	1076	1076
8/6/23	1120	1120

Table 4.2 Hourly data of visitors at the Mensa

Hourly Data				
Date	Total in	Total out	In per min	In per out
5/6/23	**1076**	**1076**	**5.98**	**5.98**
11AM -12PM	375	115	6.25	1.92
12PM-1PM	527	405	8.78	6.75
1PM-2PM	174	556	2.90	9.27
8/6/23	**1120**	**1120**	**6.22**	**6.22**
11AM-12PM	275	105	4.58	1.75
.12PM-1PM	630	410	10.50	6.83
1PM-2PM	215	605	3.58	10.08

Table 4.3 Service time data at the food counters

Food Counters	Min Time (s)	Max Time (s)	Mean Time (s)	Standard Deviation
Counter 1	5.56	23.55	13.75	5.28
Counter 2	8.70	21.72	17.7	4.1
Counter 3	6.05	21.26	15.3	4.45
Counter 4	10.55	30.16	24.5	11

Table 4.4 Time taken for collecting the coffee

Machine time	Min Time (s)	Max Time (s)	Mean Time (s)
Coffee Machine	30	77	52.4

Table 4.5 Service time data at the cash counters

Cash Counter	Min Time (s)	Max Time (s)	Mean Time (s)
Cashier 1	4.49	20	14
Cashier 2	4.93	22.17	11.52

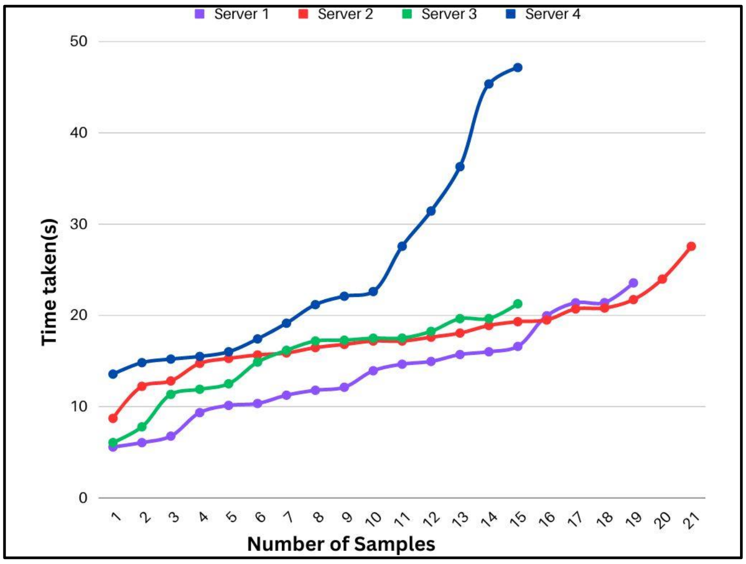

Fig 4.1 Time taken by each server

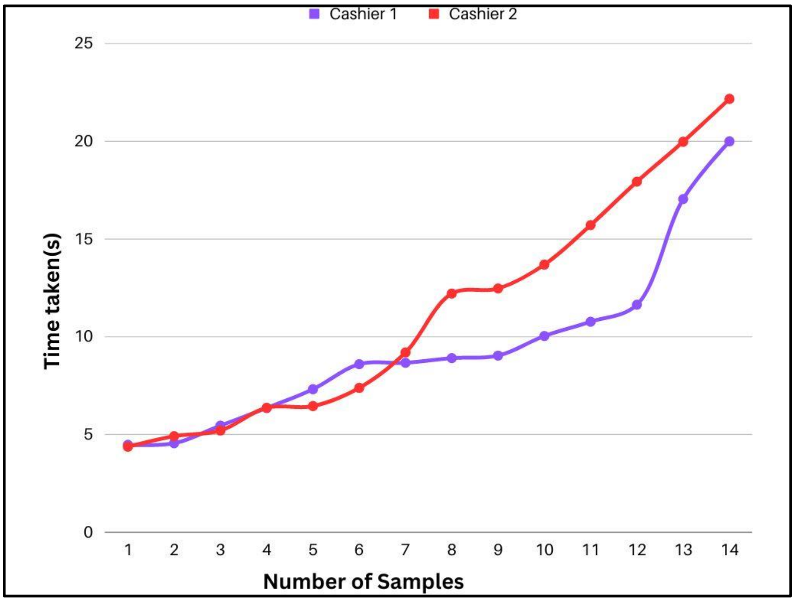

Fig 4.2 Time taken by each cashier

5. AGENT-BASED MODELLING

The main objective was to represent pedestrian movement and then translate that into Any Logic software. By understanding the areas which pedestrians accessed, it was crucial to comprehend how the people travelled through the area and interacted with the surroundings. This knowledge allowed us to define the system dynamics for our model.

Agent logic

The project's agents in the model are the visitors who visit Mensa to use the amenities. The agents' source is at the ground floor's entrance, then they follow to the first floor using the elevators. The pedestrian is directed to the mid-level and then to the first floor using the Ped Escalator function. A Ped Go To function is provided between the Elevator functions to allow pedestrians to continue moving forward to the first floor through the mid-level.

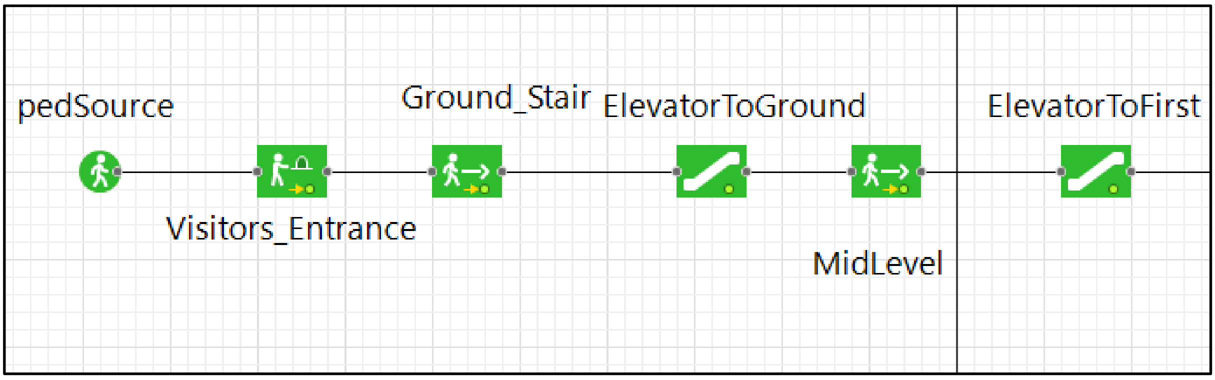

Fig 5.1 Agent logic of visitor’s entrance

The visitors, after reaching the first floor, move towards the cutlery section and collect the cutlery trays and the items. After that, they carry on to the serving section.

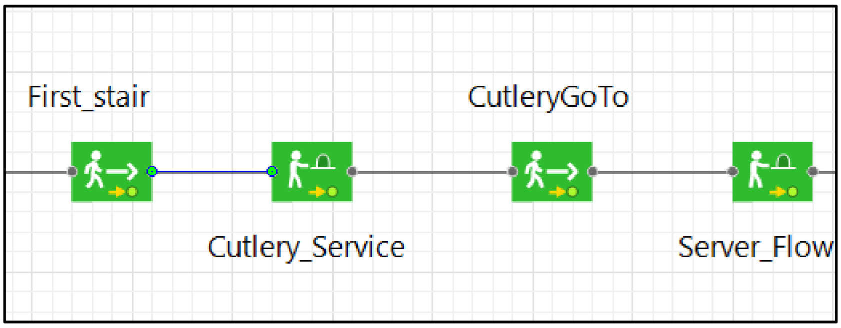

Fig 5.2 Agent logic to take the cutlery items

Visitors have the option of choosing the main salad, coffee, and beverages, or they can skip them and proceed directly to the main dish. The pedestrian distribution part in flow is explained in the Data Analysis Section.

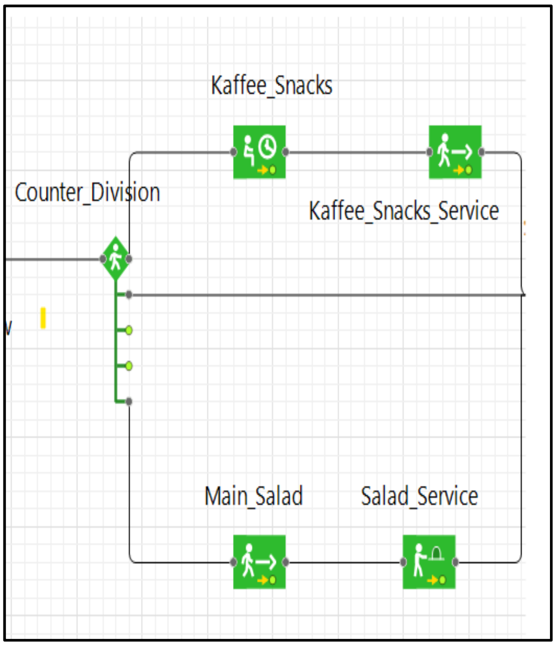

Fig 5.3 Agent logic of choosing snacks and main salad

We have planned the pedestrian flow such that everyone who obtains coffee and salad moves onto the counter to pick up the main course. The main meal consists of four food counters in which the data is distributed in accordance with the data collected.

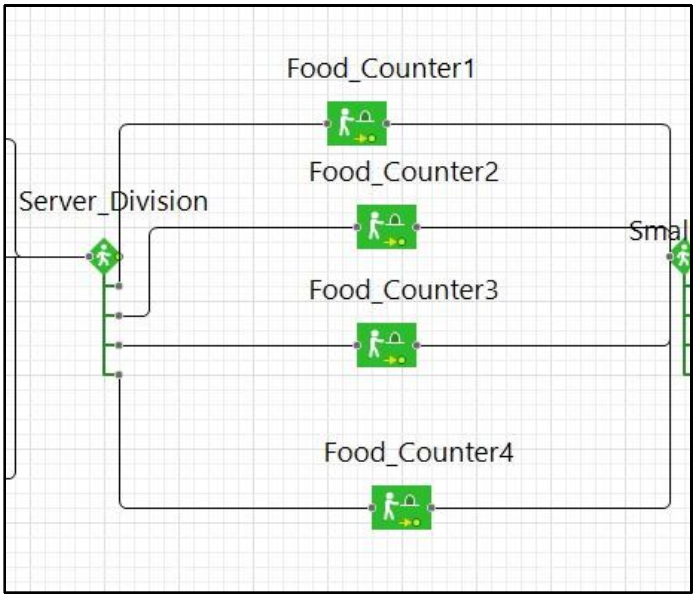

Fig 5.4 Agent logic of choosing the food

After getting the main meal, pedestrians move towards either the small dishes section or straight to the cashier section for the payment. Based on the data acquired, only a small fraction of pedestrians proceed to the salad section, while other people move forward to the cashier section.

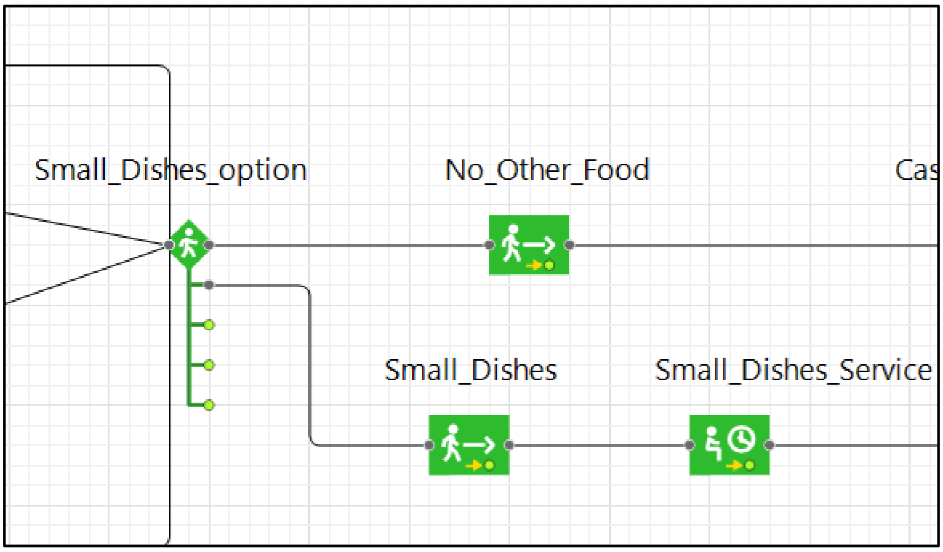

Fig 5.5 Agent logic of taking small dishes

The cashier section consists of two cashiers facing opposite each other. The pedestrians divide among the two cash counters depending on the length of the people in the queue.

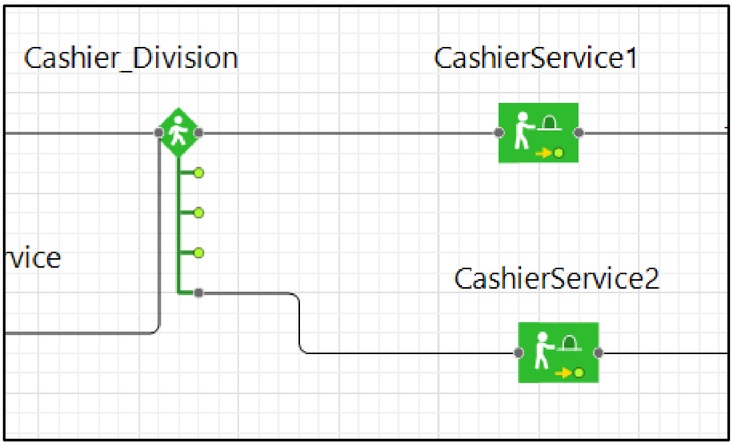

Fig 5.6 Agent logic of Cashier division

Pedestrians make their way to the dining area after paying. By aligning with the dining area's actual orientation, we divided all of the tables and chairs into a group of six service areas. We created this separation to ensure that everyone was dispersed and could be seen in all areas of the dining room. It restricts people from assembling in one area. The probability distribution of the pedestrians taking the service table area is considered based on the number of chairs and tables in the service table area. During data collection, we did not take into account the information of those entering the tables.

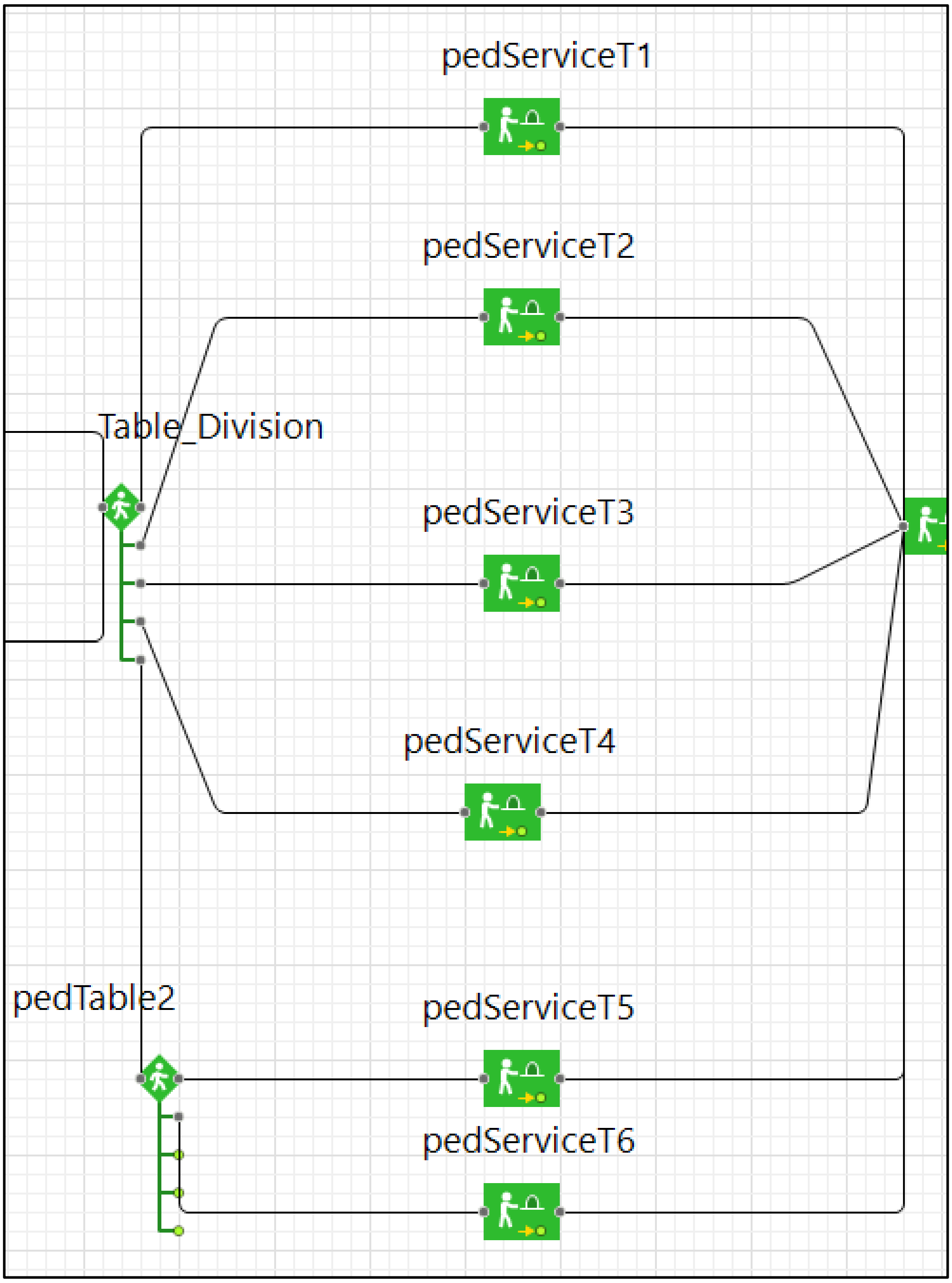

Fig 5.7 Agent logic of pedestrian sitting in the dining place

The people after finishing their meal move towards the disposal section, where they dispose the cutlery and the plates. After disposing, they move directly towards the exit. The exit is given by a Ped Sink function and provides a target line for the exit point of the pedestrians.

Fig 5.8 Agent logic of disposing cutlery and exiting

When the agents reach the first floor, they begin by gathering cutlery before entering the café. A service line is provided prior to the cutlery service for depicting the queue of people. During peak hours, it was seen that the cutlery line went all the way to the stairs. After the cutlery area another service line is provided to enter the pedestrians to further sections.

The agents then have three options after entering the service line: grab a hot beverage followed by a main meal, go straight for the main meal, and go towards the salad section. The area for hot beverages is portrayed in the model by a rectangular Node which is given a Ped Wait function for the delay of collecting Kaffee. The Delay time for Kaffee and salad section is given based on the data acquired and using a theoretical distribution.

In the main course, there will usually be four to five options of meals available. These will be provided in the four counters. Based on the type of food the queue length for each counter varies differently. Vegan options are usually provided on counter 1 and meat options on counter 4. Based on the preference of the food and type of the food, it is quite difficult to determine the probability distribution for the number of pedestrians entering each counter.

Due to this varying distribution, we have considered an almost equal probability for all counters except the vegan option getting more probability. Each counter is provided with service lines with the corresponding delay time measured which is addressed in depth. Irrespective of the food chosen by pedestrians, it eventually makes its way to the payment section. In the payment area, a service line with two queues and two lines is provided for pedestrians to process the payment.

6. INPUT DATA ANALYSIS

The most crucial and critical aspect of the simulation is providing input to the model. The model must be properly addressed and should accurately depict the situation. Every real-world system can contain one or more randomness. It is necessary to incorporate this randomness into the simulation model. The data collected from the input random variable of interest should be distributed. We have used 3 specific processes to specify the distribution:

Process 1- The Data values are directly used in the simulation procedure.

Process 2: Empirical distribution.

Process 3- Probability Distribution

Process 1 - The Data values are directly used in the simulation procedure

In this process, values are used directly for the simulation procedure, this can be used when the parameters given take a fixed value. The input Parameters will take only the specified values and it does not generate any values outside the given set of values.

Regarding the adherence to our model, this process is considered in the following areas:

- The Division of visitors after taking cutlery into the Kaffee and Snacks section, Salad section, and Main Meal.

Here the data is given in the form of probabilities in which 80% of the visitors chose to have a main meal without going to the Kaffee or Salad section. 10% of the visitors go to the Kaffee and Salad section each.

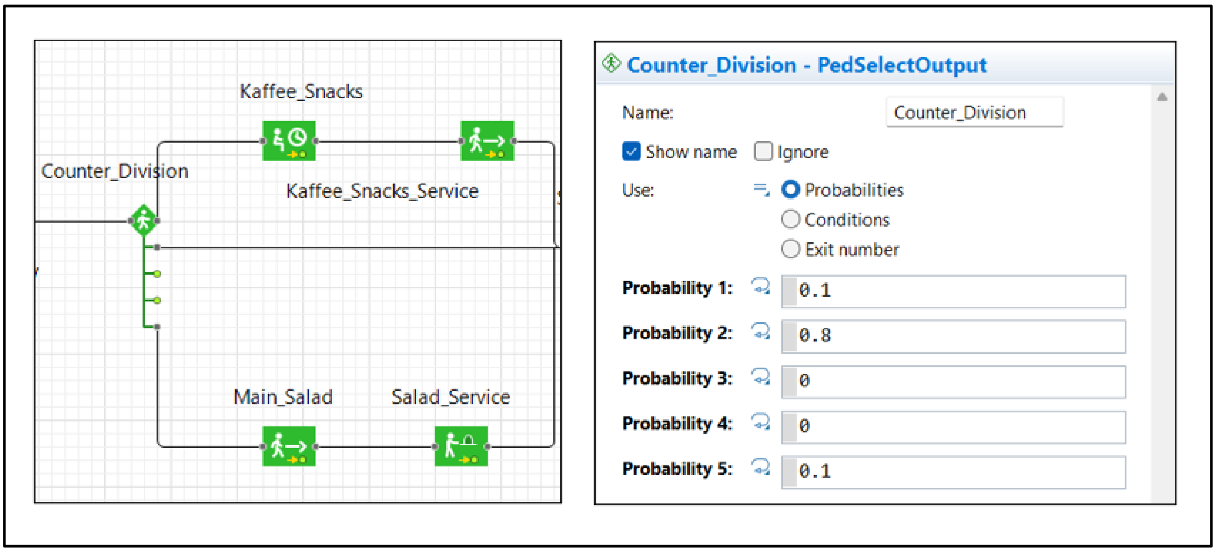

Fig 6.1 Input data for Counter division

- Food counter division in the serving area. There are four counters and different meals are served in each of the counters. 30% percent of the people take food from counter 1, 25% from counter 2, 25% from counter 3 and the remaining 20% of the visitors take from counter 4.

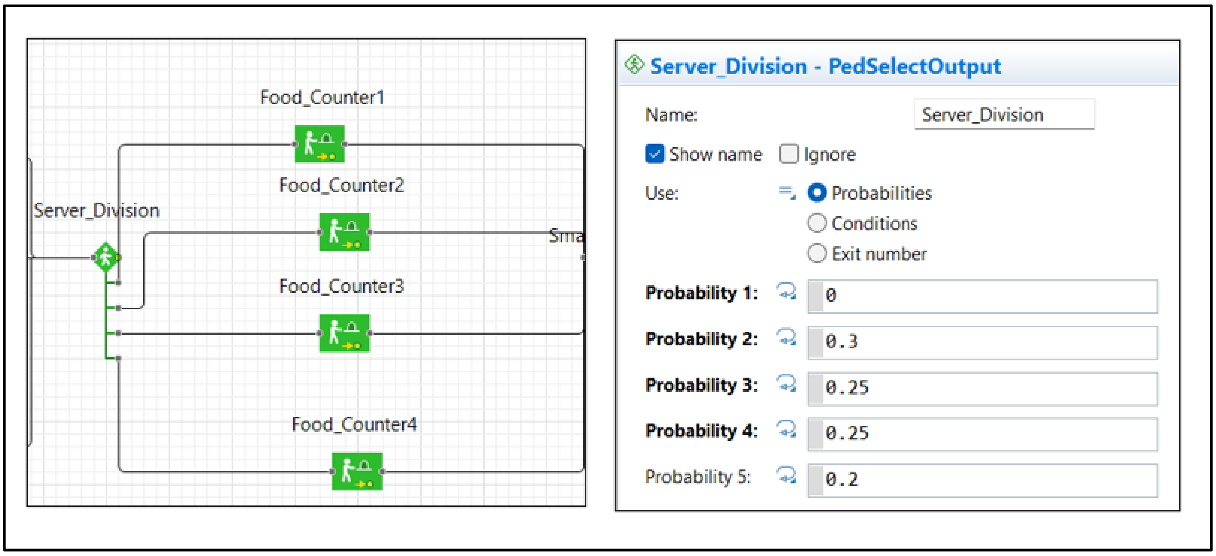

Fig 6.2 Input data for Food counter division

- Division of people taking the small salad after collecting the main meal. 90% of the people directly go to the cash counters for billing the food whereas, only 10% of the people take the small dishes.

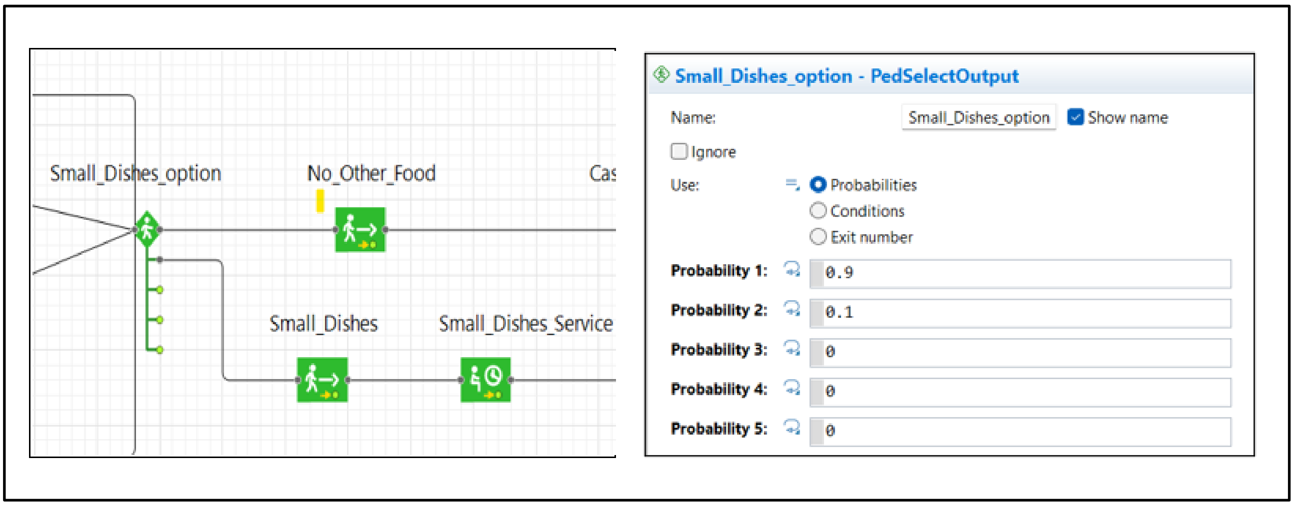

Fig 6.3 Data for small dishes

- Division of people dividing among two cash counters. 55% of people stand at the cashier 1 counter and 45% of people at the cashier 2 counter which is obtained from the data gathered.

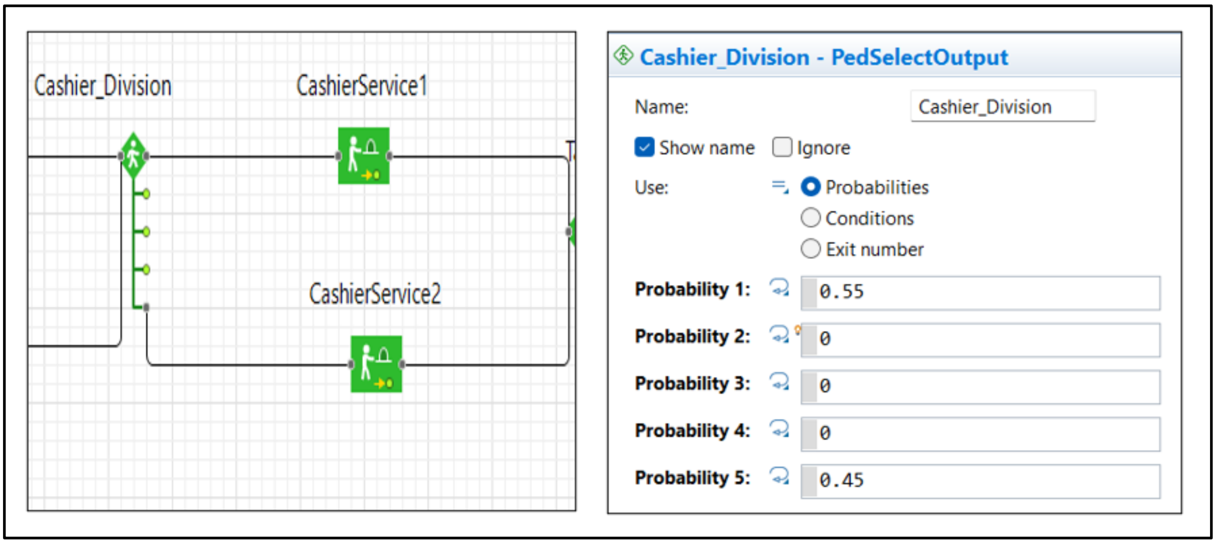

Fig 6.4 Input data for cashier division

- Division of people at the dining hall. This particular division is based on the number of tables so that the people are present equally in all the corners of the dining area.

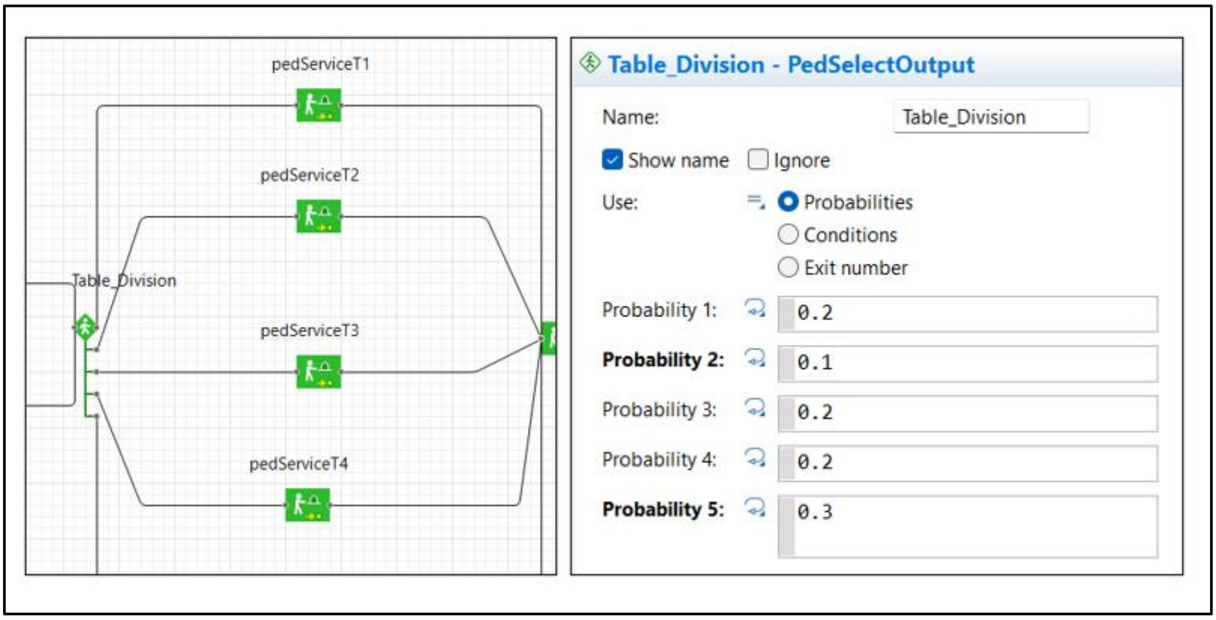

Fig 6.5 Input data for Table division type 1

Process 2- Empirical Distribution

Empirical distribution data are frequently employed while working with empirical outcome data to validate the simulation model. The key benefit of this process is that it uses data that is grounded in reality.

The data we gathered for our model covered the three-hour period from 11 AM to 2 PM. It is clear that we had to reduce our time from three hours to one hour because the simulation duration for the software is only one hour. The flow of people to Mensa is not even, the number of people entering during peak hours is very high compared to the people in non-peak hours. To incorporate this difference in the rate per hour of the entry of visitors during the peak hours, a schedule is used to give the flow of pedestrian source. The number of people entering Mensa for a time span of three hours has been scaled down as rate per hour for different time intervals by using the method of empirical distribution as shown below:

Table 6.1 Input values for visitors entering

Sl no.	Time Interval	Rate per hour
1	11:00 AM – 11:30 AM	194
2	11:31 AM – 11:50 AM	325
3	11:51 AM – 12:00 PM	780
4	12:01 PM – 12:20 PM	696
5	12:21 PM – 12:40 PM	693
6	12:41 PM – 01:00 PM	348
7	01:01 PM – 01:30 PM	232
8	01:31 PM – 02:00 PM	156

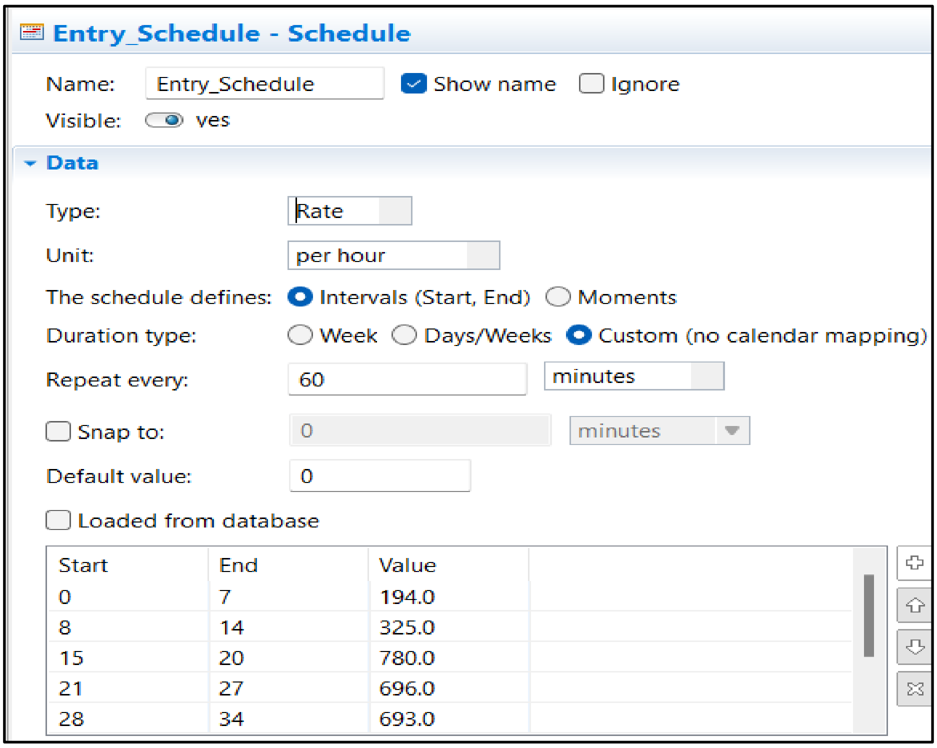

Fig 6.6 Input values in the model for visitors entering

Process 3: Probability Distribution

A probability distribution function can be used to run a simulation with random data values, particularly if the data sets differ significantly. We are able to measure and visualise the uncertainty caused by real-world data using probability distributions. If the distribution of a particular input data is known, the simulation will utilize the corresponding values, which are generated using random numbers.

We used uniform, triangular and normal functions for the probability distribution. We calculated the probability function from the data samples taken using an online probability distribution calculator. For data that have low deviations, we used a uniform function. The below figures depict some of the probability functions we used.

For cutlery Services, table service area, and disposal service there is less variance in the data, hence a uniform function with minimum and maximum value is used as the probability distribution of delay time.

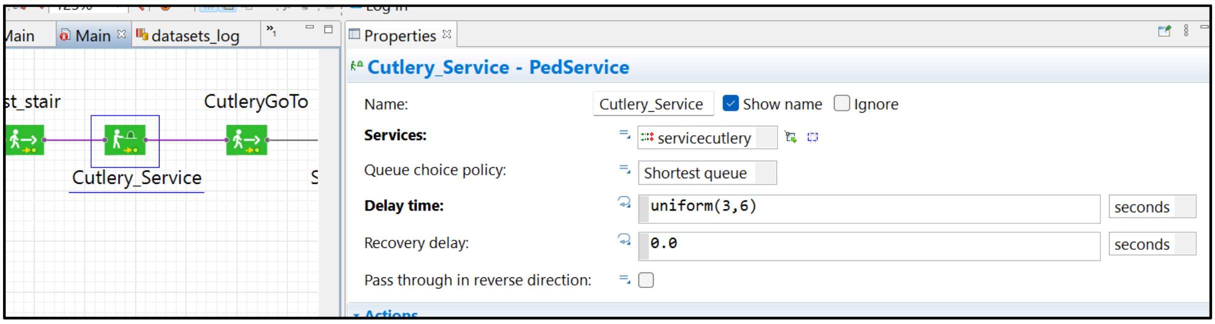

Fig 6.7 Input value for Cutlery Service

For services like Kaffee section, Salad section, and Cashier Section a triangular function is used as the probability function for the delay time. In a triangular function we give minimum, maximum and most likely occurring values. It is put to use because the data obtained shows a most frequent value, a minimum and maximum value, and both.

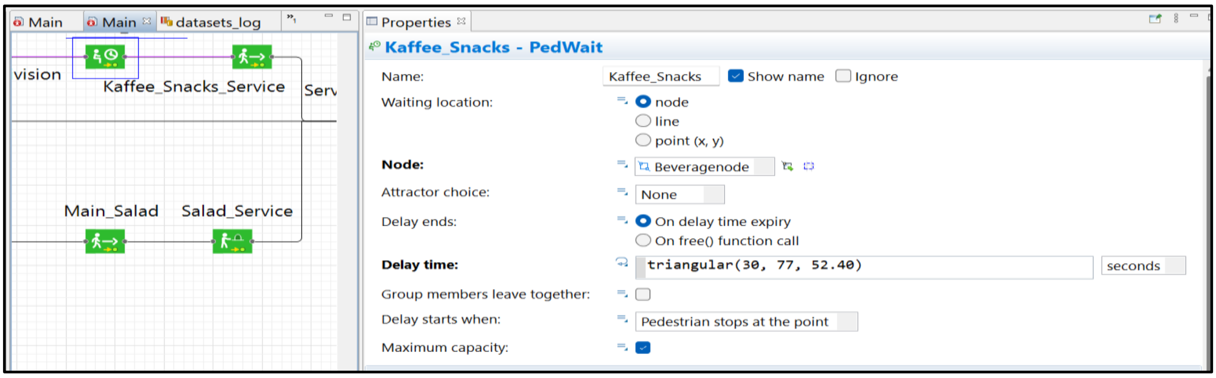

Fig 6.8 Input Value for Kaffee Snacks

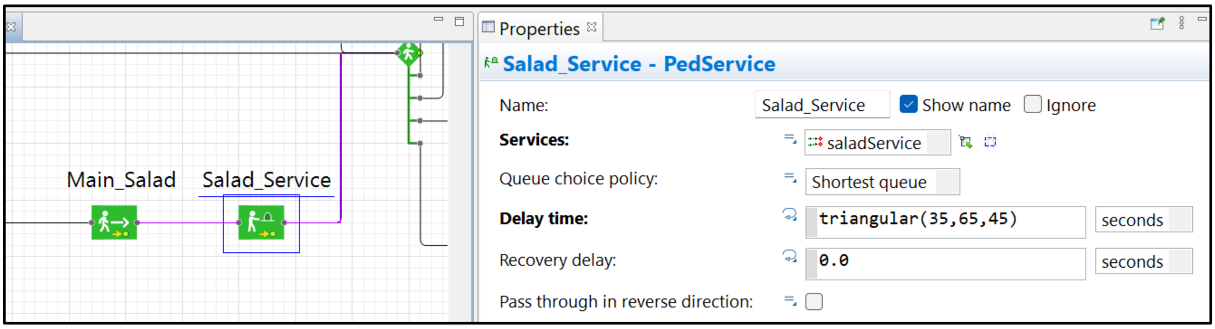

Fig 6.9 Input Value for Salad Service

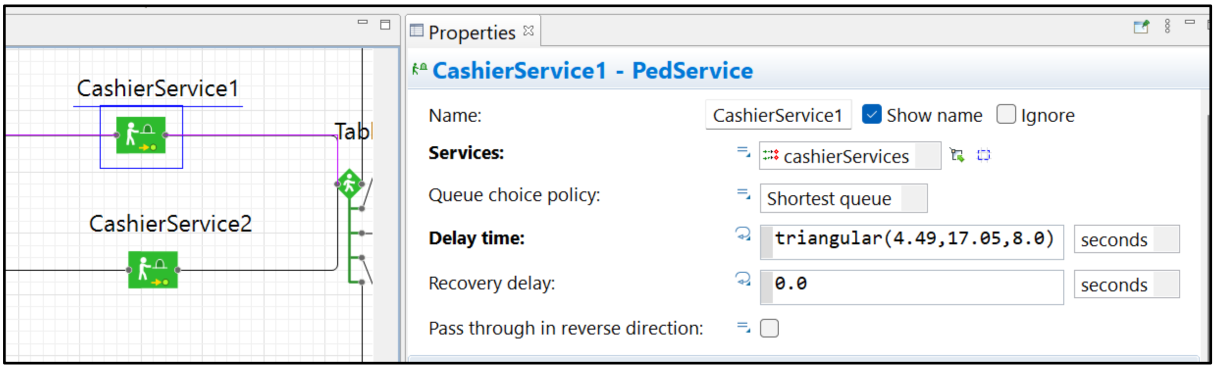

Fig 6.10 Input Value for Cashier 1 Service

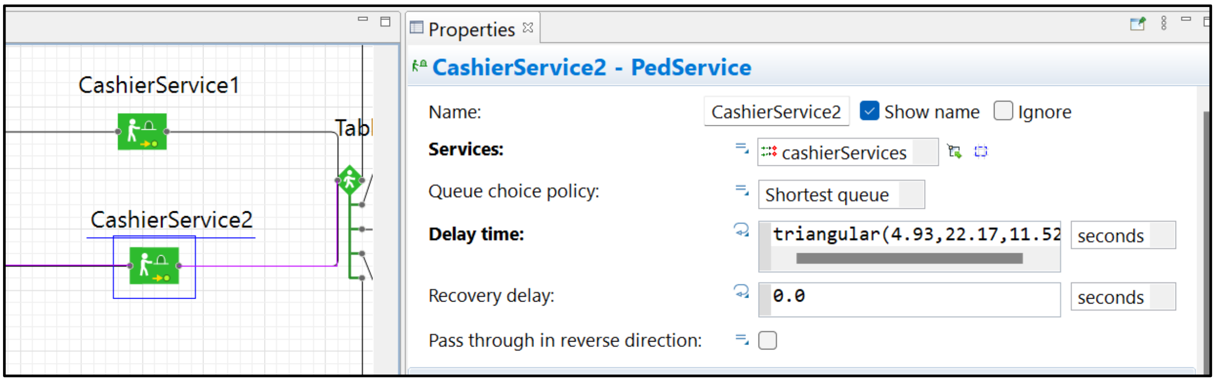

Fig 6.11 Input Value for Cashier 2 Service

For Food Counter service, a normal distribution function is used where there is variance in the data obtained. The normal distribution function is calculated using an online probability calculator. The mean and standard deviation are used for the function.

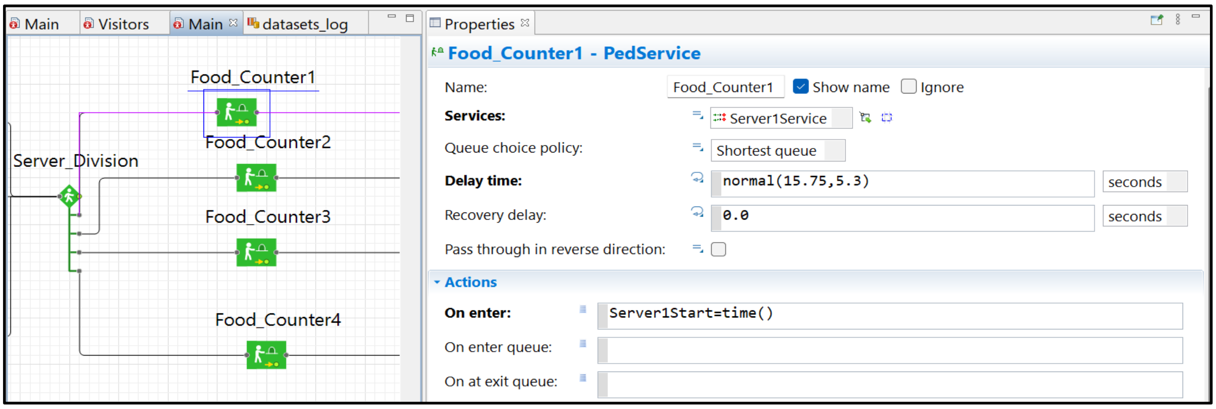

Fig 6.12 Input Value for Food Counter 1

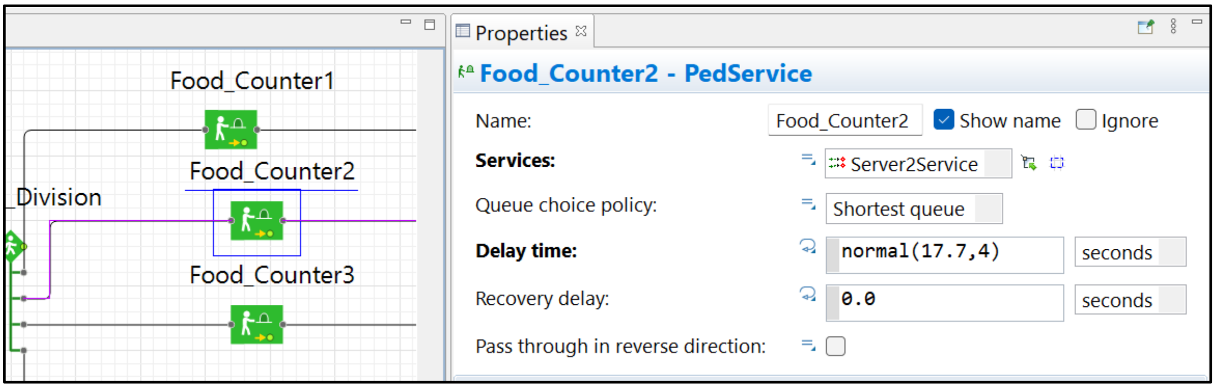

Fig 6.13 Input Value for Food Counter 2

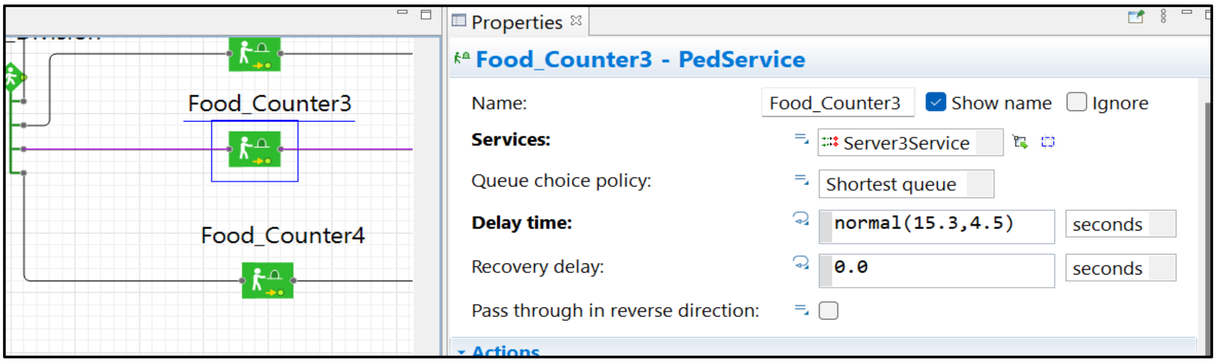

Fig 6.14 Input Value for Food Counter 3

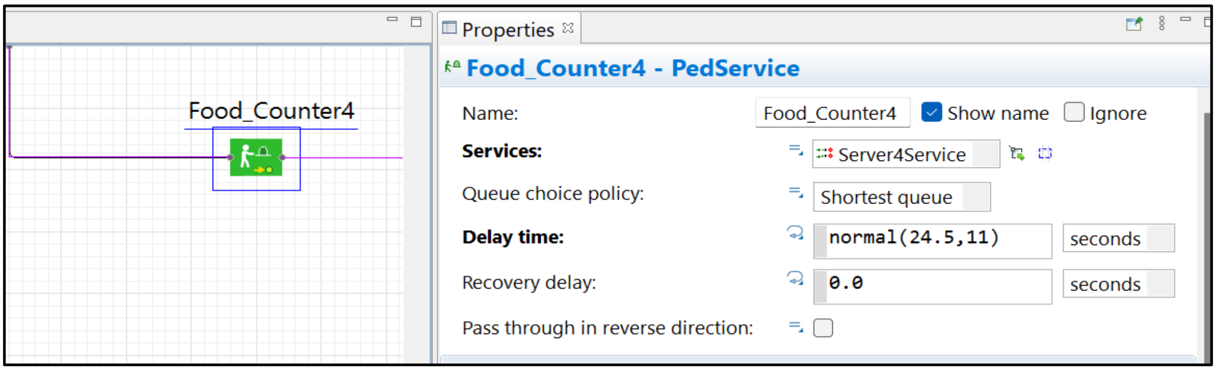

Fig 6.15 Input Value for Food Counter 4

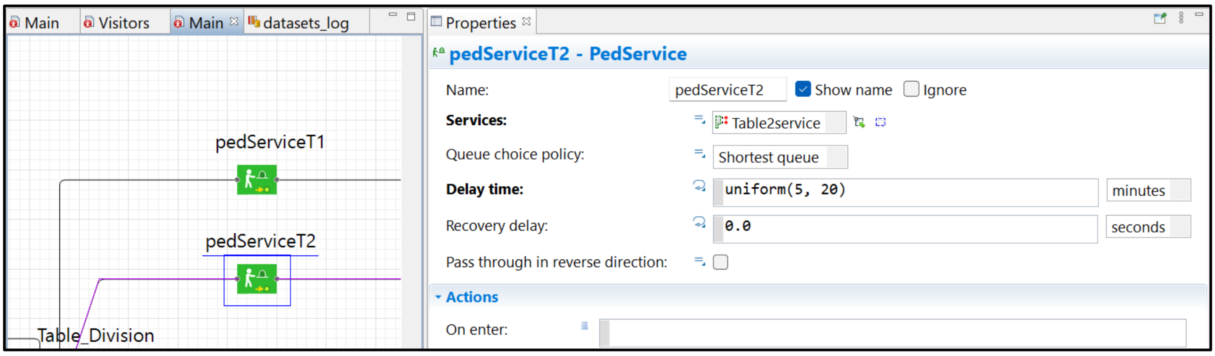

Fig 6.16 Input Value for Dining Table area

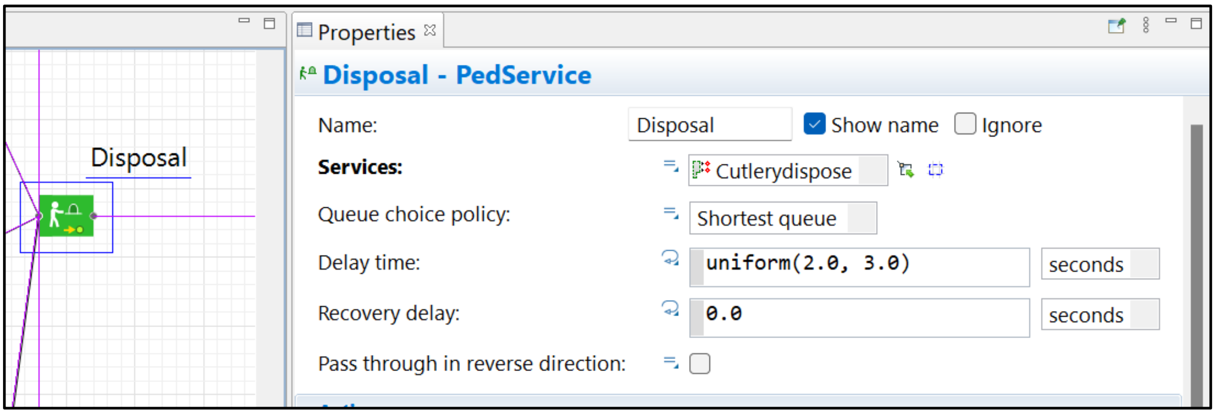

Fig 6.17 Input Value for Disposal Service

7. VERIFICATION

Once the modelling is finished and the input data is provided, we must check to see if the actual parameters were implemented correctly. Verification establishes whether a model accurately reflects the model's developer's description and its resolution. Verification makes sure that the model works by getting the maths right.

We have taken into account the following criteria for verification:

Table 7.1 Service Time at the Cashier 1

Cashier 1	Actual data	Simulated data	% Error of Mean
Mean Time (s)	14	13.55	3.21

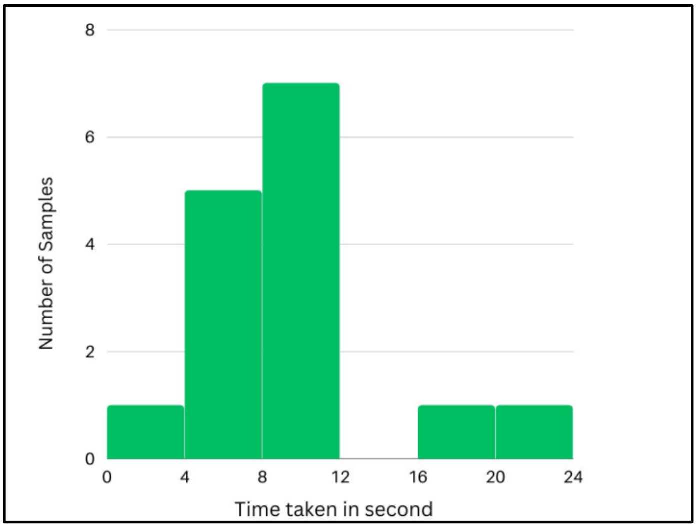

Fig 7.1 Cashier 1 mean time (Actual)

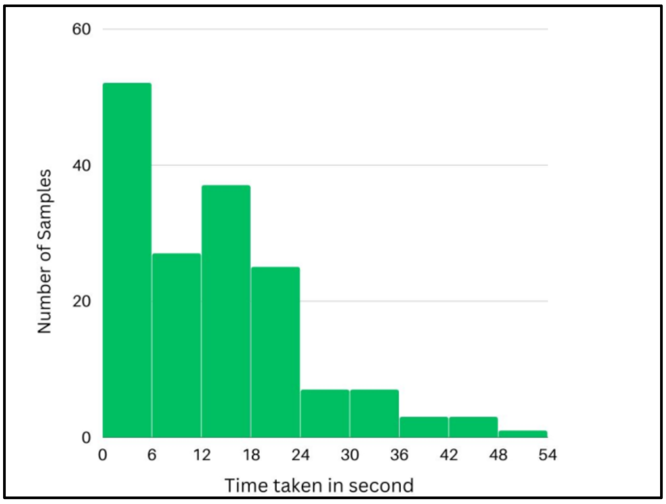

Fig 7.2 Cashier 1 mean time (Simulated)

Table 7.2 Service time at the cashier 2

Cashier 2	Actual data	Simulated data	% Error of Mean
Mean Time (s)	11.52	13.42	14.15

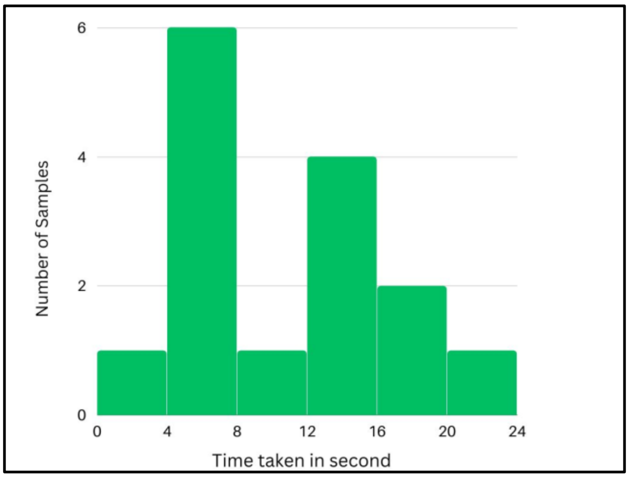

Fig 7.3 Cashier 2 mean time (Actual)

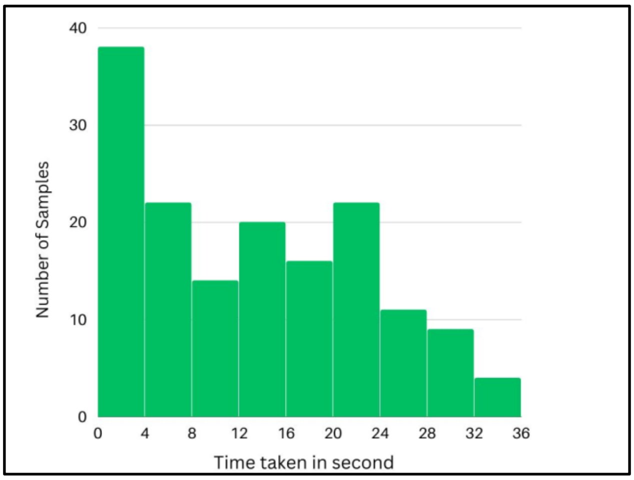

Fig 7.4 Cashier 2 mean time (Simulated)

Table 7.3 Service time at the food counter 1

Food Counter 1	Actual data	Simulated data	% Error of Mean
Mean Time (s)	13.75	11.80	14.18

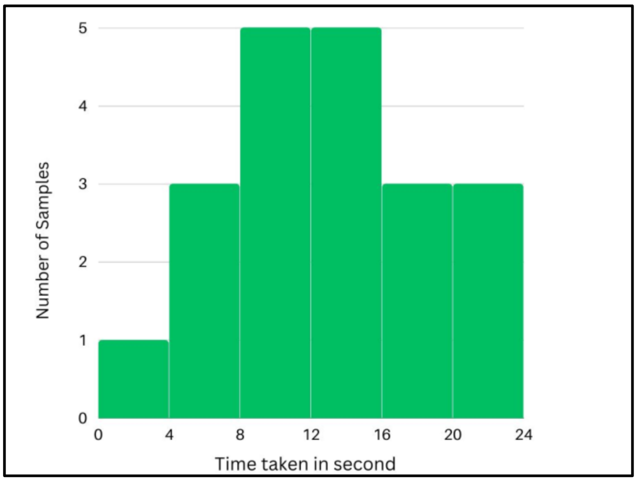

Fig 7.5 Server 1 mean time (Actual)

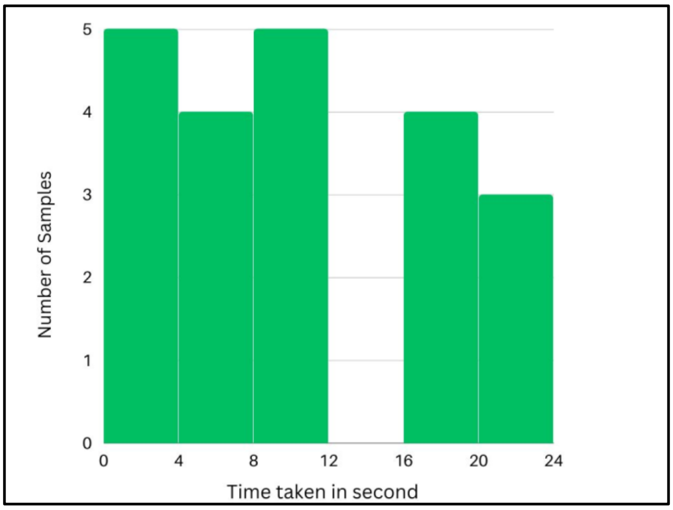

Fig 7.6 Server 1 mean time (Simulated)

Table 7.4 Service time at the food counter 2

Food Counter 2	Actual data	Simulated data	% Error of Mean
Mean Time (s)	17.7	15.61	11.80

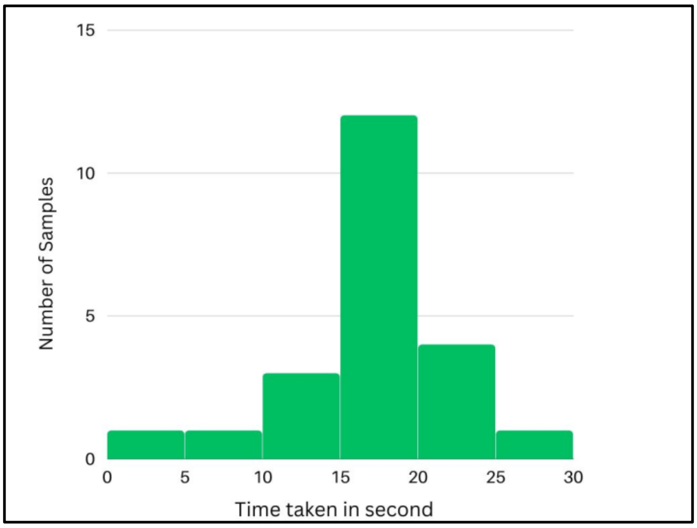

Fig 7.7 Server 2 mean time (Actual)

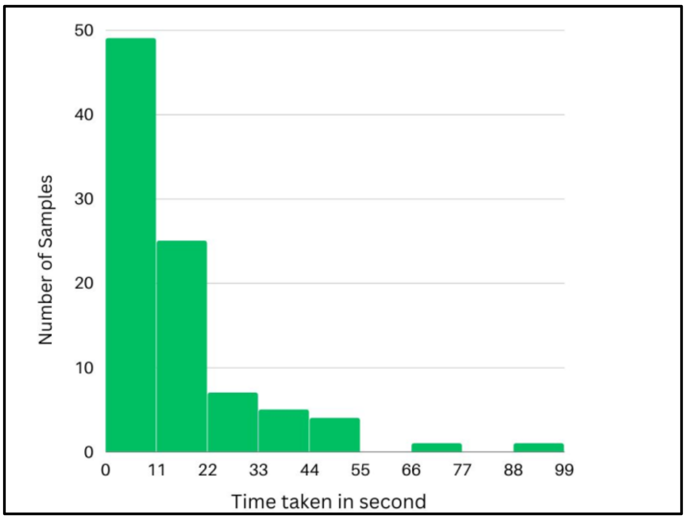

Fig 7.8 Server 2 mean time (Simulated)

Table 7.5 Service time at the food counter 3

Food Counter 3	Actual data	Simulated data	% Error of Mean
Mean Time (s)	15.3	18.14	15.65

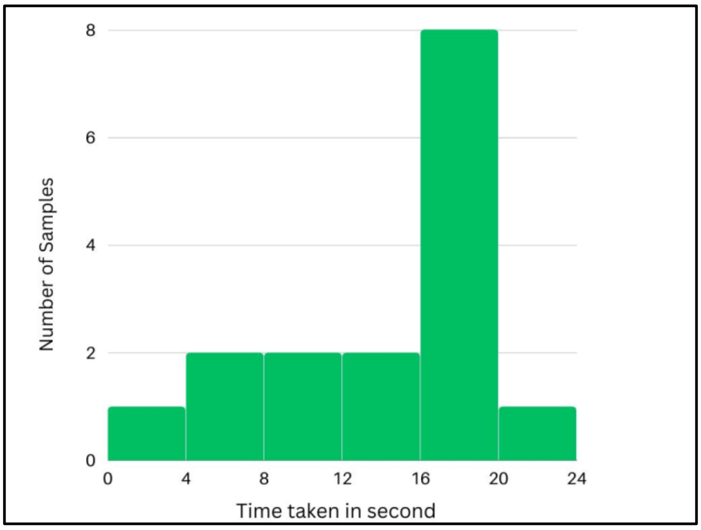

Fig 7.9 Server 3 mean time (Actual)

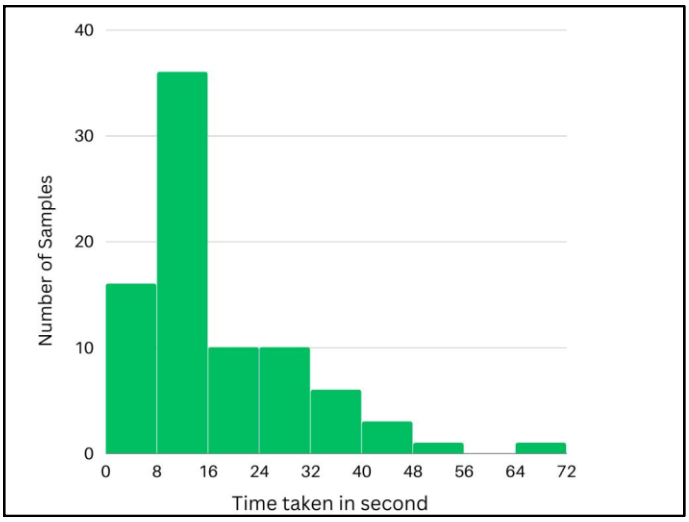

Fig 7.10 Server 3 mean time (Simulated)

Table 7.6 Service time at the food counter 4

Food Counter 4	Actual data	Simulated data	% Error of Mean
Mean Time (s)	24.5	24.77	1.09

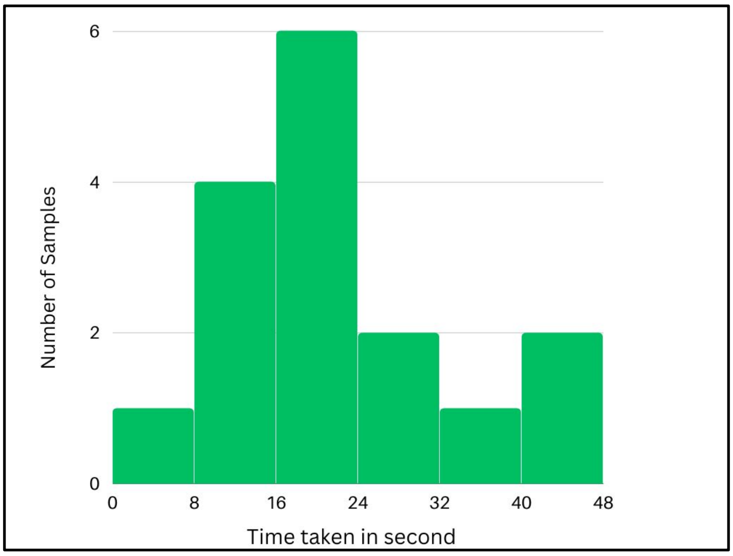

Fig 7.11Server 4 mean time (Actual)

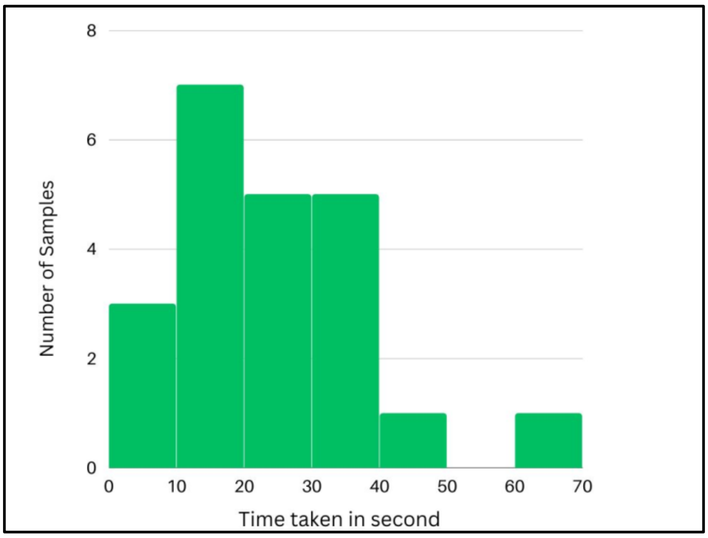

Fig 7.12 Server 4 mean time (Simulated)

The verification of our model was successful by comparing the data of the simulated model with the actual data. The percentage error was found to be from ~(1% to 15%). The graphs which are generated are similar but not identical. The values and the graphs obtained from the simulated model almost match with our actual input model data.

8. VALIDATION

The simulation model is created to analyse pedestrian crowd movement, and the defined objective is used to assess its validity. The output parameters are taken into consideration for the validation and depend on the simulation's goal. The accuracy of the simulation model is determined by the validation procedure. A simulation model's suitability and applicability for the goal are determined through validation. Validation is always done with a goal; by getting the physics correct, validation ensures that it does what it is intended to.

Our main object is crowd management; hence we have considered output parameters that are related to the crowd in Mensa. The output parameters considered mainly are the total time a pedestrian needed to wait to get the food served and queue formation.

QUEUE LENGTH

Validation also includes the experimental setup of real situations. Queue length is counting the number of people when the queue is formed at peak hours. We have validated this parameter by comparing the actual photographs of the queue formed during the peak hours in the Mensa and the queue formation in the simulated model at peak hours.

We have considered the queue formed in the serving area. The graph is obtained by plotting the number of people standing in the service line waiting for the main meal.

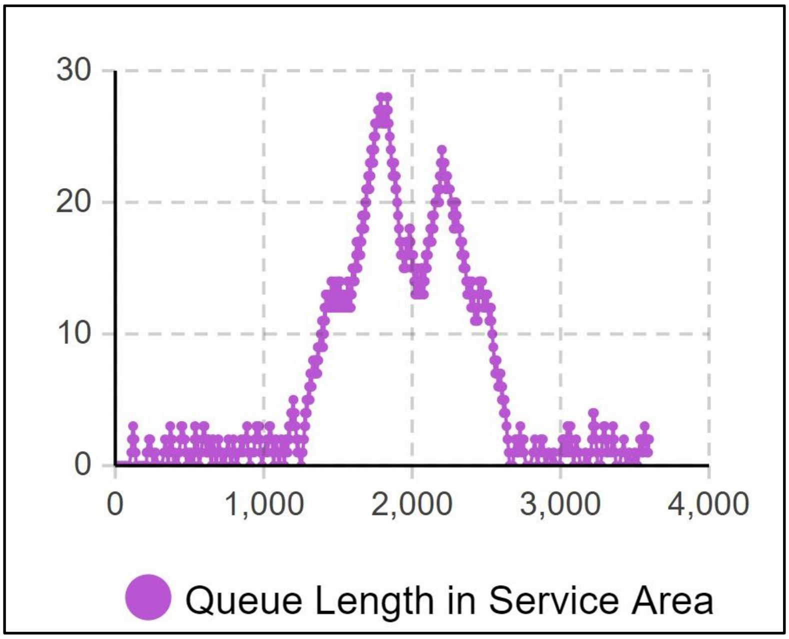

Fig 8.1 Queue length formed in the serving section

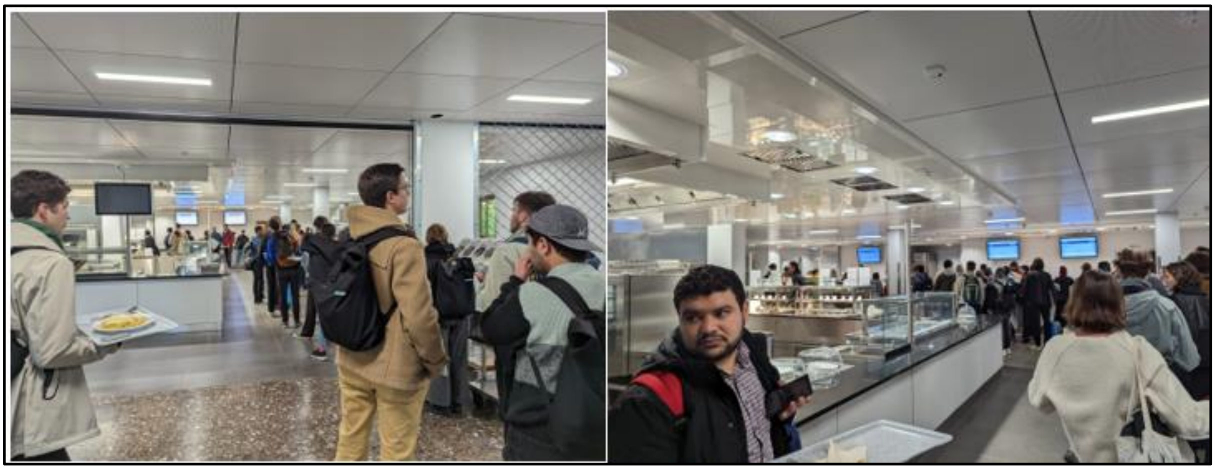

Fig 8.2 Queue formation in peak hours

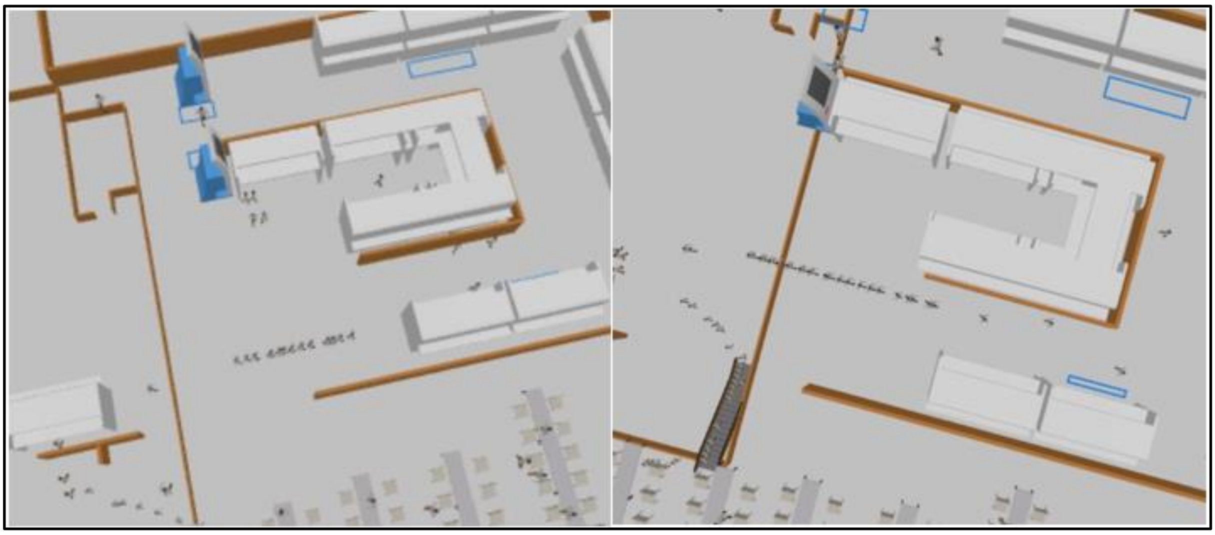

Fig 8.3 Queue formation (Simulated)

Fig 8.4 Queue formed at stairs

TOTAL TIME IN THE SERVING SECTION

Waiting time for the visitors from the beginning of the cutlery area to the endpoint of the cash counter is recorded and shown graphically. A variable called ‘TimeStartFromCutlery’ is used to record the time of each pedestrian entering the cutlery Section.

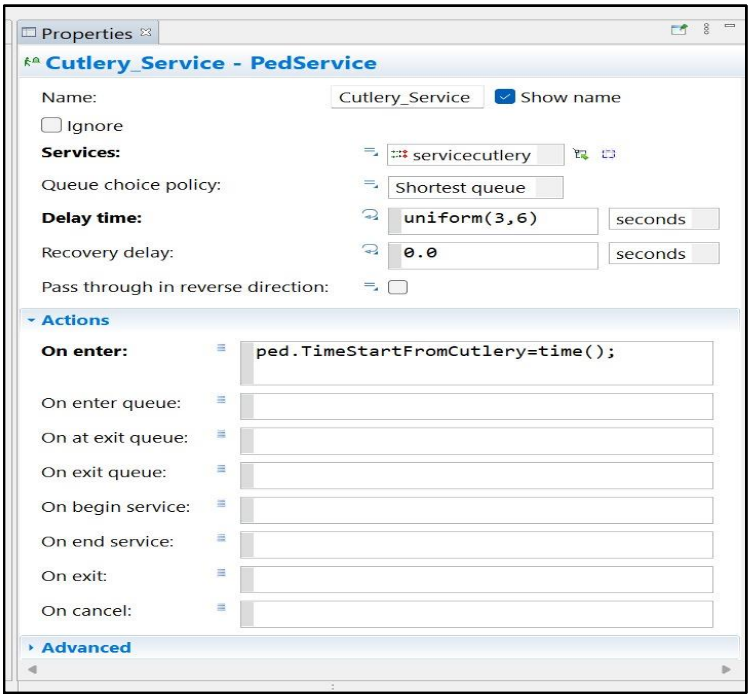

Fig 8.5 Specification of total time at cutlery

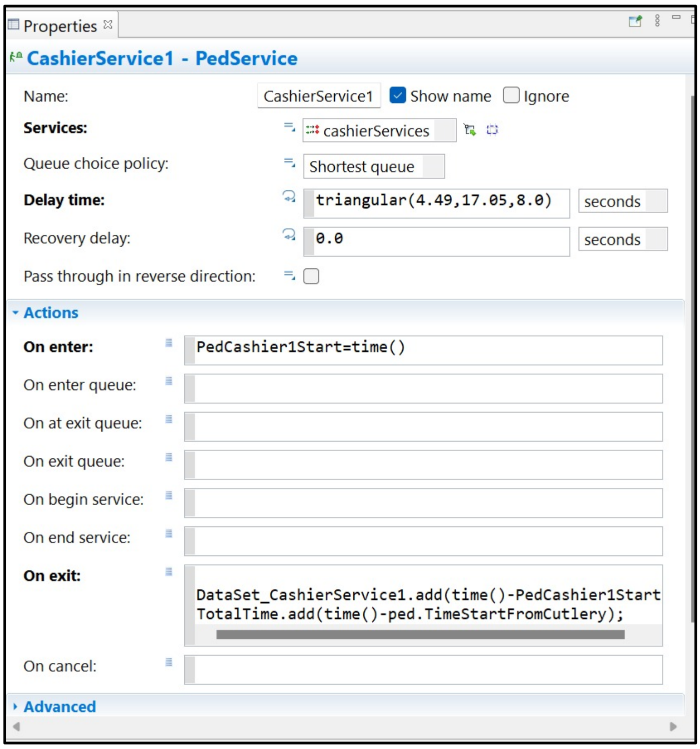

Fig 8.6 Specification of total time at cashier 1

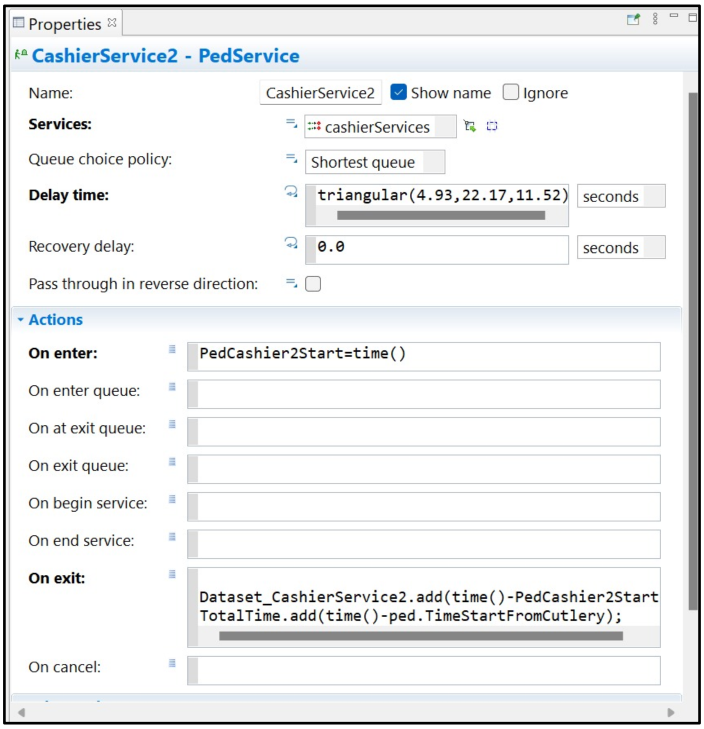

Fig 8.7 Specification of total time at cashier 2

A dataset called ‘Total Time’ is created and the time taken from the point a pedestrian enters the cutlery section to the payment section is recorded on the dataset. The total time is recorded in both the cashier counters and added to the Total time dataset. The Total time data set is plotted with the working hours of Mensa. From the below graph, it is evident that the total time for getting the meal is high during the peak hours. The maximum time obtained from the simulation is 498.46 seconds (8.3 minutes). The maximum time manually recorded from Mensa during peak hours is 9.1 minutes.

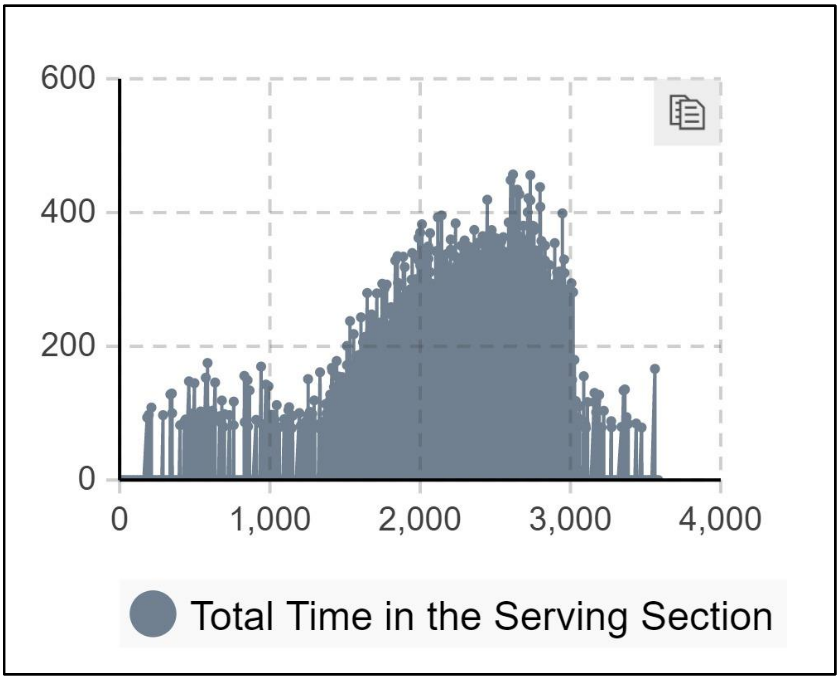

Fig 8.8 Total time taken from the cutlery section to cash counters

From the above validation tests, comparing the simulated model output with the actual system output we could conclude that the results were satisfactory. Therefore, the simulated model is valid.

The following techniques are incorporated in the validation part of our simulation model:

1. Event validity test - The test in which the events that are taking place in the simulation model are compared with the actual or the real system and concludes whether it matches the real system. The number of people in the queue, one of our output parameters, holds good for this test. Comparing the number of people in the simulated model and the number of people in the real world at a specific interval of time, we perform the event validity test.

2. Monitoring and operational graphics - These are validated by actual values and graphical figures. The actual value and the simulated values, the graph obtained by considering actual values and simulated values are plotted and compared accordingly. Both of our output parameters are obtained by using this type of validation test.

3. Sensitivity Analysis - Any change in the input parameter of the model affects the output and the behaviour of the model. We find the parameter that is very sensitive and any small change in that parameter will have a drastic impact on the output. We found out that any change in the delay time of the services in the service area will have an impact on the total time that pedestrians need to wait in the service area.

The observation from the modelling of Mensa is that changing some sensitive parameters such as the speed of the pedestrian has a greater impact on the modelling; creating a greater variance in output result from the actual output. Changing the service line for the queue will significantly impact the result generated from the simulation experiment of Mensa.

9. OPTIMIZATION

Relocating the cutlery section to the food counters

The cutlery that is currently at the service area's entrance can be moved closer to the food counters. If the cutlery trays and other items kept at the entry were moved to four different food counters, the queue would be shorter and quick movement of visitors to the next section is possible. Visitors can enter the area where the food is served directly, take out the cutlery trays and other items from that particular counter, collect the food that is being served, and then depart. Visitors can take the cutlery during the time at which food is served.

The mean total time taken by the visitors from taking the cutlery items to billing the food items was 202.27s. After incorporating our above idea, the total time will decrease to 166.22s. This is a decrease of 17.8%

Table 9.1 Optimised total time

Total time(s)	Total time after optimization (s)	Percentage change(%)
202.27	166.22	17.8

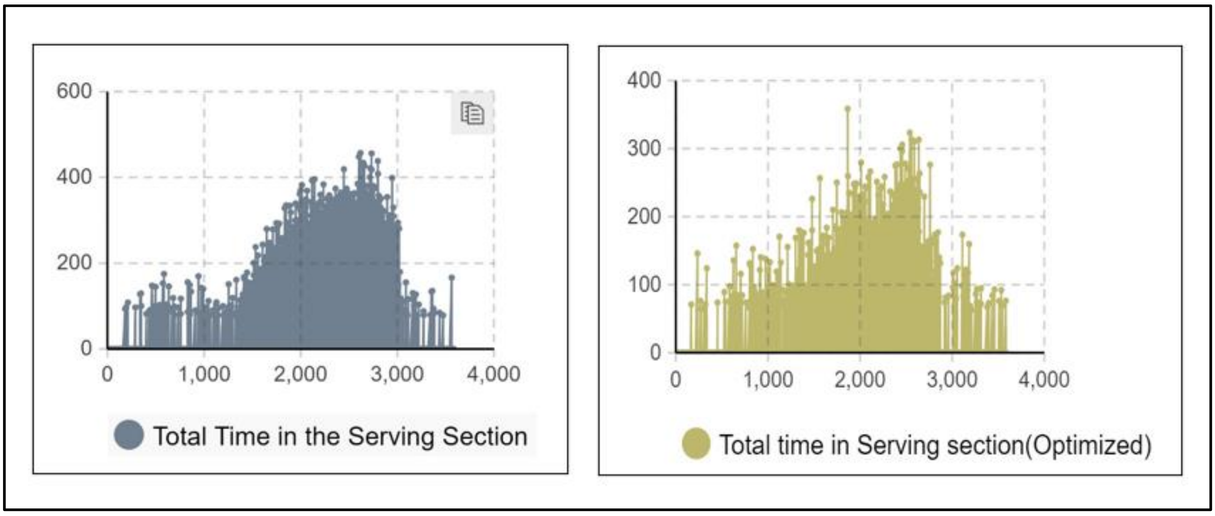

Fig 9.1 Comparing the total time and the optimized time

From Figure 9.1, we can clearly see that the time reduces after moving the cutlery items from the entrance to the food counters. This decrease is by 17.8%.

10. IMPROVEMENTS

Setting up the snacks, beverages, and coffee as an automatic vending machine on the ground floor

The coffee, beverages, and snacks section can be set up as an automatic vending machine instead of placing it in the service area. The snacks can be stored in the vending machine, the visitor can take the snack item which they wish to have by paying the money or by tapping the Thoska card.

The coffee machine can also be set up in the dining section of the first floor instead of the serving area. The visitor can put the coins or tap the Thoska and coffee can be collected.

By incorporating this method, the queue length can be reduced and there will be enough space in the serving area. This also reduces the time at the cash counters, as the cashier takes less time in billing the food items.

Using the area in the middle of the service area which is of no use

The area which is in the middle of the service area at the Mensa can be utilized for making queues. The entrance to the service area can be increased thus increasing the number of queues. Four different queues can be created at each of the food counters. This will reduce the queue length of the visitors.

Filling the food in the counters before it gets over

Once, the food is almost about to get over, the food can be filled in the food counters immediately in order to avoid the big crowd of people.

Displaying the photo of the food which is being served on the counters

Most of the visitors choose the food by its appearance. Visitors usually take a lot of time checking the food in all the counters. They usually have confusion in deciding the food item and this creates a mess in the service area resulting in blockage of the queue. so, the queue length and the waiting time of the visitors increases.

A board with the display of food items served in Mensa on that particular day along with the ingredients and the price of food both in German and English languages is displayed. The photo of the food item can be displayed on the ground floor. With this, the visitors have the option to decide which food item they would like to prefer before entering the food counters. There will be no confusion and the visitors can go straight to the food counter where their preferred choice of food item is served. There will not be any long queues in the service area and the waiting time of the visitors can also be reduced.

11. CHALLENGES FACED

Time constraint in AnyLogic Software

It is not possible to provide all three hours of data for the student version of Any Logic, which has a simulation time constraint of just one hour. If we consider only one hour data, the people entering before or after the selected time will not be considered in the model which affects the overall objective of the simulation model. Hence, using the option of schedule, we scaled the three-hour data to one hour with rate per hour for different time intervals.

Incorporation of stairs in AnyLogic

Due to the unavailability of the stair option in AnyLogic, we used a rectangular node with a slope to act as a stair in the three levels of the model. Due to compilation errors, we couldn’t make it function. We used elevator functionality as an alternative to stairs. The elevator is given from the ground floor to mid-level, connecting to the first floor. To ensure the continuous flow of pedestrians, a target line is given at the mid-level. In the simulation, pedestrians appear to have random movement in the middle level, which is not a reflection of the real-world situation. We felt the implementation of the stair portion was quite challenging as it does not accurately represent the real-world situation.

Difficulty in Data Collection during peak hours

The randomness in the movement of the visitors on the ground floor and first floor in and out of Mensa multiple times makes counting difficult. Food serving counters have rush and crowd during peak hours which makes it difficult to note the time of an individual.

12. TASK DIVISION

Group Members	Tasks
Vishal Sanjay Shivam	• Data Collection • System Analysis • Agent Based Modelling • Input Data Analysis • Validation • Report Writing
Isabel Maria Binu	• Data Collection • System Analysis • Agent-Based Modelling • Input Data Analysis • Validation • Report Writing
Anjana Muraleedharan Nair	• Data Collection • Agent-Based Modelling • Verification • Validation • Report Writing
Sharat Anand	• Data Collection • Verification • Optimization • Report Writing
Pratik Gedam	• Data Collection • Literature Review • Optimization • Improvements • Report Writing

REFERENCES

[1] https://agrimetsoft.com/distributions-calculator/Normal-Distribution-Fitting

[2] https://anylogic.help/library-reference-guides/pedestrian-library/index.html

[3] Nicolas Denz, *Process-Oriented Analysis and Validation of Multi-Agent-Based Simulations*

[4] Andrei Borshchev, *The Big Book of Simulation Modeling*, AnyLogic North America, 2013.

[5] Robert G Sargent, *Verification and Validation of Simulation Models*, Proceedings of the

2011 Winter Simulation Conference.

[6] Jerry Banks - *Introduction to Simulation*, Proceedings of the 1999 Winter Simulation Conference

[7] Anu Maria - *Introduction To Modeling And Simulation*, Proceedings of the 1997 Winter Simulation Conference

[8] JulienWalzberg, Jean-Marc Frayret, Annika L. Eberle, Alberta Carpenter, Garvin Heath - *Agent-basedmodeling and simulation for the circular economy*

[9] Faza Fawzan Bastarianto, Thomas O. Hancock, Charisma Farheen Choudhury and Ed Manley - *Agent-based models in urban transportation: review, challenges, and opportunities.*

[10] Shuntaro Masuda, Kyle Bahr, Noriyoshi Tsuchiya & Tatsuya Takemori - *Agent based simulation with data driven parameterization for evaluation of social acceptance of a geothermal development: a case study in Tsuchiyu, Fukushima, Japan.*

[11] Osman Balci, *Validation, Verification, and testing techniques throughout the life cycle of a simulation study*, Annals of Operation Research 53(1994)121-173.

[12] Nguyen Thi Bich Tram, *Simulation modeling - An effective method in doing business and management research*, Available From (PDF) Simulation modeling -An effective method in doing business and management research (researchgate.net).

[13] A. Yair Grinberger, Daniel Felsenstein, *Agent-Based simulation of COVID-19 containment measures, the case of lockdowns in cities*, Agent-based simulation of COVID-19 containment measures: the case of lockdowns in cities | SpringerLink

[14] B. Health, R. Hill, F. Ciarello, *A survey of Agent-Based Modeling Practices*, Journal of Artificial Societies and Social Simulation.