Master's Thesis

Usage Intensity in Life Cycle of Real Estate
- Quantification of Usage Intensity by Simulation

Nutzungsintensität im Lebenszyklus einer Immobilie
-Quantifizierung der Nutzungsintensität durch Simulation

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Glossary of Notations

Abbreviation

A	
ABS	Agent-based simulation
ABM	Agent-based models
Avg.	average
C	
CDM	consumer decision-making
D	
DB	Database
E	
ED	Euclidean distance
EDT	Euclidean Distance Theory
e.g.	For example
H	
Hblock	hierarchical block
I	
i.e.	id est
H	
HVAC	heating, ventilating, air conditioning
M	
MADM	Multiple Attribute Decision Making
O	
OEZ	Olympiaeinkaufzentrum (the name of the shopping mall modeled)
R	
RMS	Root-mean-square
S	
Std Dev	standard deviation
T	
TBA	time between arrival

1 Introduction

1.1 Motivation and Objective of Thesis

1.1.1 Topic of Research and Restrictions

Generally, the life span of a building component is the period during which it physically exists and fulfills its intended function.[1] In the life cycle of a building, many building components will have to be replaced due to the material attrition. In the literature, the life span of different building components such as the service life of windows, doors is stated. However, the wear and tear are strictly related to the usage intensity of the specific building components for different use. For example, a component that is more intensively used must be replaced earlier than one with less intensive usage. Therefore, the life span of building components differs from each other depending on the real estate types, user numbers, and user structure as well as the interaction between them.

As it is very time-consuming and thus not realistic to measure the actual usage intensity of specific building components, especially in a building type, where user structure and interaction are relative too complex to analyze, such as in a shopping mall. This thesis aims to develop a simulation model to quantify the usage intensity of building components in a shopping mall. A sample model of a real shopping mall with a standardized space structure was implemented in ExtendSim. Through the analysis of customer behaviour and typical usage processes in the building, the interaction between customers and building components that triggered the record of the usage intensity can be studied. Adding the logic of decision-making mechanism enables the monitoring of all the interactions between customers and the main building components in the mall.

Yet the limited sources of available data from the real shopping mall restricts the accuracy grade of this simulation model concerning customer's behaviour in a real shopping mall scenario, such as the detailed customer flow in various times, the popularity, positioning of customers and the more accurate information about customer's demographic in each shop. Also, due to the time constraints, not all of the detailed logic was included in the model, but the most important factors were considered and programmed in the equation-based blocks using ModL functions.

Nevertheless, despite the restrictions during modelling, it is of great meaning to complete such a model representing customer's movement and decision-making processes, as it is appliable and scalable for further application area, including not only shopping mall design optimization but also mall management operation optimization, etc.

[1] Hermans, M.H.: Building Performance Starts at Hand-Over: The Importance Of Life Span Information. Published in National Research Council Canada 1999. P2.

1.2 Thesis Structure

After the general introduction and delimitation of the topic, the first chapter introduces the research methodology, including the software used to simulate the shopping mall model and the fundamental simulation theories.

The second chapter explains the foundation of real estate concepts and definitions of building components. The main themes of this chapter are different categories of real estate and their life span.

In Chapter 3, concepts of simulation and modelling will be presented as the basis of the specific model explanation. After introducing the simulation and the relevant terminologies, the software ExtendSim and the conventional modelling methods for different events are covered.

Chapter 4 explains the general modelling process, the goal and limitations, and the main model components. Additionally, the customer activities and their interaction with building components and products in the operational phase of a shopping mall are defined and determined to form the foundation of the modelling work.

Chapter 5 presents an overview of the model built in ExtendSim. This section includes the main components in the model—for example, the model setups as well as the spatial arrangement and layout. An overview of the model is provided in this chapter.

Chapter 6 contains the core of the model logic. Customer movement is illustrated in flow diagrams. The Two-level decision-making method is introduced in detail, as well as the method to identify and initialize the essential parameters. It explains how the logic of interactions between customers and building components is conducted into the model.

In Chapter 7, the quantification of the research objects – usage of the building components in this model is introduced. How the usage of an object is triggered is the key to solve the problem and it determines the logic of the interaction between blocks in the model. To quantify the usage intensity of the studied objects, the influencing parameters and the measurement units are discussed accordingly.

After conducting all the necessary logic into the model, model verification and validation are covered in Chapter 8. The model can be validated by analyzing the results obtained from the simulation run and comparing it to the results intended in a real scenario.

Finally, in Chapter 9, the simulation outputs analysis is implemented. With the help of the Scenario Manager in ExtendSim, several *Factors* that to be included in the analysis and the *Responses* can be customized adjusted and get all the scenario combinations outputs exported in the database. The impact of several main factors on the intended outputs are represented in ths chapter.

In the last Chapter, the conclusions of the work are made, and further work to improve the model and some suggestions in this research area are discussed.

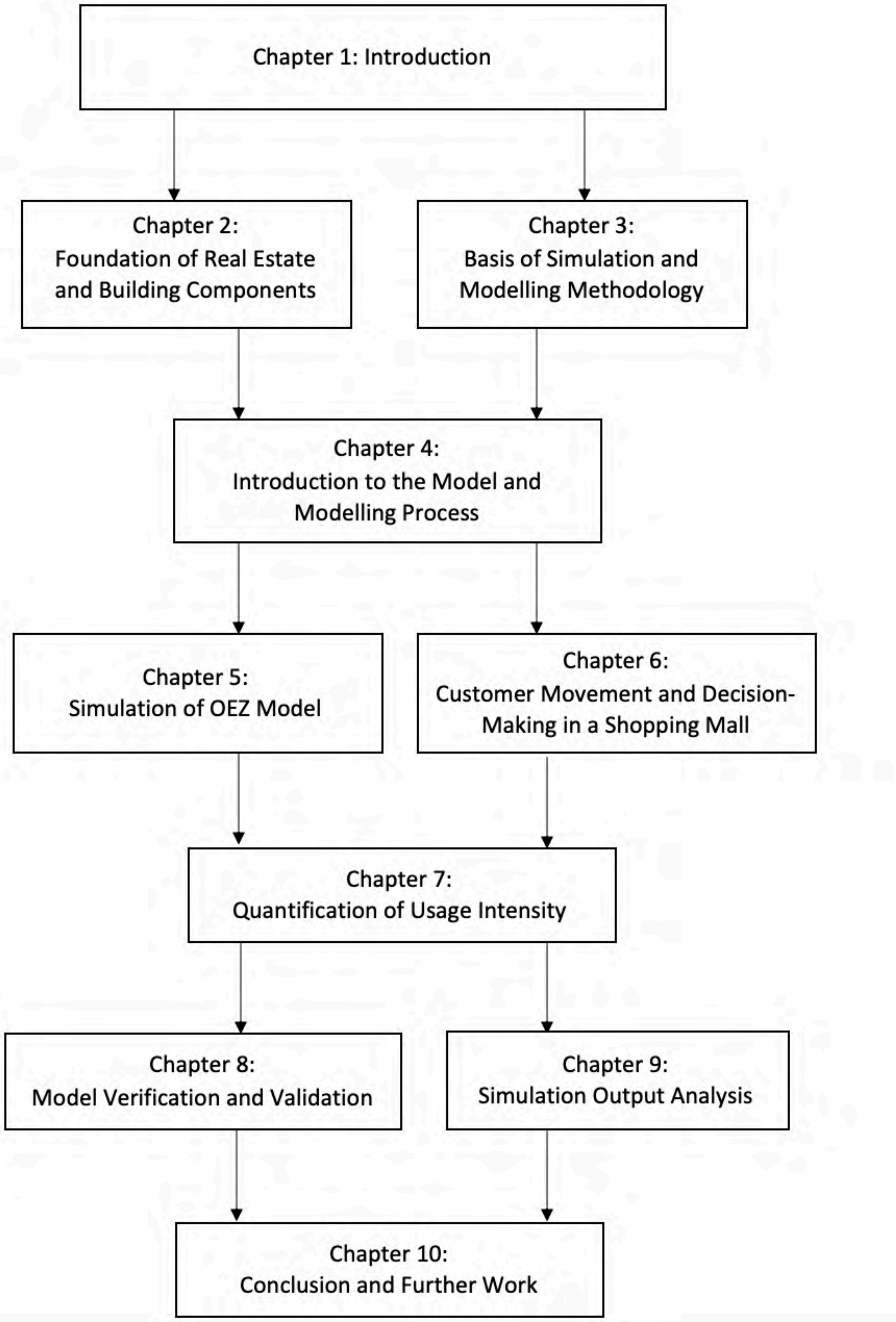

Figure 1-1: Structure of the thesis

1.3 Research Methodology

The methodologies and theoretical basis of creating a specific model are introduced in this section, such as the simulation software used for modelling, the processes to accomplish the goal of quantification of usage intensity of building components in a shopping mall.

1.3.1 Software

Although there are other capable software packages on the market to simulate customer behaviour in a shopping mall, ExtendSim was selected because of its widespread usage in the industry for simulating processes dynamically. In particular, processes could be visualized logically or in a virtual environment, which can identify problem areas before implementation and explore the potential effects of modifications.[2] This is especially useful for the optimization of the operations and identifying inefficiencies. Also, ExtendSim provides an internal relational database feature to store, manage, and report data for use in the model and to store model outputs, this is especially useful for managing data in complex models.[3] Moreover, ExtendSim allows users to create compiled custom logic in equation editor with the integrated compiled programming language and dialogue editor.

For the reasons above, ExtendSim was chosen as the program simulating the shopping mall model. The model overview and interface is shown in Figure 1-2 and Figure 1-3.

[2] Imagine That Inc: ExtendSim User Guide. 2013, P. 4.
[3] Imagine That Inc: ExtendSim User Guide. 2013, P. 826.

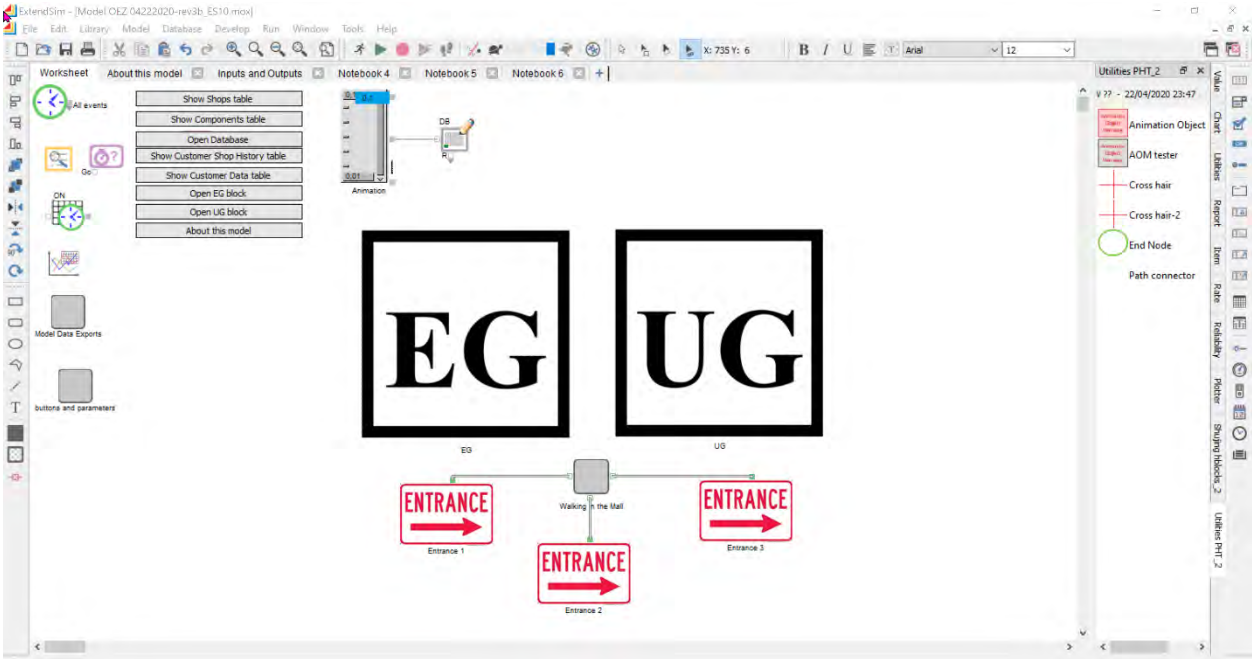

Figure 1-2: Overview of the user interface in ExtendSim

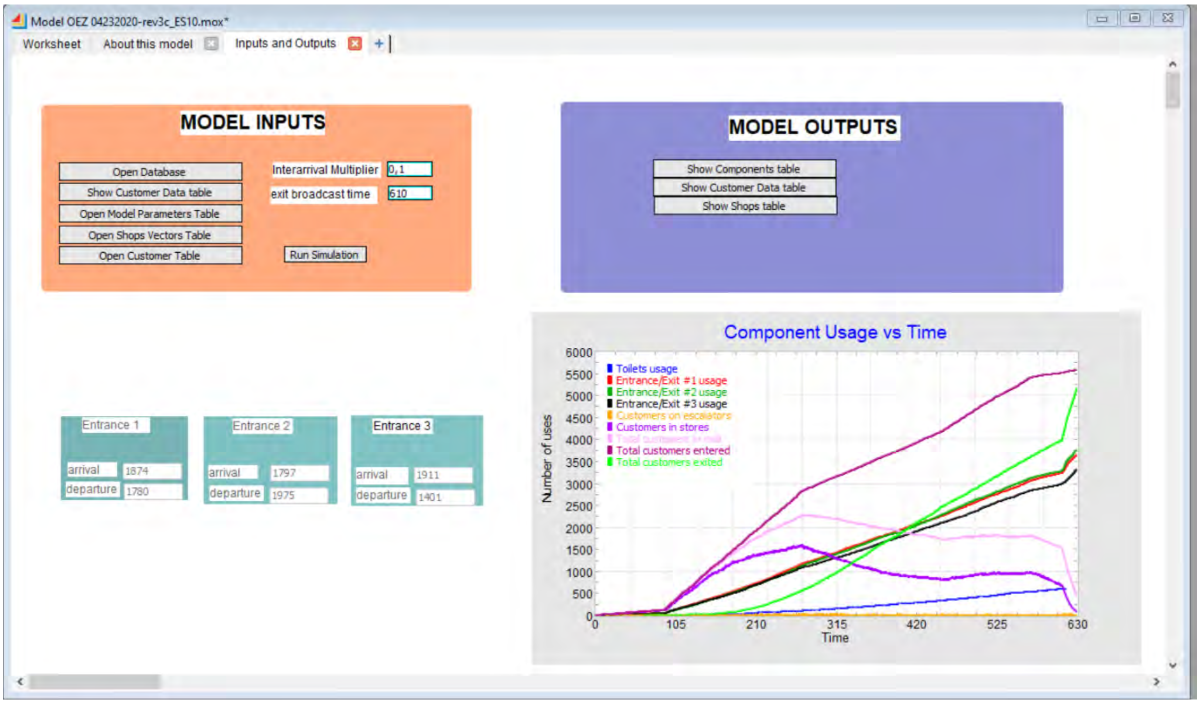

Figure 1-3: Notebook of Inputs and Outputs Overview in ExtendSim

1.3.2 Modelling Method

Most simulation models represent a system where the processes or behaviour of the components of the system are known or can be predicted in advance. This, however, does not apply to the model to be studied. In ExtendSim, there are different types of modelling approaches, such as the discrete model, continuous model, and agent-based model. Agent-based modelling is particularly dealing with dynamic models representing the interaction of the agents within a specified locality.

1.3.2.1 Agent-based Modelling

Agents are the individual entities in the system. According to Wooldridge and Jennings, agents are software-based computer systems, which are situated in an environment and can act autonomously to achieve their goals.[4] They often have a set of rules that govern their behaviour but also a certain degree of autonomy as agents have intelligence, memory, and ability to learn, unlike machines.

The focus of this model is studying the behaviour patterns of customers i.e., decision-making mechanism by analyzing how customers evaluate various alternatives and the information processing strategy underlying their selections in different activities such as shopping, toilet using, walking, and eating. This shall be discussed in the next section.

To validate the model and ensure that it reflects the real system as expected, the results shall be compared to the real system.

1.3.3 Consumer Decision-Making (CDM) Mechanism

Over the years, many researchers attempted to investigate the customer decision-making mechanism in shopping malls and to determine the variations in the customer decision making styles considering various demographic variables.[5]

Spatial shopping behaviour is identified as the outcome of the CDM process of each consumer.[6] It is assumed that individuals discriminate between the alternatives based on a set of attributes. Each shopping alternative is characterized by a set of objective attributes, the decision made depends on the evaluations of the attributes based on their utility function, for instance.[7]

As decision making is influenced by both quantitative and qualitative criteria, such as a customer´s preference or need for shopping, their gender, and age as well as the perception of various aspects of the state of the specific environment. It is necessary to find simple, systematic, and logical methods or mathematical tools to simulate customers in making decisions considering a group of selection attributes and their interrelations.[8] In this model, several CDM theories are combined with the Euclidean distance algorithm and executed in the model whenever a customer is making a decision about what to do next.

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[4] Cenani, Sehnaz & Cagdas, G.. (2013). Agent-Based System for Modeling User Behavior in Shopping Malls. Architecture in Computro [26th eCAADe Conference Proceedings / ISBN 978-0-9541183-7-2] Antwerpen (Belgium) 17-20 September 2008, pp. 635-642.

[5] Dr. N. Gangisetty; P. Mohana and Dr. T. Narayana Reddy; A Predictive Investigation of Shoppers Shopping Experience in Malls, International Journal of Mechanical Engineering and Technology 9(2), 2018. P. 482–492.

[6] Timmermans, H, Chapter 14 Retail Environments and Soatial Shopping Behavior- Psychological and Geographical Approaches,1993. P. 342.

[7] Timmermans, H. Chapter 14.

[8] L. Elmore, Kimberly; B. Richman, Michael: Euclidean Distance as a Similarity Metric for Principal Component Analysis. Published 03/2001, P.540-549.

1.3.3.1 Consumer Decision-Making

Prakash Chandra Dash & Swaroop Chandra Sahoo attempted to investigate the CDM styles in shopping malls, to determine the variations in the CDM styles across different demographic variables. Their study is based on CSI (customer style inventory) developed by Sproles & Kendall, which is an early attempt to systematically measure shopping orientations using decision-making orientations.[9] One of the most important assumptions of this approach is that each individual consumer has a particular DM style resulting from a combination of their individual DM dimensions.

The fundamental factor of the customer is purchasing power, which is oftentimes influenced by their age and income. This in result, regulates customer shopping behavior i.e., purchase behavior. The age of customer is the most significant factor in the process of CDM in shopping malls, as different age groups visit different shopping malls and stores.[10] Also, gender is another demographic variable that associates the most strongly with their DM style.[11]

1.3.3.2 Multiple Attribute Decision Making (MADM)

As discussed earlier, decision-making involves a series of processes: problem identification, preference derivation, alternatives evaluation and determination of the best alternative. MADM can be classified into: multiple attribute decision making (MADM) and multiple object decision making (MODM) for different purposes and data types.

In multiple attribute decision making (MADM) problems, a decision-maker often needs to select or rank alternatives that are associated with non-commensurate and conflicting attributes. The former is often associated with a limited number of predetermined alternatives and discrete preference ratings, whereas the MODM is more suitable for the design/planning facet.[12]

1.3.3.3 Euclidean Distance Theory (EDT)

1.3.3.3.1 Euclidean Norm:

The *Euclidean norm* of an *n*-vector *x,* denoted ||x||, is the square root of the sum of the squares of its elements,

$$||x||=\sqrt{x_1^2 + x_2^2 + \cdots x_n^2}.$$

Equation 1: Euclidean Norm

As simple examples,

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[9] Prakash Chandra Dash, Swaroop Chandra Sahoo, Customer Decision Making Styles in Shopping Malls – An Empirical Study in the Indian Context, 2010, Indian Journal of Marketing, Vol. 40, No.8, P.25-30.

[10] Dr. N. Gangisetty, S.Mohana, Dr. T. Narayana. Reddy, A Predective Investigation of Shoppers Shopping Experience in Malls, International Journal of Mechanical Engineering and Technology(IJMET) Volume 9, Issue 2, 02/2018, P. 482-492.

[11] S. Wesley; M. LeHew; A. G. Woodside: Consumer decision-making styles and mall shopping behavior: Building theory using exploratory data analysis and the comparative method. Journal of Business Research 59, 2006, P. 535–548.

[12] Tzeng, Gwo-Hshiung; Huang, Jih-Jeng: Multiple attribute decision making. 07/2011, P. 1-2.

$$\left\| \begin{bmatrix} 2 \\ -1 \\ 2 \end{bmatrix} \right\| = \sqrt{9} = 3, \qquad \left\| \begin{bmatrix} 0 \\ -1 \end{bmatrix} \right\| = 1.$$

1.3.3.3.2 Euclidean Distance

In mathematics, the Euclidean distance between two vectors *p* and *q* is the length of the line segment connecting them.

For one, two, and three dimensions, this distance is exactly the usual distance between points with coordinates *p* and *q*, as illustrated in Figure 1-4.

$$\text{dist(p,q)} = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2}.$$

Equation 2: Euclidean distance in two dimensions

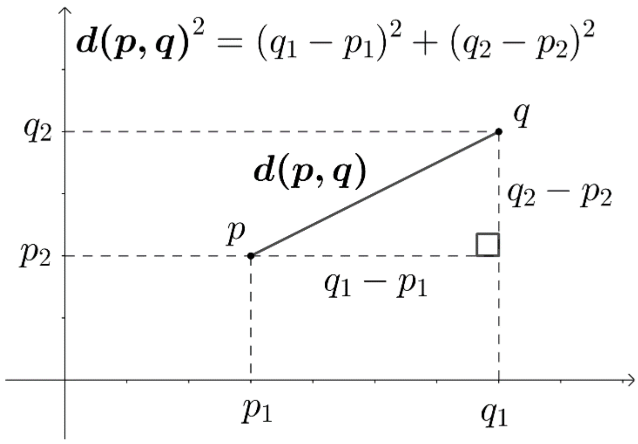

Figure 1-4: Euclidean distance between *p* and *q* in 2-dimension space

Euclidean distance is defined for vectors of any dimension. Euclidean distance between *p* and *q* in Euclidean n-space given by the Pythagorean formula.[13]

$$\text{dist(p,q)} = \|p-q\| = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + \cdots + (p_n - q_n)^2} = \sqrt{\sum_{i=1}^{n}(p_i - q_i)^2}.$$

Equation 3: Euclidean Distance for an n-dimensional space

When the distance between two *n*-vectors *p* and *q* is small, we say they are ‘close’ or ‘nearby’, and when the distance ||p − q|| is large, we say they are ‘far’. The particular numerical values ||p − q|| that correspond to ‘close’ or ‘far’ depend on the particular application.

As an example, consider the 4-vectors

$$u = \begin{bmatrix} 1.8 \\ 2.0 \\ -3.7 \\ 4.7 \end{bmatrix}, \quad v = \begin{bmatrix} 0.6 \\ 2.1 \\ 1.9 \\ -1.4 \end{bmatrix}, \quad w = \left[\begin{bmatrix} 2.0 \\ 1.9 \\ -4.0 \\ 4.6 \end{bmatrix}\right].$$

[13] Howard, Anton; Wiley, John; Sons: Elementary Linear Algebra (7th ed.), 1994, P. 170–171.

The distances between them are:

$$\|u - v\| = 8.368, \quad \|u - w\| = 0.387, \quad \|u - v\| = 8.533,$$

We can say that *u* is nearer to *w* than it is to *v*.

1.3.3.3.3 Euclidean Distance Method Application

Some examples for the application of Euclidean distance:

-Feature distance.

If *x* and *y* represent vectors of n features of two objects, the distance ||x − y|| is the *feature distance*, it measures how different two objects are. For instance, the feature vectors are patients in a hospital, with entries such as age, weight, heart disease, test results.

-Document dissimilarity

Suppose *n*-vectors *x* and *y* represent the histograms of word occurrences for two documents. The distance then measures the dissimilarity of the two documents.[14] The closer, the similar the two documents are, and vice versa. Euclidean distance is widely used in the search system.

1.3.3.3.4 Euclidean Distance Algorithm in the Model

In this model, each customer is assigned with an n-vector V_c , including the attributes that influence their shopping behavior, and each store V_s , including the attributes of the store attracting or influencing customer's shopping behavior accordingly. The Euclidean distance identifies the distance between the customer's preference and the store's supply. The closer a customer is to a store, the more attractive the store is to a customer, or in other words, the better the store accords with the customer. The shop, which fulfills the most need of the customer, which means, with the smallest Euclidean distance value, will be chosen as the next destination.

1.4 Research Applications

Instead of conveying and measuring the usage intensity of the building components in a shopping mall, it is of real significance to accomplish this during modelling with the help of simulation tools. By building a real shopping mall with over 100 shops on two floors, with all the attributes and features assigned and set in the model, the general scenario of customers shopping and moving in a mall could be simulated as long as the customer movements are designed as accurately as possible. Besides, due to the significant advantage of simulation tools, the parameters can be adjusted and changed in any block in the model when needed.

[14] Boyd, Stephen; Vandenberghe, Lieven: Introduction to Applied Linear Algebra, Cabmridge University Press. 2018, P.48-51.

The expected results of this paper are the usage intensity of building components and building products in the operational phase of a shopping mall. However, there is much more valuable information that could be used in various fields. On the one hand, this model helps with the prediction of customer's movement in each corner of a mall by adjusting the layout of the mall based on this sample model, architects can optimize their design of similar building types by analyzing and finding out the potential problems to be avoided before a shopping mall is constructed. On the other hand, it is especially with commercial value for not only the store managers but also the shopping centre manager. The store managers can get the rough visits for different periods of time, while the centre manager can have an overall image of how the shopping mall could be better operated and maintained, including the services and utilities as well as the improvement of tenants portfolio of the mall, to meet the profitability goal and the trend that is changing rapidly with the time.

Based on this sample model of a specific shopping mall, it is applicable and scalable for further shopping malls by adjusting the model with customized layouts.

2 Foundation of Real Estate and Building Components

Before the start of modelling, some basic concepts regarding real estate and building components and the foundation of simulation shall be introduced first.

2.1 Real Estate Definition and Characteristics

2.1.1 Definition and Characteristics of Real Estate

Real estate is a tangible asset and real property that consists of land, buildings, and other improvements on it.

ZIMMERMANN explains that, unlike other economic and investment goods, real estate has the following characteristics[15]:

- immobility: immobility and thus location dependence
- Uniqueness: every property on the market is unique
- Heterogeneity: the objects are dissimilar, but compete with each other
- Long service life: durability and longevity, with high operating costs
- Third-party use: no flexibility of use depending on the type of property
- High capital requirement: financing through equity and debt
- Transactions: non-transparent market, little information about the objects of comparison
- Transaction cost: registration tax, notary, and agent fee, etc.

2.1.2 Differentiation of Real Estate Types

Zimmermann differentiates real estate into two categories: real estate that is direct quantifiable from a functional operation and non-quantifiable real estate from a functional operation, based on whether the revenue through the functional operation of the property is quantifiable or not. The two categories are further classified into different types, as shown in Table 2-1.

[15] Zimmermann, Josef: [Real Estate Project Development, lecture script at the Bauprozessmanagement und Immobilienentwicklung in Technical University of Munich], Immobilienprojektentwicklung, 04/2017, P.1-8.

Table 2-1: Real Estate Types according to ZIMMERMANN[16]

Immobilientypen		
Erlöse aus Funktionsbetrieb		
Direkt quantifizierbarer Funktionsbetrieb	Nicht direkt quantifizierbarer Funktionsbetrieb	
Betriebswirtschaftlich messbar	Volkswirtschaftlich messbar	Immateriell
- Wohnen - Büro - Logistik - Hotel - Gastronomie - Shoppingcenter - Produktionsgebäude - Kliniken - Pflegeheime etc.	- Straßen - Öffentliche Verwaltung - Flughäfen - Eisenbahn - Schulen - Universitäten/Hochschulen - Museen etc.	- Religiöse Einrichtungen - Denkmale etc.

According to Berner, real estate is classified into four types based on different uses, namely[17] :

- residential real estate, for the use of living, for example, single or multi-family houses.
- commercial real estate, properties used for commerce, such as office buildings, retail buildings.
- special real estate.
- industrial real estate, such as factories, farms.

Table 2-2: Real estate types according to BERNER[18]

Real estate Types			
Residential real estate	**Commercial real estate**	**Special real estate**	**Industrial real estate**
-Single-family house	-Office building	infrastructure	Transportation building
-Multi-family house	-Service buildings (hotels)	Sport buildings	Water project building
-High rise residential building	-Retail building	Military buildings	
	-Logistic building -Leisure industry -Agricultural building -Multi-functional real estate	Historic building	

[16] Zimmermann, Josef: [Real Estate Valuation Methods, lecture script at the Bauprozessmanagement und Immobilienentwicklung in Technical University of Munich], Immobilienwert und Wertermittlungsmethoden, 05/2017, P.1-4.

[17] Berner, Fritz: Universität Stuttgart. Institut für Baúbetriebslehre: [Real Estate Types] Immobilienaten. Internet source.

[18] Berner, Fritz: Universität Stuttgart. Institut für Baúbetriebslehre: [Real Estate Types] Immobilienaten. Internet source.

Commercial real estate is often distinguished from industrial real estate, which is practical space used in manufacturing products. In this paper, the model is about a simulation model of commercial real estate - a shopping mall.

2.1.3 Life Cycle of Real Estate

Life Cycle Assessment (LCA) is a method for evaluating the environmental load of processes and products during their life cycle. It is playing a more and more important role and it is of great meaning to understand the life cycle of a building. The life cycle of a building refers to a building over the course of its whole life from concept to demolition. For example, in relation to real property, this would include design, construction, operation, and disposal.
Where in this paper, we only look at the use stage or operational phase (in German “Nutzungsprozess” in the life cycle of a shopping mall. The operation phase encompasses the activities associated with the use of the building over its life span.[19]

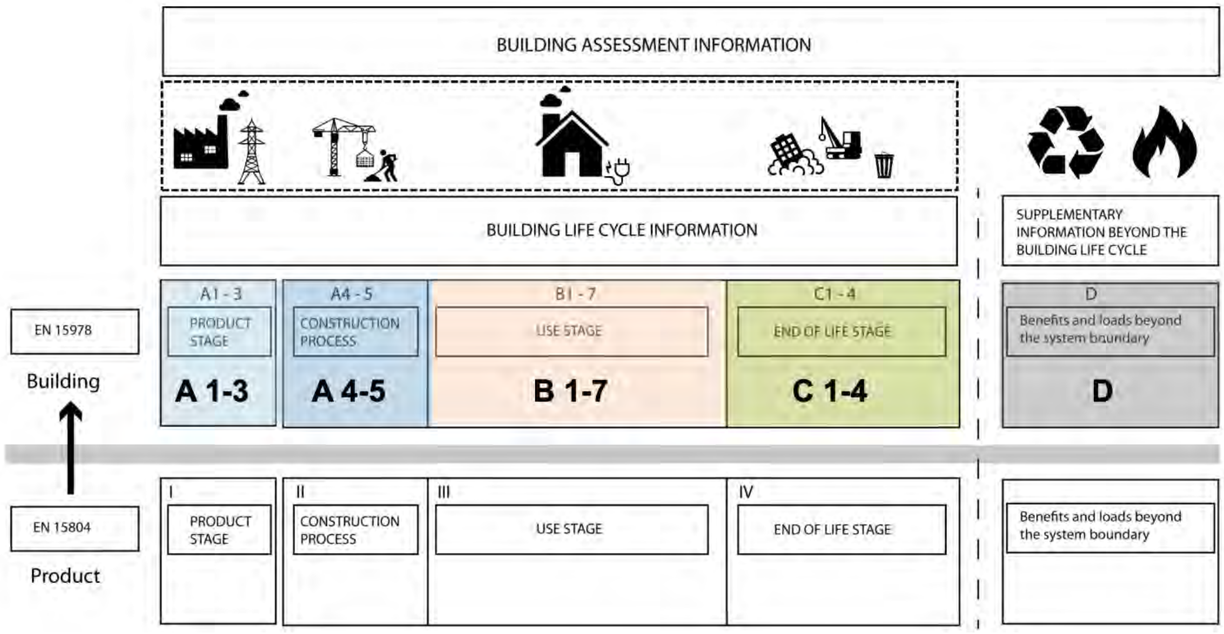

Figure 2-1: The life cycle of a building[20]

2.2 Service Life and Building Components

2.2.1 User profile of Real Estate

This section explains and compares the different types of real estate regarding their functions and user activities in them.

Residential real estate

[19] Ramesh, T.; Prakash, R.; Shukla,K. K.: Life cycle energy analysis of buildings: An overview. Energy and Buildings, 42(10), 1592–1600. doi:10.1016/j.enbuild.2010.

[20] DIN EN 15643-2: Sustainability of construction works – Assessment of buildings- Part 2 : Framework for the assessment of environmental performance, 2011-05.

As mentioned above, residential real estate mainly includes, for example, single or multi-family houses contain living rooms, bedrooms, kitchen, toilet, etc. it supplies a function of living, either for private use or for renting.

The user activities include daily routines such as sleeping, resting, toilet using, cooking. The usage of the rooms varies from each other depending on the users. The time of user occupation is difficult to evaluate as people have different living habits.

Commercial real estate

Common examples of commercial real estate are office buildings, hotel buildings, restaurants, and shopping malls. The function of commercial real estate varies compared to residential real estate. It supplies more possibilities and flexibilities for users in the operational phase, and each has a main function, for instance, the office is used primarily for the conduct of working or business related to administration, clerical services, etc., a hotel provides lodging and gastronomy as well as various personal services for the public. A shopping mall is a special area containing shops and restaurants in which people can walk between.

Figure 2-2 shows the user profile for different types of property according to DIN EN 15232-1:2017-12, which serves as a standard. It includes the occupancy of different property types as a percentage on the Y-axis and the time course of a day in 24 hours.

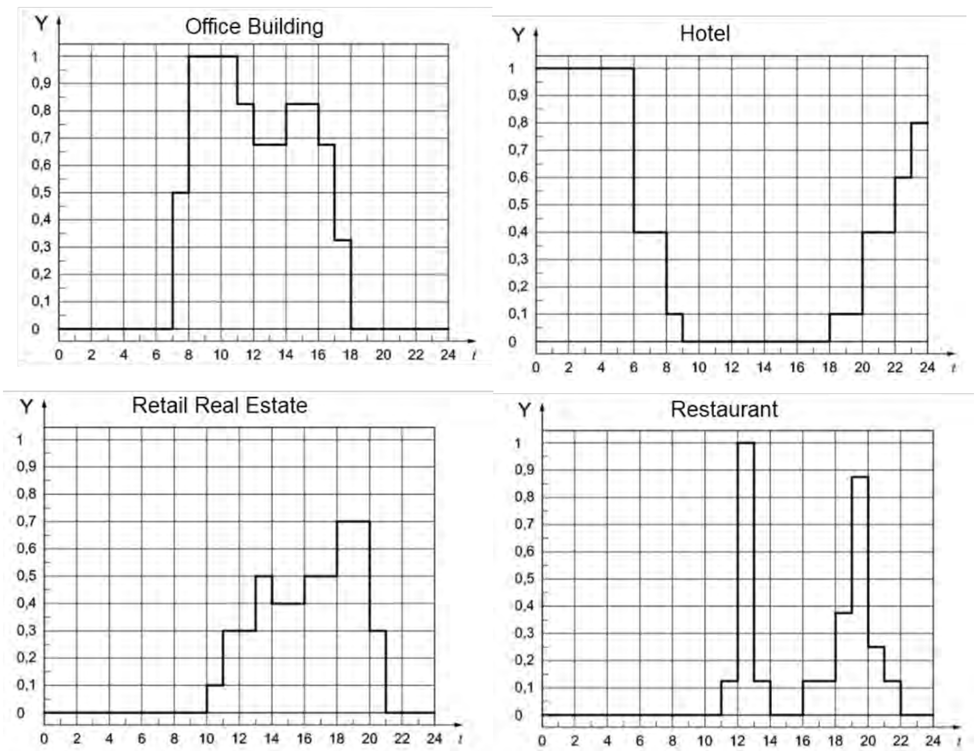

Figure 2-2: User profile for different commercial real estate according to DIN EN 15232-1: 2017-12[21]

[21] DIN-Deutsches Institut für Normung e.V.: Energieeffizienz von Gebäuden – Teil 1: Einfluss von Gebäudeautomation und Gebäudemanagement. DIN EN 15232-1:2017-12. P.70.

In Figure 2-2, an office building is occupied between 7:00 A.M. and 6:00 P.M. and available from 6:00 P.M. to 7:00 A.M. The occupancy rate of an office property decreases around noon between 11:00 and 14:00.

Additionally, retail buildings are presenting a different distribution of occupancy rate, as seen in the third graph, retail real estate is occupied from 10:00 to 21:00. It shows a higher occupancy rate between 18:00 to 20:00 than 10:00 to 13:00. This is because most people get off work after 18:00.

2.2.2 Building Components

Generally, a building can be defined as an enclosed structure intended for human occupancy. It includes structural and nonstructural components (e.g., cladding, interior walls, HVAC systems, roofing) permanently installed to and supported by the structure.

Building Elements
Building elements are the main components of a structure, for example, a component of a building can be broadly summarized as follow:

- Foundation
- Walls
- Floors
- Roof etc.

Building Products
Building products are usually finished items that are manufactured combinations of building materials or other products such as doors, windows, light fittings, and so on.

It is impossible to analyze some components in the operational phase of a building, such as foundation and roof. Therefore, the following objects are included in the paper.

- Floor
- Doors
- Elevator
- HVAC
- Light fittings

Specially, HVAC and light fittings are controlled by the mall center, and their use accords with the opening time of the mall, they are not included in the model.

2.2.3 Duration of Building Components

2.2.3.1 Technical Service Life

Technical service life is the period between the installation and its failure. It describes the life span during which a component is physically available and meets the required functions. The technical life of a component comes to an end when it has to be removed and replaced as soon as the function intended is no longer fulfilled.[22] Figure 2-3 shows the development process of the technical life of a building component.

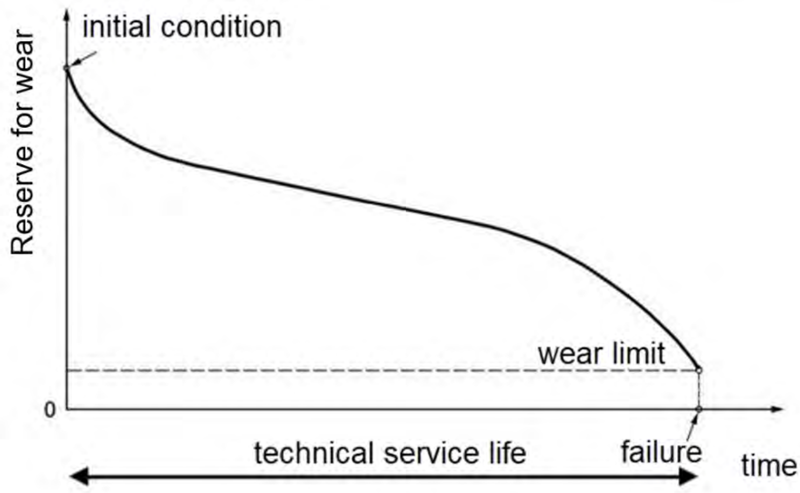

Figure 2-3: Technical service life during the reduction of a reserve to wear[23]

Building service life data enable engineers to predict the type and frequency of activities required to maintain, repair, and replace building materials and structures.[24] It is clear that the service life of a building mainly depends on the durability of each building component that the building is composed of and the building material used. When the service life of building components is lengthened, the environmental impact associated with the production process of the components and material as well as waste processing can be reduced. Therefore, it is of meaning to study about the service life of components to optimize the durability.[25] However, the component performance in the life cycle and the requirements both will change over time. The life span of a building component can be longer or shorter due to different types of change.[26]

2.2.4 The Usage Intensity of Building Components

This section covers the relevant regulations and standards for components classification in Germany.

2.2.4.1 Doors and Windows

According to the German standard norm, DIN EN 12400L2003-01 with the title of "Windows and Doors – mechanical stress-Requirements and classifications", which serves as regulations for the classification of openable windows and doors regarding long term functional efficiency, the classes consider the normal and predicted usages.[27]

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[22] Kalusche, Wolfdietrich: [Technical Life of Building Components and Economic Life of a Building] Technische Lebensdauer von Bauteilen und wirtschaftliche Nutzungsdauer eines Gebäudes. 2004,P.2.

[23] DIN-Deutsches Institut für Normung e.V.: Grundlagen der Instandhaltung. DIN 31051:2012-09. P.8.

[24] Rauf, A.; Crawford, R. H.: Building Service Life and Its Effect on the Life Cycle embodied Energy of Buildings. Energy 2018,P.140−148.

[25] Blom, Inge Suzanne: Environmental Impacts During the Operational Phase of Residential Buildings, 2010.

[26] M.H, Hermans: Building Performance Starts at Hand-Over: the Importance of Life Span Information. Published in National Research Council Canada 1999, P2.

[27] DIN-Deutsches Institut für Normung e.V.: Fenster und Türen – Mechanische Beanspruchung – Anforderung und Einteilungen. DIN EN 12400:2006-01, P.1-4.

The following table shows the classification according to DIN EN 12400:2003-01 for windows and doors. It is based on the number of cycles and the associated mechanical stress and serves as a general guide for the selection of classification relating to the expected mechanical load.

The durability will be tested as the title described to conclude the number of possible cycles for the overall technical life span of a window or door, for example, windows with Class 2, the technical life span is reached after 10,000 cycles and the window fails. Class 0 indicates the elements when they do not qualify Class 1. Furthermore, the table shows that windows do not achieve 50000 cycles, the utilization of doors is differentiated from occasional to very frequent. The test centre for building components declares that the necessary number of cycles for the classes in Table 2-3 is specified by planners, and it serves as a guide.[28]

Table 2-3: Classification of the durability of windows and doors DIN EN 12400:2003-01[29]

<table>
<tr><th>Class</th><th>Number of cycles</th><th>Window</th><th>Door</th></tr>
<tr><td>0[a]</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>1</td><td>5000</td><td>light</td><td>occasional</td></tr>
<tr><td>2</td><td>10000</td><td>medium</td><td>rare</td></tr>
<tr><td>3</td><td>20000</td><td>heavy</td><td>seldom</td></tr>
<tr><td>4</td><td>50000</td><td rowspan="5">-</td><td>medium</td></tr>
<tr><td>5</td><td>100000</td><td>normal</td></tr>
<tr><td>6</td><td>200000</td><td>frequent</td></tr>
<tr><td>7</td><td>500000</td><td>heavy</td></tr>
<tr><td>8</td><td>1000000</td><td>Very frequent</td></tr>
</table>

2.2.4.2 Floors

DIN EN ISO 10874:2012-04 entitled "Resilient, textile and laminate floor coverings – Classification" establishes a classification system for the floor covering mentioned in the title. The classification of floor coverings is based on practical requirements and intensity of usage. The standard also points out, other factors influencing the wear of the floor should also be taken into account when applying the classification system, such as shoe types, traffic density. As can be seen in Figure 2-4, the norm distinguishes between the three application areas in residential, commercial and light industrial real estate respectively.

In residential property type, the intensity of utilization is differentiated into four levels, namely: moderate/low, normal/medium, normal and high. For commercial real estate, the intensity of use is divided into moderate, normal, high and very high. The class is described in a two-digit number, where the first digit indicates the type of use, i.e., the type of property, and the second

[28] Prüfzentrum für Bauelemente: [Manual – Suggestions for the Use and Bids Invitation of Windows and Doors According to the Products Norm], Leitfaden – Empfehlung für den Einsatz sowie die Ausschreibung von Fenstern und Außentüren nach der Produktnorm DIN EN 14351-1 und DIN 18055. P.35.

[29] DIN-Deutsches Institut für Normung e.V.: Kriterien für die Anwendung von Fenstern und Außentüren nach DIN EN 14351-1. DIN 18055:2014-11. P.32.

digit the level of usage intensity.[30] For example, class 32 represents the floor covering used in commercial real estate in a normal intensity of utilization.

The intensity of use of floor coverings, as shown in the figure, depends on the number of users. The more people are walking on the floor, the higher the intensity of use of floor coverings.

Klasse	Symbol	Verwendungsbereich	Beschreibung
		Wohnen	**Bereiche, die für die private Nutzung vorgesehen sind**
21	21	Mäßig/gering	Bereiche mit geringer oder zeitweiser Nutzung
22	22	Normal/mittel	Bereiche mit mittlerer Nutzung
22+	22+	Normal	Bereiche mit mittlerer bis intensiver Nutzung
23	23	Stark	Bereiche mit intensiver Nutzung
		Gewerblich	**Bereiche, die für die öffentliche und gewerbliche Nutzung vorgesehen sind**
31	31	Mäßig	Bereiche mit geringer oder zeitweiser Nutzung
32	32	Normal	Bereiche mit mittlerer Nutzung
33	33	Stark	Bereiche mit starker Nutzung
34	34	Sehr stark	Bereiche mit intensiver Nutzung
		Leichtindustriell	**Bereiche, die für die Nutzung in der Leichtindustrie vorgesehen sind**
41	41	Mäßig	Bereiche, in denen die Arbeit hauptsächlich sitzend durchgeführt wird und in denen gelegentlich leichte Fahrzeuge benutzt werden
42	42	Normal	Bereiche, in denen die Arbeit hauptsächlich stehend ausgeführt wird und/oder mit Fahrzeugverkehr
43	43	Stark	Andere Bereiche der Leichtindustrie

Figure 2-4: Utilization Classes for elastic, textile and laminate floor covering according to DIN EN ISP 10874:2012-04[31]

2.2.4.3 HVAC

The following table shows the hours of usage and operating hours concerning air conditioning systems, cooling systems, and heating systems, as well as the annual days of use for various types of property under DIN V 18599-10:2018-09. The values in the table serve as a guide. The

[30] DIN-Deutsches Institut für Normung e.V.: Elastische, textile und Laminat- Bodenbeläge – Klassifizierung. DIN EN ISO 10874:2012-04. P.4.

[31] DIN-Deutsches Institut für Normung e.V.: Elastische, textile und Laminat- Bodenbeläge – Klassifizierung. DIN EN ISO 10874:2012-04. P.5.

values of retail property, with daily use of 12 hours in 300 days in a year, and the HVAC system including heating, cooling, air conditioning system 14 hours a day within 300 days in a year, are useful for comparison with the results derived from the model later.

Table 2-4: Time of Use and Operation according to DIN V 18599-10:2018-09[32]

Time of Use and Operation according to DIN V 18599-10:2018-09					
Real Estate Type	**Daily time of use**	**Yearly time of use**	**Daily operation hours RLT, WLA, cooling**	**Daily operation hours Heating**	**Yearly operation days**
	$t_{use,d}$ **[h/d]**	$d_{use,a}$ **[d/a]**	$T_{v,op,,d}$ **[h/d]**	$Th_{,op,,d}$ **[h/d]**	$D_{,op,a}$ **[d/a]**
office	11	250	13	13	250
Hotel	11	365	24	24	365
Gastronomy	14	300	16	16	300
Retail	12	300	14	14	300
Logistic	24	365	24	24	365
Hospital	24	365	24	24	365

2.2.4.4 Lifts and Elevators

The guideline VDI 4707 Part 1 entitled “Lifts Energy Efficiency” was published in 2009 and serves as the “Assessment and labeling of energy efficiency of new passenger and goods lifts”. It describes the total energy demand of an elevator depends on the building types, the use types of the elevator, and the number of users. The following figure shows the utilization categories for the elevator based on the daily average travel time in hours. The frequency of usage is differentiated into very low, low, medium, heavy, and very heavy, and the frequency of usage is divided into very seldom, rarely, occasionally, frequently, and very frequently.

[32] DIN-Deutsches Institute für Normung e.V.: Energetische Bewertung von Gebäude – Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung – Teil 10: Nutzungsrandbedingungen, Klimadaten. DIN V 18599-10:2018-09. P.23-25.

Nutzungskategorie	**1**	**2**	**3**	**4**	**5**
Nutzungsintensität/-häufigkeit	sehr gering sehr selten	gering selten	mittel gelegentlich	stark häufig	sehr stark sehr häufig
Durchschnittliche Fahrtzeit in Stunden pro Tag*)	0,2 (≤ 0,3)	0,5 (> 0,3–1)	1,5 (> 1–2)	3 (> 2–4,5)	6 (> 4,5)
Durchschnittliche Stillstandszeit in Stunden pro Tag	23,8	23,5	22,5	21	18
Typische Gebäude- und Verwendungsarten	• Wohnhaus mit bis zu 6 Wohnungen • kleines Büro- und Verwaltungsgebäude mit wenig Betrieb	• Wohnhaus mit bis zu 20 Wohnungen • kleines Büro- und Verwaltungsgebäude mit 2 bis 5 Geschossen • kleine Hotels • Lastenaufzug mit wenig Betrieb	• Wohnhaus mit bis zu 50 Wohnungen • mittleres Büro- und Verwaltungsgebäude mit bis zu 10 Geschossen • mittlere Hotels • Lastenaufzug mit mittlerem Betrieb	• Wohnhaus mit mehr als 50 Wohnungen • hohes Büro- und Verwaltungsgebäude mit über 10 Geschossen • großes Hotel • kleines bis mittleres Krankenhaus • Lastenaufzug in Produktionsprozess bei einer Schicht	• Büro- und Verwaltungsgebäude über 100 m Höhe • großes Krankenhaus • Lastenaufzug in Produktionsprozess bei mehreren Schichten

Figure 2-5: Utilization categories for elevators according to VDI 4707 Part 1[33]

[33] Verein Deutscher Ingenieure (VDI): [VDI 4707 Part 1:2009-03 – Elevators Energy Efficiency], VDI 4707 Blatt 1:2009-03 - Aufzüge Energieeffizienz. Berlin 2009, P.23.

3 Basis of Simulation and Modelling Methodology

3.1 Simulation Concepts

3.1.1 Simulation

Simulation is a method allowing to study the behaviour of reality based on a model and thereby predict its future development.[34] With the help of various simulation tools, how a real-world activity performs under different conditions can be observed and various hypotheses tested at a fraction of the cost of performing the actual activity in the real world. One of the principal advantages of simulation is it enables the achievement of good approximations of extremely complex problems by refining the model gradually based on a simple approximation of a process.[35] This is especially useful in the engineering field, as it is resource-intensive and in large-scale in most cases.

With the help of ExtendSim, instead of interacting with a real system, a logical model that corresponds to the real system in certain aspects can be created. One can simulate the operations or dynamics of the system, then analyze one or more areas of interest, to reduce risk and uncertainty so that informed, timely decisions could be made.[36]

3.1.2 Systems

According to Ludwig. Von. Bertalanffy's Systems Theory, the core idea was the organic whole concept. Ludwig. von. Bertalanffy emphasized that the real world could be seen as being composed of systems. Each system is an organic whole. However, it is not simply a mechanical combination or addition, but a set of components or entities interacting with each other under some rules or operating policies of the system.[37]

Systems can be mathematically straightforward, for instance, a flower grows in the soil and turns to the sun direction to maximize photosynthesis. Or they can be more complex, such as supply chain operations, including planning, selling, distribution, production, and sourcing subsystems.[38]

A system is composed of a set of abstract nodes that are characterized by the fact that they have relations to other nodes. They may represent groups, individuals, or even activities or an abstract entity.[39] In this model, the shopping mall is viewed as a system of the customer moving in a shopping mall. The entities of the system are the internal components of the system, such as customers and shops that are involved in the operational phase of the shopping mall. The

[34] Zimmermann, Josef: Principle of Simulation. Vorlesungsskriptum zur gleichnamigen Vorlesung am Lehrstuhl für Bauprozessmanagement und Immobilienentwicklung an der Technischen Universität München. Ausgabe 04/2018, P. 1-2-1-3.
[35] Imagine That Inc: ExtendSim User Guide. 2013, P. 4.
[36] Imagine That Inc: ExtendSim User Guide. 2013, P. 45
[37] Imagine That Inc: ExtendSim User Guide. 2013, P. 42.
[38] Imagine That Inc: ExtendSim User Guide. 2013, P. 44.
[39] Dr.rer.nat.Wolfgang, Eber: Principles of Optimisation, 10/2018, P.2.

system state changes dynamically over time, which is caused by the activities and interactions of entities.

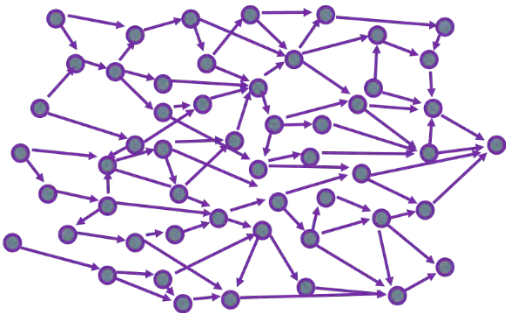


Figure 3-1: Graphical Representation of a System

3.1.3 Models

A model is an abstracted and simplified representation of a system at one point in time, to capture the realism of the system or for efficiency, reliability, and ease of analysis. Instead of reaching every aspect of a matter, a model should only capture the most important aspects of the real system.

Most models can be classified into four basic types:

• A scaled representation of a physical object, such as a 1:18 diecast model of a Ferrari, a scale model of the solar system.

• A graphical or symbolic visualization, such as a flow chart of office procedures or an architect's plans for a building.

• An analytical or mathematical formula that yields a static, quantitative solution. For instance, an analytic model might consist of several independent sample observations that have been transformed according to the rules of the model. Common examples of analytic models are spreadsheet models or linear programming models.

• A mathematical description that incorporates data and assumptions to logically describe the behaviour of a system. This type of model is typically dynamic—it has a time component and shows how the system evolves. ExtendSim products are tools for building mathematically-based, dynamic models of systems.

Dynamic modelling is the foundation for computer modelling.

ExtendSim models typically have a time component and can show cause and effect and the flow of entities throughout a system.

3.2 The Methodology of Modelling and Comparison

A modelling methodology is a formalism used to specify a system. Different methods can be used to model different aspects of real-world systems. The main three modelling methodologies include:

- continuous event
- discrete event
- discrete rate event

These methodologies are discussed in this chapter. In addition to the main modelling methodologies mentioned above, there are also other modelling approaches that are useful and will be introduced in the later topics in this chapter. These approaches are usually based on one of the three main methods and include:

- Monte Carlo
- Agent-based
- State/Action

3.2.1 Introduction and Comparison of main modelling methodologies

The three main modelling methodologies are continuous event, discrete event, and discrete rate. The next will introduce and compare the three modelling methodologies respectively.

In all three simulation types, the granularity of the modeled object and what causes the model state to change are of concern.[40]

3.2.1.1 Continuous model

In a continuous model, the interval between time steps is fixed at the beginning of the simulation and advances in equal time increments. The state changes continuously concerning time.[41]
An example of a continuous model would be: in a temperature control system, the temperature changes continuously over time.

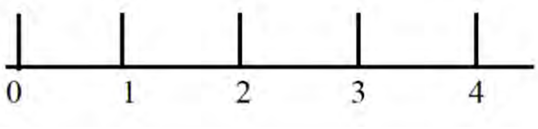


Figure 3-2: Time line for continuous simulation

3.2.1.2 Discrete Event Model

In discrete event models, the system will not change until events occur. Different from a continuous model. The time between events is unlikely to be equal.[42] A typical example of a

[40] Imagine That Inc: ExtendSim User Guide. 2013, P. 46.
[41] Imagine That Inc: ExtendSim User Guide. 2013, P. 43-45.

discrete event model is the queue length in a queueing system which depends on the events caused the queue such as the customer arrival, customer departure.

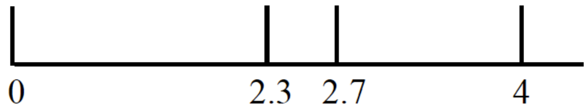


Figure 3-2: Time line for discrete event simulation

3.2.2 Discrete Rate Simulation

Accordingly, discrete rate simulation is a hybrid combination of continuous and discrete event modelling. The flow of stuff rather than items will be simulated, and rates and values will be recalculated only when events occur.[43]

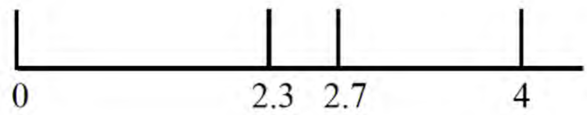


Figure 3-3: Timeline for discrete rate simulation

3.2.3 Monte Carlo Simulation (MCS)

Monte Carlo simulation uses a stochastic procedure to solve some complex problems in a mathematical context based on a series of calculations from random input parameters by running the model several times.[44] The calculation results will be recorded as observations, which are statistically summarized, and an indication of more likely results and the range of possible results will be indicated. In this way, it is possible to see what could happen under different circumstances, more important, the probability of occurrence.[45]

The comparison of the three main modelling methodologies are shown in the table below.

[42] Imagine That Inc: ExtendSim User Guide. 2013, P. 43-45.
[43] Imagine That Inc: ExtendSim User Guide. 2013, P. 43-45.
[44] Zimmermann, Josef: Principle of Simulation. Vorlesungsskriptum zur gleichnamigen Vorlesung am Lehrstuhl für Bauprozessmanagement und Immobilienentwicklung an der Technischen Universität München. Ausgabe 04/2018, P. 1-13-1-14.
[45] Imagine That Inc: ExtendSim User Guide. 2013, P. 43-45.

Table 3-1: Comparison table of the three main modelling methods [46]

Modeling method	ExtendSim library	What is modeled	Examples
Continuous time	Value library Electronics library	Processes	Processes: chemical, biological, economic, electronics.
Discrete event	Item library	Individual items	Things: traffic, equipment, work product, people. Information: data, messages, and network protocols at the packet level.
Discrete rate	Rate library	Flows of stuff	Rate-based flows of stuff: homogeneous products, high speed production, data feeds and streams, mining.

3.2.4 Agent-based Model (ABM)

Agent-based modelling has been discussed in the previous chapter in detail. To capture the system as realistic as possible, various customer logic needs to be conducted by integrating Equation into the blocks. Blocks and the enclosed data have specific characteristics that enable them to be searchable in the model. This simplifies the process of building intelligent behaviour and facilitates interaction from block to block and other features between blocks.

Besides, there are several helpful categories of functions in the Developer's Reference when creating an agent-based model, of which the animation function enables the visualization of the total simulation processes. Using the animation feature, the model shows the customers physically moving around within the model based on the model configuration. This is especially useful when validating and verifying the model.

3.3 Introduction to ExtendSim

ExtendSim is chosen as the tool to generate the shopping mall simulation model. Like all other popular simulation tools such as MATLAB. ExtendSim has its own integrated compiled programming language and dialogue editor in the program. ExtendSim's built-in APIs enables access code created in other programming languages such as Delphi, Visual Basic, Visual C++.[47] In particular, in ExtendSim Processes could be visualized logically or in a virtual environment. This can identify problem areas before implementation and explore the potential effects of modifications, which is especially useful in optimizing the operations and identifying inefficiencies. ExtendSim can simulate any system or process by creating a logical representation in an easy-to-use format.[48] The following figure shows a Bank Model with a customer interface as an example in the ExtendSim model library.

[46] Imagine That Inc: ExtendSim User Guide. 2013, P. 47.
[47] Imagine That Inc: ExtendSim User Guide. 2013, P. 5.
[48] Imagine That Inc: ExtendSim User Guide. 2013, P. 5.

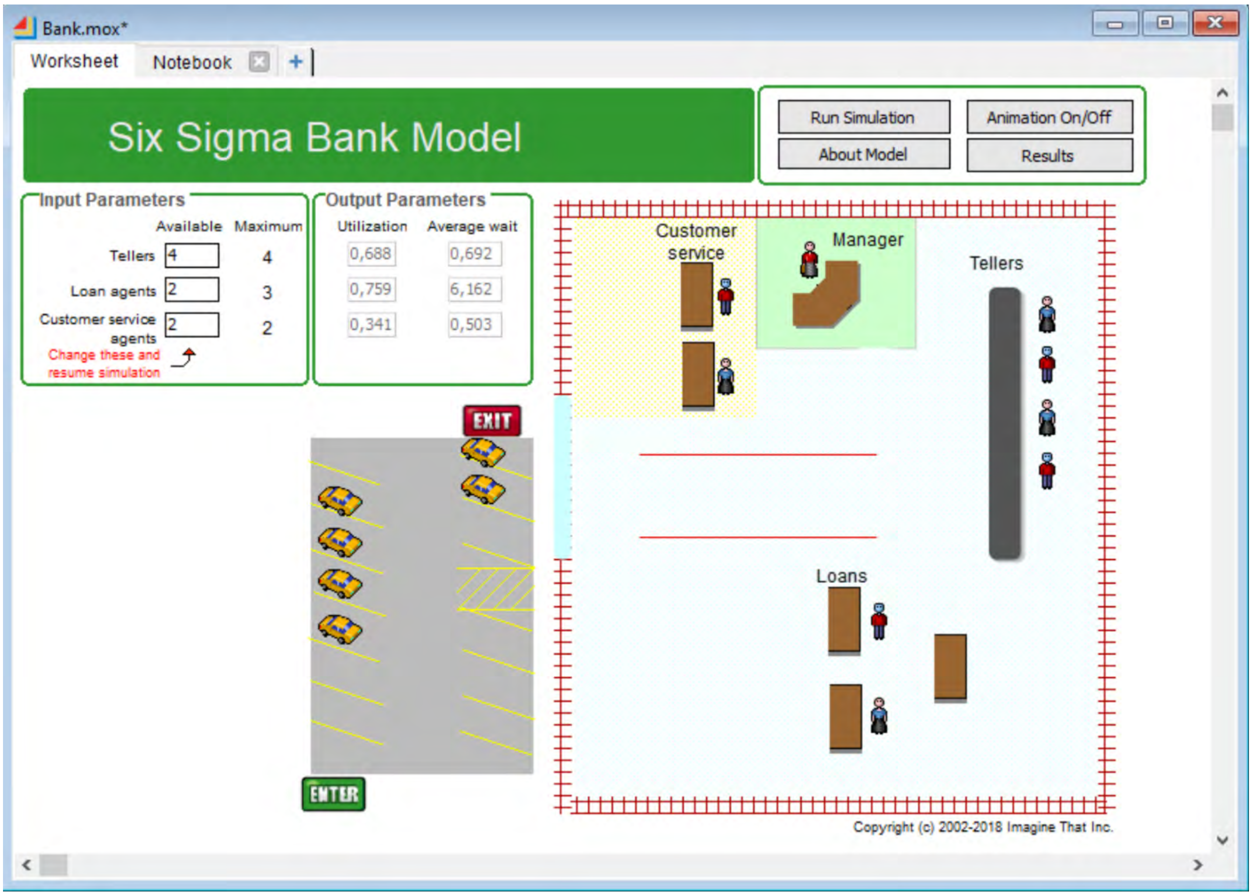


Figure 3-4: An example model of a Bank Model in ExtendSim

3.3.1 Terminology in ExtendSim

Before building a discrete event model, it is helpful to understand the terminology that is used in the model and to have an overview of discrete event architecture in ExtendSim.

ExtendSim models always consist of blocks and connections. As a model runs, information or items flow through blocks and will be processed or modified before being sent on to the next block via a connection (see Figure 3-5).[49]

[49] Imagine That Inc: ExtendSim User Guide. Ausgabe 2013, P. 15.

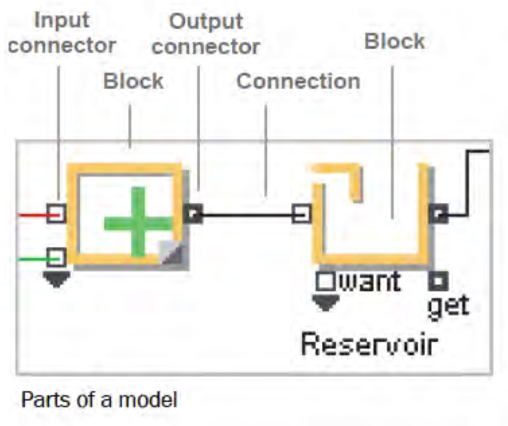


Figure 3-5: Blocks and connections in ExtendSim

3.3.1.1 Blocks

Blocks are the main elements in a model in ExtendSim, which indicates portions of processes or systems being modelled. Each block has its name, such as Queue, Create, Set, Throw, Catch. A user-defined label could be added to blocks for differentiation of different blocks in a specific model, such as a Create block labeled Customer Arrival.[50]

3.3.1.2 Connections

As the name suggests, connections are used for connecting two blocks. Information is transmitted from block to block in a model. The simulation could be seen as a series of processes along the connections' paths repetitively.[51] In this shopping mall model, blocks are representing nodes in the theory of graphs and connections indicate the edges, customers move along the connections and make different decisions with the help of Equation blocks, in which the logic could be defined by programming with ModL codes.

3.3.1.3 Libraries and Hierarchical Blocks

Libraries are the repositories where the blocks are stored. For a discrete event model, the item library simulates those systems using blocks that mimic industrial and commercial operations and timing that represent the actual occurrence of events.

More important, ExtendSim enables users to define custom libraries for specific models if necessary. One advanced function about libraries is that several often used blocks could be included as a new Block and resided in a user-defined library, the new blocks in the new custom library could be modified anytime as a unit and automatically updated in the model, this is very helpful in this shopping mall model as there are several similar blocks such as shops and restaurants and entrances, where they share a similar block structure.

Also, ExtendSim has another useful feature as an additional enhancement: Hierarchical Blocks. In short, it allows users to create hierarchical blocks (H-blocks), which combine a series of blocks into one block. At the same time, it is possible to access the individual blocks by drilling

[50] magine That Inc: ExtendSim User Guide. Ausgabe 2013, P. 15.
[51] magine That Inc: ExtendSim User Guide. Ausgabe 2013, P. 16.

down into the lower levels.[52] In this rather complex shopping mall model, there are over 100 shops to represent, which, however, has similar settings and logic. The hierarchy feature reduces the workload significantly by creating a universal Block used in most of the shops. For example, the three entrances are sharing the same H-block called Entrances as shown in Figure 3-6:

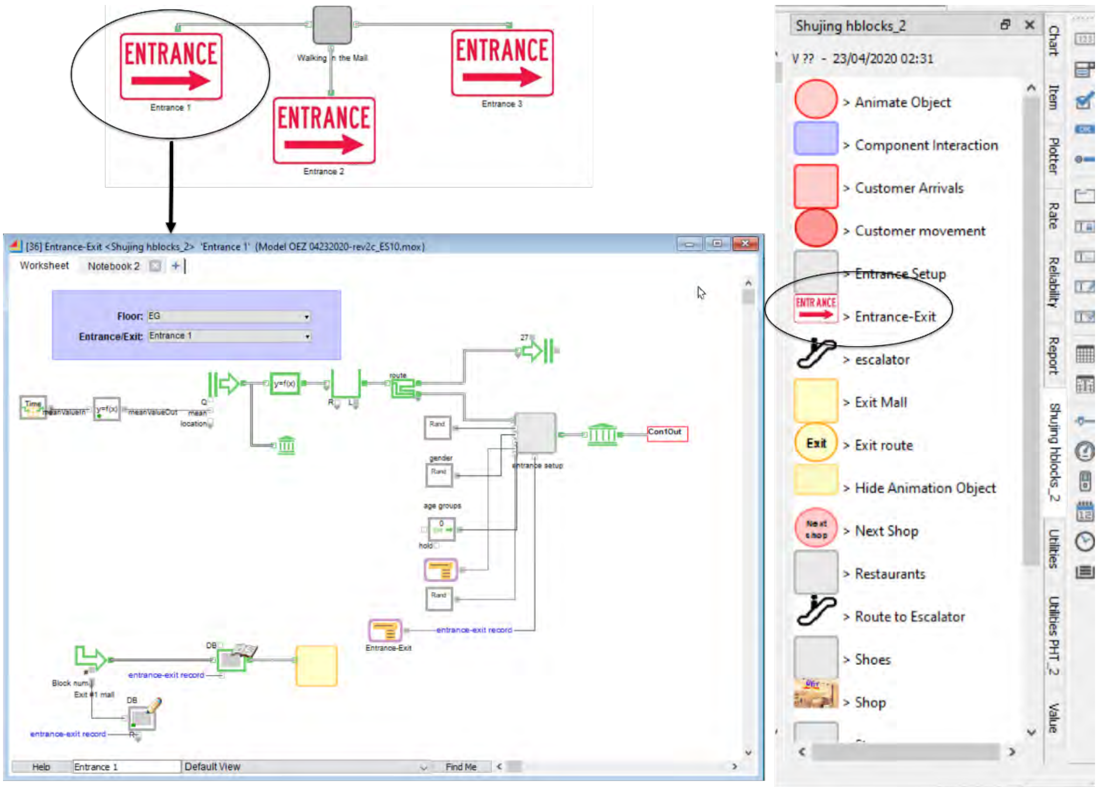


Figure 3-6: Entrance Hblock in ExtendSim

3.3.1.4 Database (DB)

As the simulation is typically used to model relative complex systems, it is common for modellers to use internal relational databases to store and manage information required and generated by the model. ExtendSim has an internal database that enables the centralized management of data used in a different portion of the model, and it is used to store and report inputs, outputs, and everything in between. The database is the foundation of the whole model that consists of most of the input information required for the model and outputs generated by the model.

3.3.1.4.1 Database Schema

One can create one or more Databases, each with a unique index number assigned in ExtendSim. The Index numbers are used for referring to the database in equations or ModL code.

An overview of the Database created in this shopping mall model can be seen in Figure 3-7.

[52] Imagine That Inc: ExtendSim User Guide. 2013, P. 37.

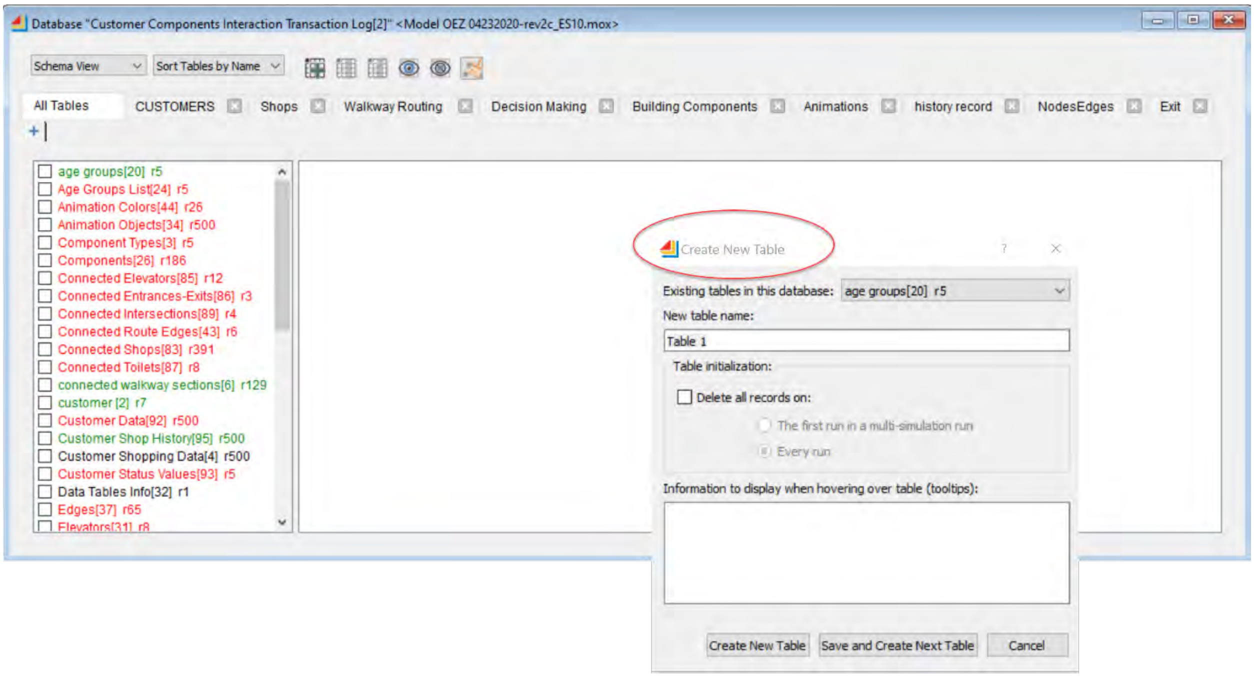


Figure 3-7: An overview of the Database in the shopping mall model

In the created Database, one can add tables and fields to store records, a table consisting of columns (called “fields” in database lexicon) and rows (“records”) is used for storing information. For instance, the database table named “age groups” contains three Fields, namely, “age”, “Probability” and “Preference value”, each field includes five Records as seen in Figure 3-8 below.

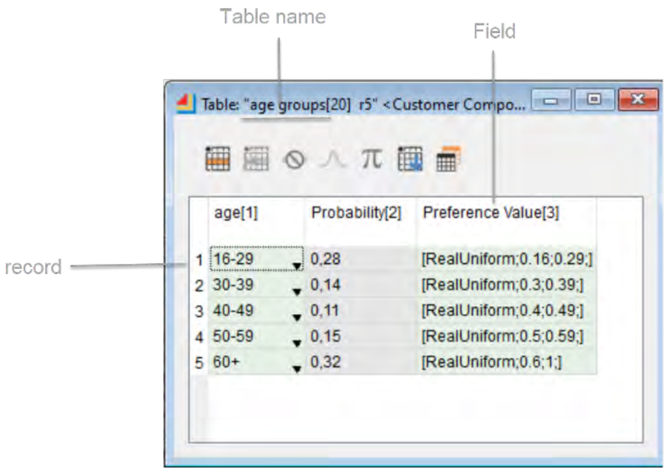


Figure 3-8: Table “ age groups“ in the database

3.3.1.4.2 Relational Database

Based on the interactions between two tables, one can establish a relationship to link the records in one field to the records in the same or another field in another table.[53] Relational databases are efficient and fully integrated with ExtendSim, which link block components and database tables through dynamic data linking.

[53] Imagine That Inc: Database Tutorial & Reference. 2018, P. 2.

For instance, Parent/Child relationships are established between Tables or Fields, which enables a table to get values from a connected parent table. Parent fields have a red background, while child fields have green backgrounds, as presented in Figure 3-9.

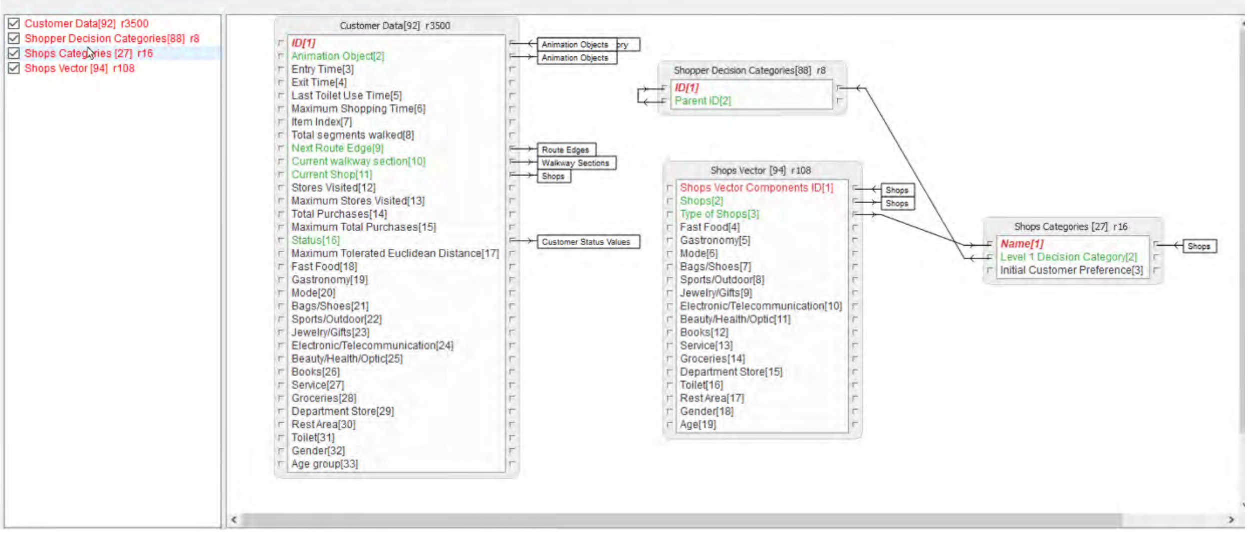


Figure 3-9: An Example of Parent/Child Relationships of Tables in Database

3.3.1.5 Animation

Animation functions in ExtendSim provide a visual indication of block-to-block interaction, such as the influence of one block on another. In this model, for example, the animation functions would present the customers moving from the entrance and along the walkway till they exit the mall within the model. It slows down the speed of the simulation run. However, it is very helpful to validate and debug the model when needed, with the help of visualization of all the activities in the model.

With the Animation feature turned on, each circle in different colours represents an individual customer passes from block to block and walks along the walkway set in this model, as shown in Figure 3-10.

Figure 3-10: Animation of a customer's movement in the shopping mall in the model

3.3.1.6 Cloning

In addition to Animation feature, the Clone Layer tool in ExtendSim is also significantly useful when one wants to have an intuitive observation of any parts of information in a model. it can be realized by dragging clones of the desired dialogue items such as variables, the whole dialogue block or plotters, onto anywhere in the model desired. The block item being cloned will be automatically synchronized such that any changes made in the clone are instantaneously updated in the original item in the block from which it was cloned. This enables the user to organize, monitor and interact with data during simulations. The following figure is an example notebook that was completely built by cloning the dialogue items needed for a better presentation of the model built.

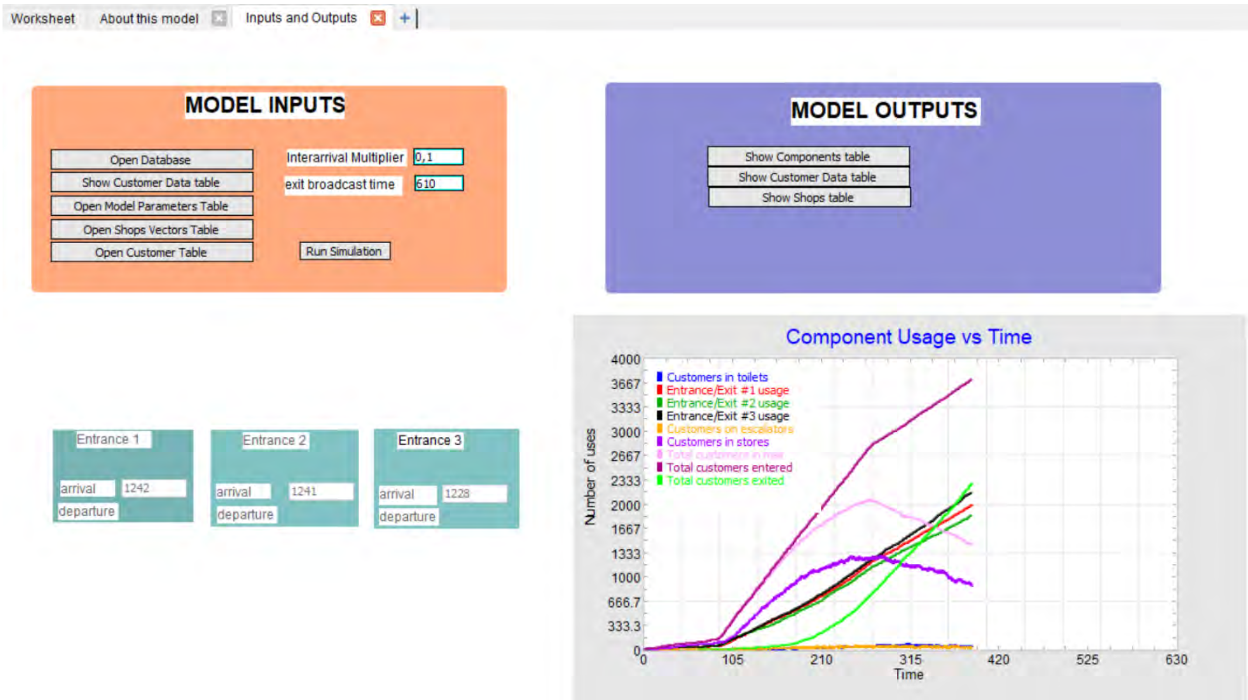


Figure 3-11: Notebook created by using a cloning tool in ExtendSim

3.4 Discrete Event Systems and Processes in the Model

3.4.1 Discrete event systems and processes

Most of the service system, logistics system, manufacturing system, and the model is going to be built are discrete systems. Most systems are composed of real-world elements such as people, procedures, materials, equipment, information, space, and energy (called items in ExtendSim) and resources that interact when particular events occur, such as equipment, tools, and personnel. This section explains discrete event modelling and several commonly used distributions in Extendsim.

Items and informational values

Discrete event models pass entities (called items) through blocks as events occur during the simulation run. The items (customers) can have properties, such as attributes and priorities, which are information provided and assigned to items (customers) to make the item unique. For example, each customer has their age, gender, shopping preference, shopping time, etc.

Values provide information about items and model conditions. The items (customers) in the model are generated as a random distribution within specific parameters, or as a scheduled list of when events will occur. In this model, the customer arrival interval is following a random exponential distribution, as the arrival time varies in different periods in a day, a lookup table with stepped interval is connected to the input connector as the mean value of the exponential distribution.

Activities

Each process is a series of activities for a specified outcome that are logically related. Activities usually have a delay and involve the use of process elements and resources, which happens with the occurrence of events such as receipt of an order, a telephone call, and in this model, a customer arrival.[54]

In this shopping mall model, customers will shop in a store, walk on the walkway, take elevators to change floors, eat in a restaurant, rest in rest area etc. These are so-called activities in this model. Each activity always has an either fixed or random duration. In the model, for example, the shopping time and eating time in a restaurant.

Item Library

The Item Library is the main source of discrete event blocks. The blocks in the Item library usually have both item connectors and value connectors, where an item connector passes an item and all the associated information to the next connector, a value connector provides specific information about the item and its properties, etc (see Figure 3-12).

Figure 3-12: Item library in ExtenSim

3.5 Common used Distributions in ExtendSim

ExtendSim provided a table for the selection of a plausible distribution for common use, especially when there is no or not enough data available. The following table includes the most used distributions applied in this model.

[54] Imagine That Inc: ExtendSim User Guide. 2013, P. 93.

Table 3-2: ExtendSim Distributions[55]

Distribution	Definition
Beta	Distribution of random proportion, such as the proportion of defective items in a shipment, or time to complete a task.
Empirical	Used to generate a customized or user-defined distribution with a special shape when the probability of occurrence is known.
Exponential	Primarily used to define intervals between occurrences such as the time between arrivals of customers or orders and the time between failures or time to repair for electrical equipment.
Normal	The well-known Gaussian or bell curve. Most often used when events are due to natural rather than man-made causes, to represent quantities that are the sum of a large number of other quantities, or to represent the distribution of errors.
Triangular	Usually more appropriate for business processes than the uniform distribution since it provides a good first approximation of the true values. Used for activity times where only three pieces of information 9 (the minimum, the maximum, and the most likely values) are known.
Uniform Real	Describes a real value that is likely to fall anywhere within a specified range. Used to represent the duration of an activity if there is minimal information known about the task.

[55] Imagine That Inc: ExtendSim User Guide. 2013, P.706.

4 Introduction to the Model and Modelling Process

This model simulates the customer behaviour in a real shopping mall in Munich in Germany–Olympiaeinkaufszentrum (OEZ), which was opened in 1972 with over 130 shops in a shopping area of 56000 m^2.

4.1 Layout of OEZ and the Model

4.1.1 Mall Layout and Statistics

Layout

The shopping mall is a two-storey building, the floorplan of the mall is shown in Figure 4-1 and Figure 4-2, where EG means ground floor and UG means the underground floor. The brand list and categories in the mall are listed in Figure 4-3.

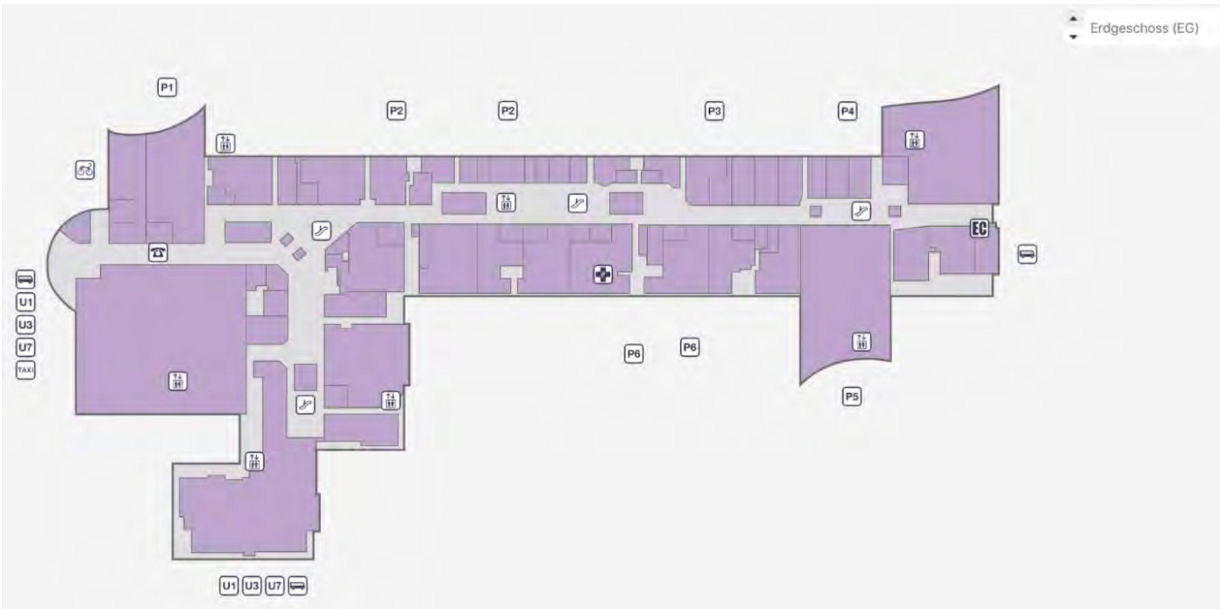


Figure 4-1: Ground Floor EG Layout of Olympiaeinkaufszentrum(OEZ)

Figure 4-2: Underground Floor UG Layout of Olympiaeinkaufszentrum(OEZ)

WARENHÄUSER / KAUFHÄUSER

Galeria Kaufhof	EG/UG	69	14 32 10
Karstadt	EG	30	14 84-0

MODE

1–2–3	EG	103	14 01 07 94
Andreas Krebs	EG	89	14 90 49 50
Bonita	UG	15	14 07 90 46
C&A	EG/UG	32	14 32 20
Calzedonia	UG	8	15 92 52 20
Camp David	UG	17	14 07 90 80
Desigual	UG	43	12 11 28 09
Engbers & Emilio Adani	UG	20	14 30 33 14
Eterna	UG	47	14 30 34 74
G-Fashion	UG	35	14 34 07 80
Gerry Weber	UG	45	14 30 37 76
GIULIETTA	EG	91	
H&M	EG	77	0800/665 59 00
H&M Man	EG	107	0800/665 59 00
Hallhuber	EG	81	356 24 11 00 16
Herzog & Bräuer	EG	84	14 34 59 92
Hollister Co	EG	126/127	15 00 24 00
Hunkemöller	EG	96	28 85 98 00
Intimissimi	UG	12	92 28 46 50
Jack & Jones	UG	50	15 98 70 71
Leos Pure Jeans	UG	19	12 11 26 65
Levi's	UG	39	15 98 47 99
mister*lady	UG	37	14 07 92 21
Mustang	UG	22	14 34 78 91
New Yorker	UG	59	12 11 28 96
Olymp	UG	16	14 33 48 77
Only	UG	49	14 32 58 86
orsay	EG	95	149 52 12
pimkie	EG	98	14 39 00 25
s.Oliver	EG	112	15 92 38 60
Street One	EG	83	15 89 18 86
Tally Weijl	EG	99	14 32 58 40
Tezenis	UG	6	92 28 74 25
Vero Moda	UG	57	14 72 74 09
Wöhrl	EG	61/134	143 47 10
X-Large	EG	88	149 33 14
Zara	EG/UG	46	14 01 02 61

LEDER / TASCHEN / SCHUHE

Crocs	EG	136	14 72 75 77
Deichmann	EG	75	14 07 93 26
Görtz	UG	38	12 11 28 62
O bag	EG	92	15 89 12 30
Parfois	EG	123	01590/417 61 05
Roland	EG	106	14 30 36 52
Salamander	UG	40	141 82 02
Timberland	EG	79	14 33 75 11
Tretter	EG	122	51 99 21 08

SPORT / FREIZEIT

Foot Locker	EG	78	92 28 82 88
Jack Wolfskin	EG	135	15 88 13 00
JD Sports	EG	119	92 28 69 45
Karstadt Sports	UG	30	14 84-0
Puma	EG	90	998 29 73 20
Runners Point	EG	101	21 89 24 87
Sidestep	UG	23	30 70 05 15
Snipes	UG	42	14 72 96 50

SCHMUCK / GESCHENKE / HARTWAREN

Bijou Brigitte	UG	36	149 52 92
Depot	UG	60	12 17 77 15
Euroshop	EG	104	0931/90 00 44 94
Fossil	EG	137	12 17 76 96
Juwelier Christ	UG	14	140 53 87
Juwelier Christ	EG	86	140 22 73
Juwelier Meyra	EG	121	14 33 55 20
NANU-NANA	UG	62	14 22 63
Non Plus Ultra	EG	128	54 80 79 50
Pandora	EG	125	14 01 05 36
Schmuckrausch	EG	113	92 28 86 00
Swarovski	EG	87	14 33 54 41
WMF	UG	5	14 01 06 76

ELEKTRONIK / TELEKOMMUNIKATION

Apple Store	EG	131	204 00 28 00
Gamestop	EG	100	12 11 27 88
M-net	EG	124	0800/878 80 89
O_2	UG	27	14 30 35 77
Smart Repair	EG	140	95 41 62 46
T-Punkt	UG	24	14 88 37 50
Vodafone	UG	63	0172/891 46 84

BEAUTY / GESUNDHEIT / OPTIK

Apollo Optik	UG	25	14 33 53 24
Apotheke SaniPlus	EG	116	143 80 80
Beauty + More	UG	31	78 79 78 37
Body Shop	UG	48	140 14 47
City Parfümerie	EG	102	92 28 74 03
dm-drogeriemarkt	EG	73	12 11 26 58
Douglas	EG	80	149 43 46
Eyes + More	UG	33	92 28 72 91
Fielmann	EG	130	143 47 20
Krass Optik	UG	9	149 10 03
MAC	EG	120	12 11 27 66
Müller Drogerie	UG	61	121 40 06 60
Obey Your Body	UG	7	
Rituals	UG	11	92 28 55 03
Sunglass Hut	EG	118	12 06 77 48
Vitalia	UG	56	14 90 42 54
Yves Rocher	UG	18	14 33 47 55

BÜCHER / PAPETERIE / TABAK

Hugendubel	EG	105	30 75 75 75
McPaper	UG	4	14 30 34 85
Wolsdorff	EG	74	141 97 02

DIENSTLEISTUNGEN

Bel Hair	EG	85	12 11 26 40
Blatter (Friseur)	EG	133	141 60 61
Fahrschule Körber	OG	72	141 94 94
Jochen Schweizer	UG	21	70 80 90 90
Karstadt Reisebüro	UG	29	148 44 88
L'tur Reisebüro	UG	2	14 34 03 40
Mister Minit	UG	26	15 98 58 63
Photo-Porst	UG	28	149 10 90
Schneiderei & Reinigung Ares	UG	3	149 26 41
Schnittstelle (Friseur)	UG	44	14 33 52 47
Studioline Photography	UG	10	149 42 68
Ticketvorverkauf Karstadt	UG	30	140 11 26
TUI ReiseCenter	EG	76	141 60 66

LEBENSMITTEL

Alte Brennerei	EG	93	14 72 74 71
Bäckerei Wimmer	EG	71	89 08 29 28
Bäckerei Wünsche	UG	1	14 33 75 76
Dunkin Donuts	UG	58	14 33 55 33
Edeka	UG	1	149 10 91
Eilles	EG	129	14 33 53 06
Fruchtwerk	UG	53	14 90 45 60
Gepp's Feinkost	EG	82a	51 56 21 70
Hofpfisterei	EG	108	52 02 44 30
Hussel	EG	114	149 52 45
mymuesli	EG	117	92 28 43 43
Räucherland/Wurstpoint	UG	52	
Tchibo	EG	97	01805/82 90 00
Vinzenz Murr	UG	65	14 33 56 26

GASTRONOMIE

Café Rischart	EG	94	23 17 00 34 10
Côcos Korean Thai Bar	EG	109	14 72 99 60
coffee fellows	UG	13	14 01 03 41
Eiscafé Ti amo	EG	82b	141 95 13
Eiskiosk Ti amo	UG	51	
Emilia	UG	68	14 34 64 20
Haiky Asia Snack	UG	66	92 28 72 22
Kaimug	EG	132	14 30 33 89
McDonald's	UG	67	15 89 30 51
Nordsee	EG	111	141 94 84
Nordsee Snack	UG	55	
Oliviva	EG	115	23 71 67 88
Pommes Freunde	EG	110	14 30 38 80
Roma	EG	138	14 34 00 60
Segafredo-Bar	UG	41	149 27 25
Toastastic	UG	54	92 28 27 47
Tokyo	UG	64	

LADENSTRASSE

Amor	EG	142	
Sky	EG	139	0180/5 51 44 51
Vodafone	UG	34	15 00 26 65

Stand: Dezember 2018

OLYMPIA EINKAUFSZENTRUM

Öffnungszeiten
Montag – Samstag
von 9.30 – 20 Uhr

Figure 4-3: Shopping Guide and Categories

Statistics

According to the statistics provided by the management centre of OEZ:

1. Avg. daily mall traffic: circa 33500 people
2. Customer gender ratio: Male/Female: 46%/54%
3. Customer age groups distribution:
   - 16-29: 28%
   - 30-39: 14%
   - 40-49: 11%
   - 50-59: 15%
   - 60+: 33%

Additionally, based on research conducted by Hu and Jasper, customers tend to spend 1.5-2h in a mall averagely (see Table 4-1).[56] These available statistics are the basis of the determination of parameter values in the model.

Table 4-1: Shopping time difference in Mall Shopping Behaviors

Mall Shopping Behaviors	A 2004 mail survey: < 55 years old (n = 127)	B 2004 mail survey: >= 55 years old (n = 97)	C 2006 interview: convenience sample >= 55 years old (n = 30)	*t* test results A-B	 B-C	 A-C
Average Age	42	66	64			
Mall Visit Frequency (Average trips per month)	2.27	2.25	1.74	0.093	1.668	1.853
Average expenditure per trip ($)	108.27	95.26	75	1.433	1.840	2.924
Length of stay per trip (hours)	1.85	1.88	1.91	-0.313	-0.064	-0.176

4.1.2 Layout and Elements of the Mall in the Model

The layout of shopping mall is the foundation of the model building. It is designed based on the real layout of the Olympiaeinkaufszentrum and includes the following elements:

- 105 shops, including restaurants and cafes etc.
- 4 toilets in the mall
- 12 categories such as Mode, Gastronomy, Bags/Shoes, Jewelry (see Figure 4-6).
- 3 Entrances/Exits
- 4 walkways, two on the ground floor(EG), two on the underground floor(UG), each walkway is divided into different walkway sections in the same distance, for example: walkway_1 starts from walkway_1section_1 and end with walkway_1section_25, walkway_2 is from walkway_2section_1 to walkway_2section_6 (see Figure 4-7).
- 8 elevators in the mall (see Figure 4-4, Figure 4-5).

Also, the following parameters are applied in the model based on the statistics collected:

- Daily customer: around 33000 people
- Male/Female ratio: 46%/54%
- Age Structure (see Appendix B)

An overview of the model is presented in Figure 4-8.

[56] Haiyan Hu, Cynthia R. Jasper, A Qualitative Study of Mall Shopping Behaviors of MatureConsumers. Journal of Shopping Center Research, 2007, P.28.

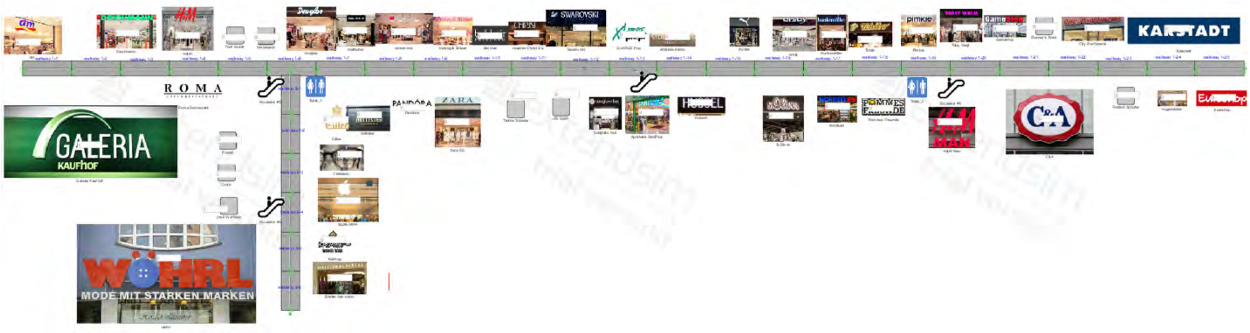


Figure 4-4: Layout of UG in the model

Figure 4-5: Layout of EG in the model

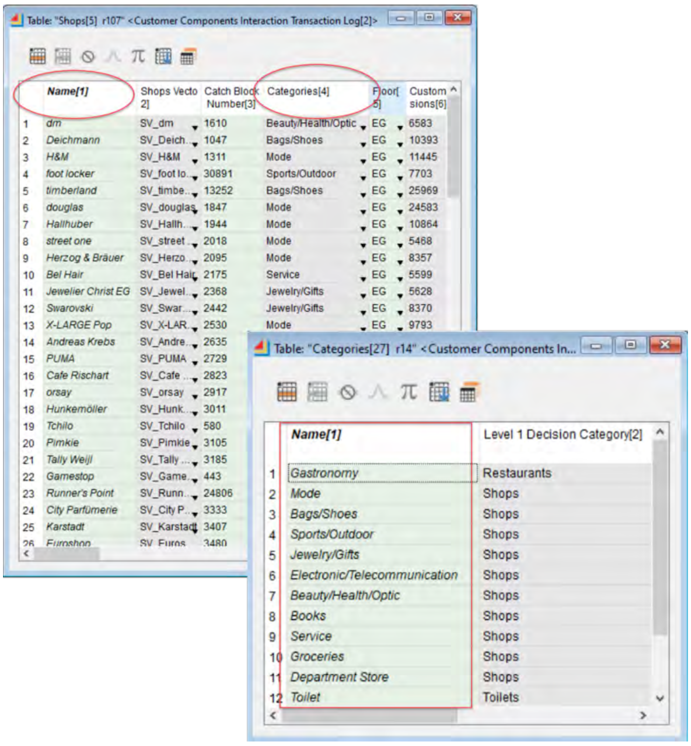


Table: "Shops[5] r107" <Customer Components Interaction Transaction Log[2]>

	Name[1]	Shops Vector[2]	Catch Block Number[3]	Categories[4]	Floor[5]	Customer sions[6]
1	dm	SV_dm	1610	Beauty/Health/Optic	EG	6583
2	Deichmann	SV_Deich...	1047	Bags/Shoes	EG	10393
3	H&M	SV_H&M	1311	Mode	EG	11445
4	foot locker	SV_foot lo...	30891	Sports/Outdoor	EG	7703
5	timberland	SV_timbe...	13252	Bags/Shoes	EG	25969
6	douglas	SV_douglas	1847	Mode	EG	24583
7	Hallhuber	SV_Hallh...	1944	Mode	EG	10864
8	street one	SV_street ...	2018	Mode	EG	5468
9	Herzog & Bräuer	SV_Herzo...	2095	Mode	EG	8357
10	Bel Hair	SV_Bel Hair	2175	Service	EG	5599
11	Jewelier Christ EG	SV_Jewel...	2368	Jewelry/Gifts	EG	5628
12	Swarovski	SV_Swar...	2442	Jewelry/Gifts	EG	8370
13	X-LARGE Pop	SV_X-LAR...	2530	Mode	EG	9793
14	Andreas Krebs	SV_Andre...	2635			
15	PUMA	SV_PUMA	2729			
16	Cafe Rischart	SV_Cafe ...	2823			
17	orsay	SV_orsay	2917			
18	Hunkemöller	SV_Hunk...	3011			
19	Tchilo	SV_Tchilo	580			
20	Pimkie	SV_Pimkie	3105			
21	Tally Weijl	SV_Tally ...	3185			
22	Gamestop	SV_Game...	443			
23	Runner's Point	SV_Runn...	24806			
24	City Parfümerie	SV_City P...	3333			
25	Karstadt	SV_Karstadt	3407			
26	Euroshop	SV_Euros	3480			

Table: "Categories[27] r14" <Customer Components In...

	Name[1]	Level 1 Decision Category[2]
1	Gastronomy	Restaurants
2	Mode	Shops
3	Bags/Shoes	Shops
4	Sports/Outdoor	Shops
5	Jewelry/Gifts	Shops
6	Electronic/Telecommunication	Shops
7	Beauty/Health/Optic	Shops
8	Books	Shops
9	Service	Shops
10	Groceries	Shops
11	Department Store	Shops
12	Toilet	Toilets

Figure 4-6: Store Categories and List of Shops in model

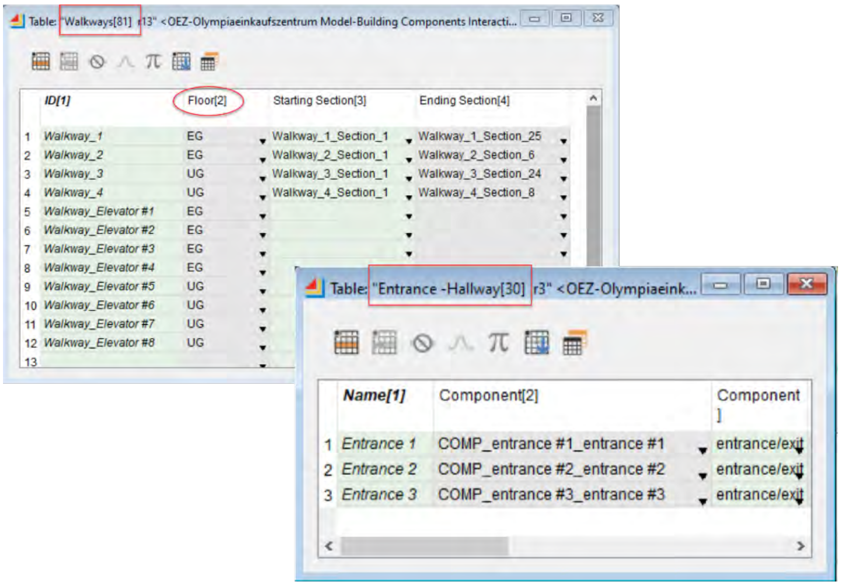


Figure 4-7: Walkway, Floor, Walkway sections, Entrance Table in the model

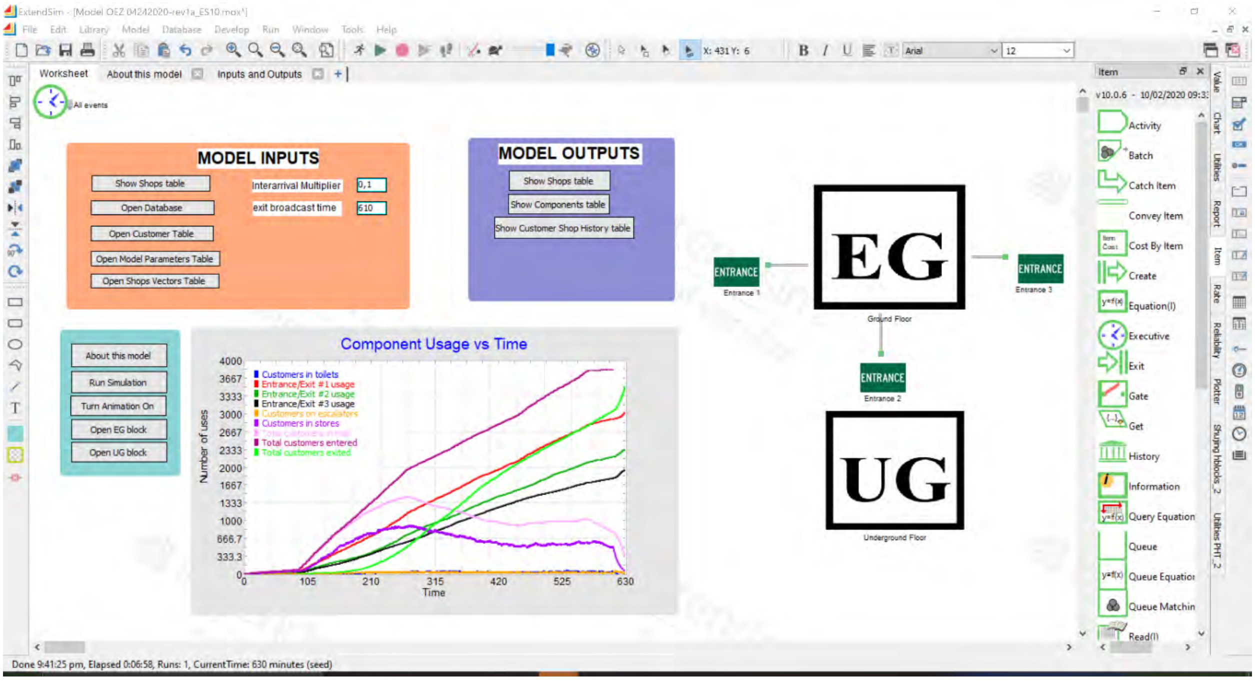


Figure 4-8: Overview of the Model

4.2 Modelling Process of the Shopping Mall Model for the Quantification of Use Intensity of Building Components in Operational Phase

An ExtendSim simulation model often involves building a logical model of the system, running the simulation, analyzing the data, optimizing the solutions, and interpreting and presenting the results. In this section, a brief overview of the general modelling process in ExtendSim is given.

4.2.1 Simulation Process

Creating a new model is an iterative process. It is always better to plan what is to be modeled before starting to build the model. For a model performed in ExtendSim, the following steps are the typical basic processes while creating a new model, which are also the rules governing the modelling processes of this shopping mall model[57].

1) *Formulate the problem and project question.*
While building a model, it is always essential to start with determining what the specific questions to be answered are. The problem and the objective of the model need to be defined and determined above all.

2) *Describe the flow of information.*
Describe how information flows from one to another section of the model and how they interact with the blocks in the model.

3) *Build and test the model.*
Build the system using ExtendSim blocks from small, then refine the model to the extent of complexity expected.

4) *Acquire data.*
This is often a very time-consuming step and includes the collection of the numerical data values required for the model and determination of mathematical formulas such as distributions for random events or parameters.

5) *Run the model.*
After the simulation setup, then run the model.

6) *Verify the results and validate the model.*
Compare the results from the simulation run to that expected from the model and the real system when available.

7) *Results analysis.*
Based on the simulation results, specific inferences or conclusions should be drawn from the model.

8) *Document.*
State the model's purpose, assumptions and logics, modelling approaches, data, and formulas used as well as the results of the simulation run after implementing all steps above.

9) *Implement decisions.*
The last step is to apply the results obtained in the real world.

[57] Imagine That Inc: ExtendSim User Guide. 2013, P. 57.

In the later sections, how the shopping mall model developed based on the modelling process mentioned above is explained in detail.

4.2.2 Goal and Limits of Modelling

4.2.2.1 Model Components

This model involves a combination of elements such as **customers**, **shops**, **walkways**, **entrances/exits**, and **different building components** in the mall. Customers have interactions with building components while the logically related activities are undertaken, for example, a customer arrives through one of the entrances, walks along the pathway on one of the walkway sections, shops in a store, eats at a restaurant, uses the bathroom, takes the elevator to reach another floor and so on.

4.2.2.2 Goals and Objectives of Modelling

Specific goals of modelling efforts can be one or more of the following: to interpret the system, analyze its behaviour, manage, operate or control it to achieve desired outcomes; to design methods to improve or modify it, to test the hypothesis about the system, or to forecast its response under varying conditions.

The goals of this specific model are:

- Interpret the shopping mall system with customer undertaking different activities
- Analyze customer behaviour under specific scenarios and the decision-making logic behind it
- Record the usage of building components in the operational phase of the shopping mall, such as the door use of each shop, use of toilets and elevators
- Compare the simulation results with existed statistics
- Test different scenarios under varying conditions, for example, test the outcome by changing the parameter of interarrival rate and average shopping time, etc.

To achieve the specified outputs of how often components/resources are used over time, the following things will be needed at a minimum:

- The list of components required to be monitored
- A list of the actions that will cause these components to be used
- A mechanism for triggering these actions
- A mechanism for recording the usage of these components when the actions occur
- The data and relations needed to represent the system being modelled
- The simulation model structures, e.g., blocks, connections, etc.

4.3 Determination of Customer Activities in the Shopping Mall and Components Interaction

As previously stated, the focus of this model is the behaviour patterns i.e., the decision-making mechanism of a customer. The relevant parameters that related to each activity have a significant impact on their decision-making during shopping and thus play a great role in the accuracy of the model.

This section discusses the main functions of the shopping mall i.e. the customer activities to be modelled, and the interaction between customers and the corresponding building components or building products during the activities. The parameters for the quantification of the desired outcome are stated in the later chapters.

4.3.1 Shopping

Nowadays, the shopping mall has developed into a meet point of complex functions, in addition to shopping, it is now able to meet the customer social and cultural needs, as well as the needs of entertainment, recreation, sport or relaxation.[58]

The first primary function of the shopping mall is still shopping. A shopping mall supplies various shops and facilities for the customers to meet different purchase needs, such as mode, shoes and bags, jewelry.

This activity includes not only shopping inside a store but also walking through the walkway between shops and wandering outside the store windows etc. customers will make decisions when facing more options based on their preferences or needs or personal habits etc.

Specific logic is added in the corresponding blocks using ModL Codes, to simulate customer's shopping behavior.

4.3.2 Eating

Some customers might come to the mall mainly for food, for example, people who work or live nearby. Some customers get hungry during shopping. Accordingly, there are various options for customers to select, fast food, restaurants, café, etc. customers who have more time to spend in the mall or visit the shopping mall for a particular restaurant tend to more likely choose restaurants whereas customers work nearby or have less time prefer fast food. Moreover, the needs of the customer are dynamically changing during their shopping, this is more evident in the physiological needs, such as food or toilet (see Figure 4-9). For example, the need for food will start to increase over time when a customer shops for some time, then decrease to 0 when a customer is eating in a restaurant and increase again afterwards. The cycle continues in the process of shopping. The dynamic of the preference can be described as a function of time when the last time a customer ate. This is also appliable at toilet using and resting for example. The logic assigned to the customer in the model will be introduced in detail in the next chapters.

[58] Hameli, Kujtim; Sc, M.: The Role Of Shopping Malls In Consumer's Life: A Pilot Study With Kosovar Consumer.2017.

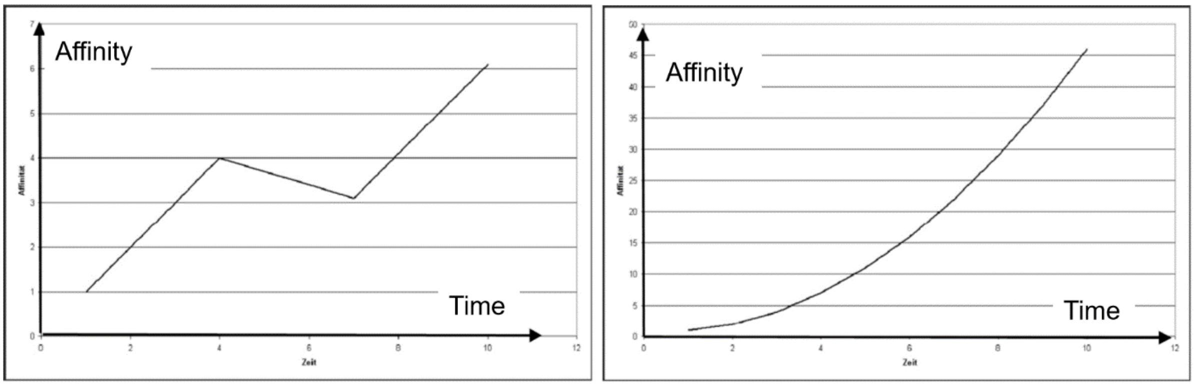


Figure 4-9: Modelling strategies for customer's dynamic preference

4.3.3 Resting

To attract customers to stay in the mall as long as possible and to increase the purchase value of customers indirectly, most of the shopping malls have separate areas throughout the whole area. For example, outside of the food court, the rest area is designed for customers to have a break from shopping. Some café and ice stations are also set in the middle of the walkway. Customers who stroll for a relatively long time or especially during lunch/dinner time, the rest area is often fully occupied.

4.3.4 Use of Toilet

To maximize sales and, at the same time, offer a pleasant shopping experience for customers, retail space needs to be carefully considered. Washroom facilities for the customer are one of the important parts required to be planned properly.[59] Besides hygiene, appearance and durability etc., the intensity of utilization of the toilet should also be considered and simulated in this model.

Similar to rest areas and restaurants, customers who stroll longer are more likely to use toilets than those who stroll shorter. During the simulation of the occupancy rate and utilization frequency of toilets in the mall, customer satisfaction could be in a way presented for the use of optimization of the mall, considering that, the longer the waiting time is, the more negative impact it has on the customer shopping experience.

As just mentioned, the need for toilets changes with time depending on the last time when the customer used the toilet. A similar formula is used to represent the dynamic change of toilet using in the model.

4.3.5 Use of Elevator

In a multi-storey and multi-purpose retail centre, which is characterized by variety and balance for visitors to shop, enjoy leisure activities or eat, etc. Escalators can be a critical factor directly affecting customer flow. Shopping malls need to enable easy access to the retail space from the parking facilities or public transportation and enable customers to move freely through all areas

[59] Cubicle Centre: Shopping and Retail Washroom Guide, internet source.
https://www.barbourproductsearch.info/CubicleCentre-retail-washroom-guide%20UPDATED%20pdf-file089483.pdf

of the centre without feeling being forced in a particular direction or hitting dead ends. The more balanced the circulation, the better the income from tenants.[60]

Studying the utilization intensity of elevator, on the one hand, tells the frequency of utilization of the equipment for the prediction of the wear, lifetime, and capacity of the equipment. On the other hand, an overview of which escalator is being used more often than the other could be observed from the simulation outcome. This is very useful for the management operation of the shopping mall to improve sales performance, for example.

Noticed that most of the restaurants located on the underground floor (UG), the hunger level and consumption of food is a major element influencing the escalator utilization. Therefore, it is important to represent the dynamics of customer's hunger during their movement in the mall. Also, exits are on the ground floor(EG), customers on UG have to take the elevator to exit the mall. These logics are programmed in the Equation block in the model.

4.4 Quantification of Usage Intensity of Building Components in a Shopping Mall

To quantify the usage intensity of building components, the intended building components and the unit of measurement need to be identified first.

In the following table, the customer's activities in the simulation model, the interacted building components to be quantified and the unit for quantification are listed. The intended outcome items are therefore determined.

Table 4-2: Activities in the operational phase in the mall and the unit for quantification of building components usage intensity

Activities in Operational Phase	Interacted component	components	Unit (/day)
Entering/Exiting	Entrance/Exits Door	Main Door	Number of uses/day
Walking	Walkway Section	Floor	Person/day
Shopping	Store Door	Door	Number of uses/day
Eating	Restaurants Door	Door	Number of uses/day
Using toilet	Toilet Door	Door	Number of uses/day
Using Escalator	Escalator	Escalator	Number of uses/day

60 KONE: A Handbook for Architects, Developers, and Builders, Planning retail people flow.Internet source. 2014. https://eritrea.kone.com/Images/handbook-planning-retail-people-flow_tcm69-19032.pdf

5 Simulation of OEZ Model

5.1 About the Model

The model represents a shopping mall in Munich in Germany. It aims to simulate the customer's movements in the mall and to quantify the interaction between the customers and the associated building components. The discrete event model will be developed using agent-based modelling approach in ExtendSim, with the customers logic programmed in blocks in the model.

The concept for this model is that each customer is defined as an individual agent that interacts with other local agents, and the model adheres to the following rules:

- Customers are generated at a given interval rate schedule.
- Most inputs and outputs parameters are stored in the internal database.
- Customers are shopping with strategies. Shopper's behaviour depends on various factors, including the customer attributes, the needs or preferences of customers, the shopping time, the shop's properties etc.
- The decision making is based on the calculated Euclidean Distance value
- Customer will exit if:
    1. a customer's shopping time is running out
    2. the number of maximum shops visited is reached
    3. the shopping mall is closed,
- Once customers exit the mall, they are removed from the system.

The items that are included in the model are listed in Table 5-1.

Table 5-1: Item list in the model layout

Item	Total Number	Description
Floor	2	EG and UG
Entrance/Exit	3	Entrance1, Entrance2, Entrance3
Number of Stores	95	/
Restaurants	10	Including café, fast food, etc.
Toilet	4	/
Elevator	8	4 on each floor
Walkway	4	2 on each floor

5.2 Simulation Setup

5.2.1 Simulation Parameters

The shopping mall opens from Monday to Saturday from 9:30 to 20:00 for 10.5 hours.

Setup of the simulation parameters (see Figure 5-1):

- Global time units: minutes
- End time: 630

- Number of runs: 1

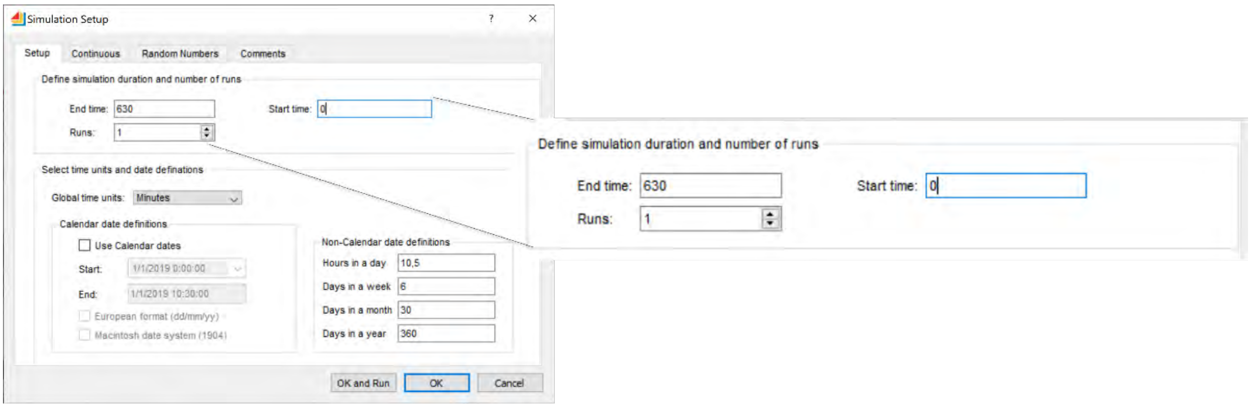


Figure 5-1: ExtendSim - Simulation Setup Block

When the model has stochastic inputs or when performing sensitivity analysis, it is common that one will build and run the model multiple times to generate a range of values representing possible outputs and facilitates model analysis.[61]

5.2.2 Executive Block

The Executive block is for event scheduling, attribute management, and item allocation. It must be presented on the top left corner of the model worksheet in every discrete event model to handle events.

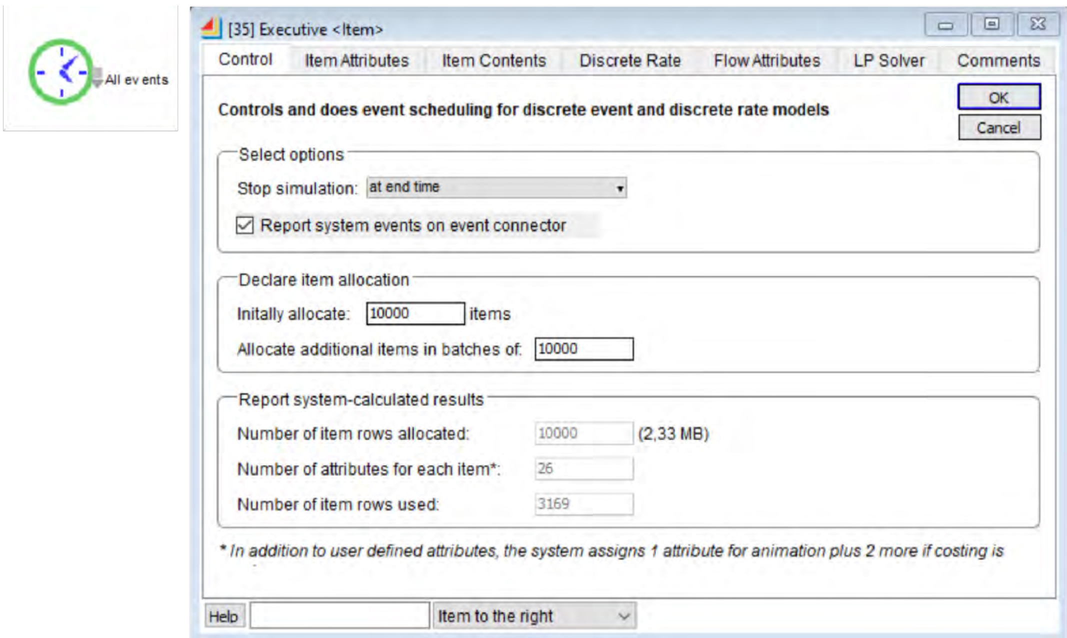


Figure 5-2: ExtendSim - Executive Block

5.2.3 Assumptions and Conditions in the Model

[61] Imagine That Inc: ExtendSim User Guide, 2013, P. 600.

Assumptions for the model are:

- The model runs for a simulated time of 10.5 hours (630min)
- Customers arrive randomly using a random exponential distribution.
- Assume there are 105 shops, including rest area and restaurants on 2 floors.
- There are 3 entrances (exits), 2 walkways on each floor as in the shopping mall layout, 4 escalators connecting two floors.
- Customers will make decisions while they are walking through the shopping mall. Based on their attribute, they will select one store to visit; however, physiological needs such as hunger and need of using the toilet will be the priority when facing multi-options.
- 90% of customer exit the mall through the same entrance where they enter from. The rest 10% will select exits randomly.
- Each store has a door, and each visit will create one time usage of the door of the shop.
- Shopping time is an attribute using a real uniform distribution which is assigned to each customer.
- The blocks come from the Item, Value, and Plotter libraries.

5.3 Model System

Firstly, the model needs to be illustrated as a graph composed of nodes and multidirectional edges according to the graphic theory.[62] A node indicates a store or a walkway section, as well as an entrance/exit. Characteristics of a node would be the name, type, average delay etc. Edges connecting the nodes represent the relationships between nodes. The directions of the arrows determine the possibilities of the customer's movement directions along the edges in the mall (see Figure 5-3). Based on the graph theory and the diagrams of the nodes graph, the layout of this shopping mall is represented using blocks in ExtendSim. The detailed settings of walkways, as well as the logic that has impacts on the customer's movement in the mall, will be explained in this section.

[62] Zimmermann, Josef: Principle of Simulation, 04/2018. P.18.

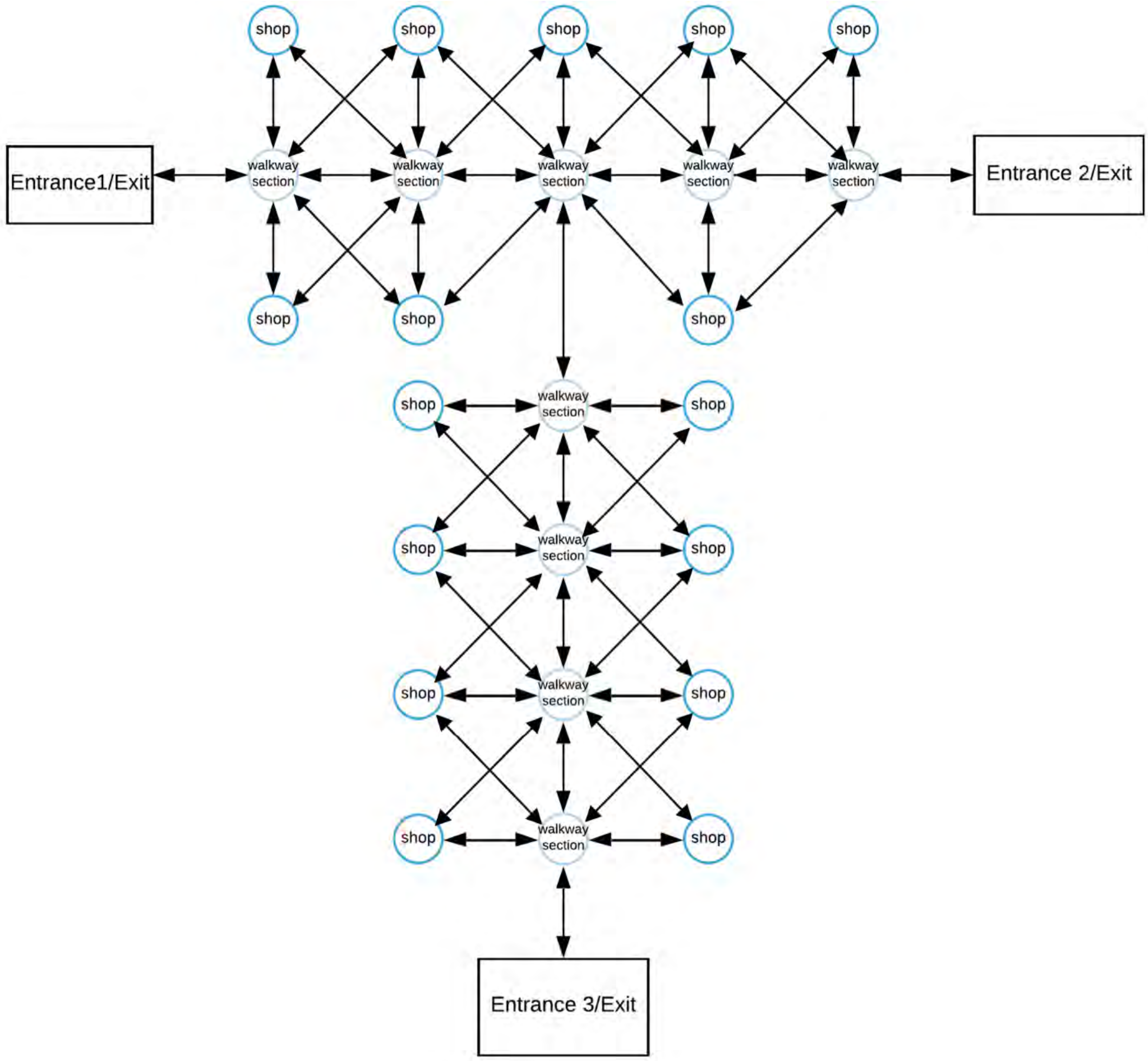


Figure 5-3: Nodes Graph

5.3.1 Entrance/Exits Hblock

Three entrances/exits are distributed in three different directions (see Figure 5-4). Nevertheless, based on the real statistics of daily customer stream, Entrance 1 is the main entrance that is mostly used, while Entrance 2 and 3 are relatively less used. This is represented by the different mean values of the time between arrival (TBA) in the Create blocks.

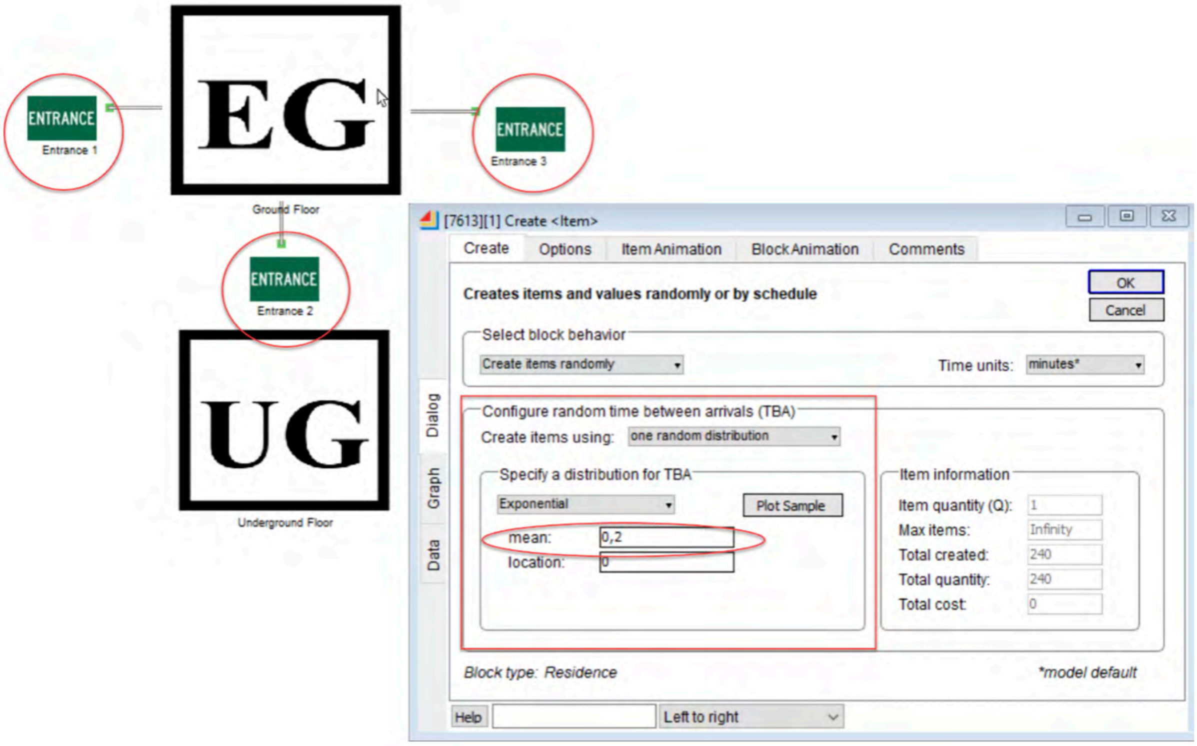


Figure 5-4: Entrances in the Layout and Create block

5.3.1.1 Create Block

Customers in the model can be generated randomly using an exponential distribution in the Create block, which can generate items randomly by schedule or infinitely. In reality, customers arrive in the shopping mall with a different frequency; for example, more customers are visiting during lunch and dinner time while fewer customers in the morning and the evening. The following figure shows the average customer flow on Wednesday, Thursday, Saturday from google map. The value of TBA is set partially based on the data below.

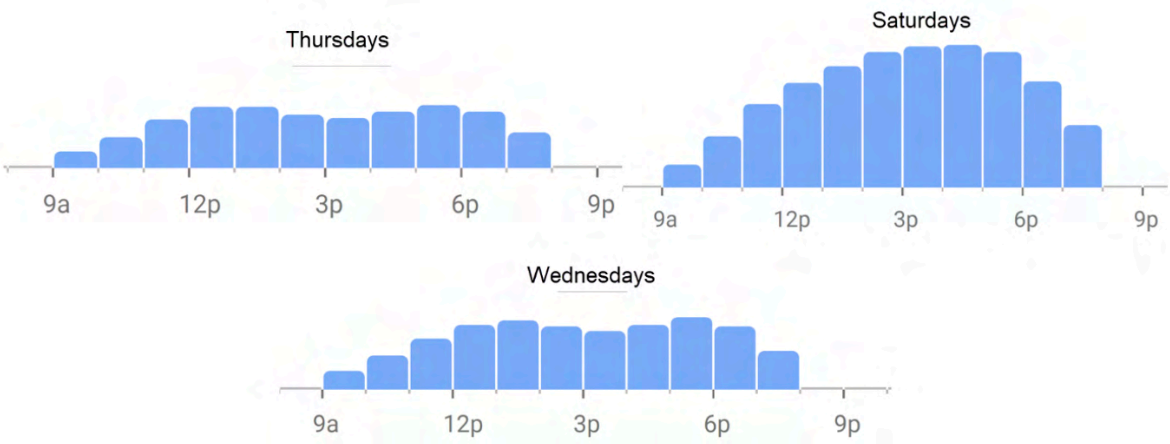


Figure 5-5: Customer visits to OEZ based on data on Google Map

5.3.1.1.1 Random intervals with dynamic parameters

In this block, the default setting is that items are created randomly using an exponential distribution primarily used to define intervals between occurrences, and it has a "Mean" parameter. However, according to the statistic distribution on google map, the TBA varies every hour. ExtendSim enables customer arrivals to be scheduled by connecting a Lookup Table block to the Create block. This causes the mean value of the distribution to come from the Lookup Table during the simulation run, which dynamically changes the average mean value of TBA (see Figure 5-6).

With a daily customer traffic of about 33000 customers, of which around half of the traffic is from the main entrance – Entrance 1, the detail distribution of the time-varying mean values of the interval and customer flow in different periods of a day is shown in Table 5-2. These values are entered in the Lookup Table blocks connected to Create blocks in the three Entrance Hierarchical Blocks respectively.

The values can be manually changed based on the real customer traffic of any specific shopping mall on a particular day. For instance, there can be a significantly higher customer flow at weekends compared to weekdays because of the "weekend effect".

Table 5-2: Customer flow distribution of three entrances

Period	Entrance 1		Entrance 2		Entrance 3	
	Interval(min)	customer	Interval(min)	customer	Interval(min)	customer
9:30-11:00	0.2	450	0.5	180	0.5	180
11:00-14:00	0.02	6000	0.02	6000	0.035	3429
14:00-17:00	0.04	4500	0.07	2571	0.07	2571
17:00-18:00	0.03	2000	0.05	1200	0.05	1200
18:00-19:40	2	20	2	20	2	20
19:40-20:00	-	-	-	-	-	-

As can be seen in the table above, the mean value of the intervals between 11:00-14:00 and 17:00-18:00 is much smaller than in other periods, which means customers arrive more frequently during these periods. With the given interval mean values for Entrance 1, one customer arrives approximately every 0.2 minutes for the first 1.5 hours, every 0.02 minutes from 11:00 to 14:00, and so on. Notice that from 19:40 to 20:00 no customer is coming into the mall anymore, this is because there will be an announcement reminding customers in the mall that it is going to close and no customer is allowed to enter 20 minutes before the mall closes.

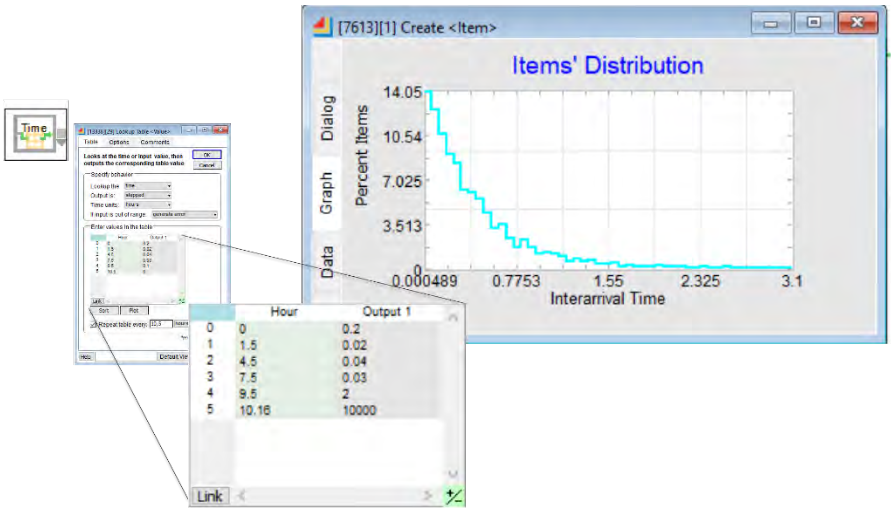


Figure 5-6: ExtendSim – Lookup Table of Interval time mean value

What is more, as the amount of daily customer flow in this shopping mall is relatively large, which causes an extremely long simulation run due to the required number of computations over the simulation timeframe. A parameter, namely the interarrival time multiplier is thus set in the model so that it could control the customer flow during the simulation run dynamically as required or for the use of data analysis with different mall traffic. This is executed by adding an Equation block between Lookup Table block and Create block (see Figure 5-7). The equation is described as:

meanValueOut= meanValueIn / multiplier.

meanValueOut: output
meanValueIn: input
multiplier: model parameter for controlling customer arrivals

Equation 4: Customer arrivals slider parameter

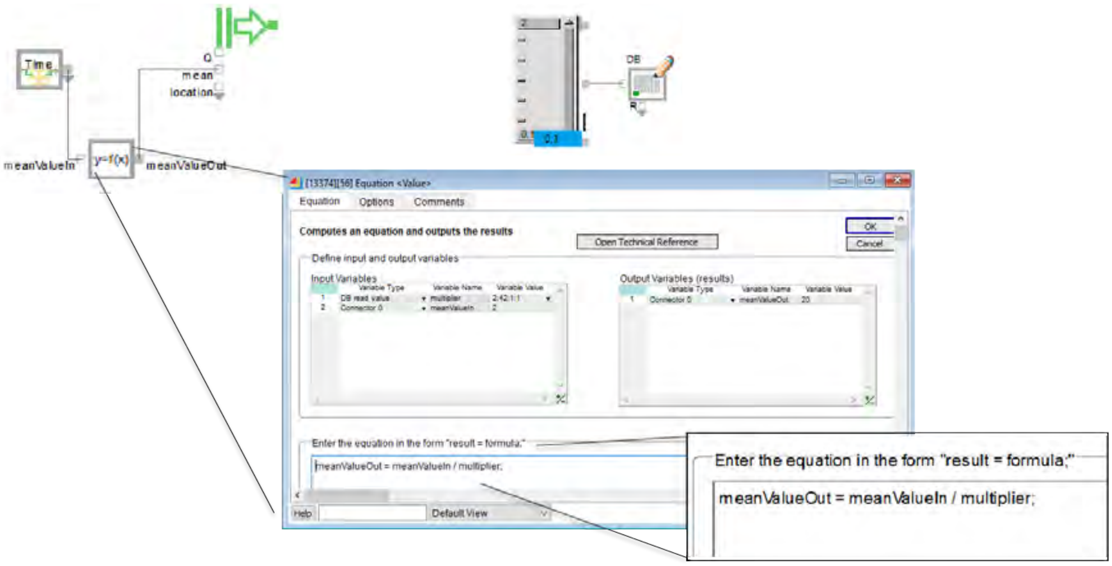


Figure 5-7: ExtendSim – Interarrival Time Multiplier

5.3.2 Walkway

There are many possible ways to build the layout structure for this shopping mall model. With the help of the animation function in ExtendSim, the walkway can be represented in the form of a connection of Nodes and Edges, whose relations are set in the database.

5.3.2.1 Edges and Nodes

There are two interconnecting walkways on each floor as shown in the overview of this model in Figure 5-8 and Figure 5-9. Each walkway section is connected by two nodes in green and each node is connected with two edges from both sides. Their relations are defined and set in the Nodes and Edges Table in the Walkway Tab in the Database, as shown in Figure 5-10 and Figure 5-11. While the model is running, customers walk from the beginning of the walkway and move from segment to segment. The end of each walkway section is where each store decision is made.

Each walkway section is connected to several shops, toilets, elevators, entrances/exits, and intersections within reach. The database structure is shown in Figure 5-12 below. When customers walk on a walkway section, they select the best option from the reachable options that meet most of their preferences based on the Euclidean Distance Theory. The decision logic shall be introduced in the following sections.

Figure 5-8: EG overview of shopping mall layout

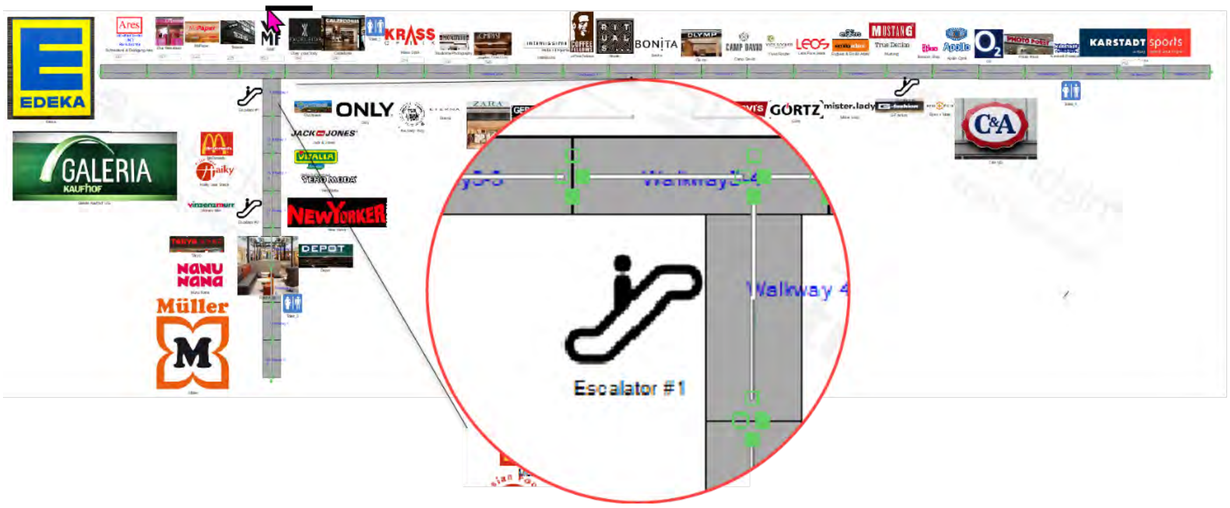


Figure 5-9: Nodes and Edges of Walkway Sections in the Model

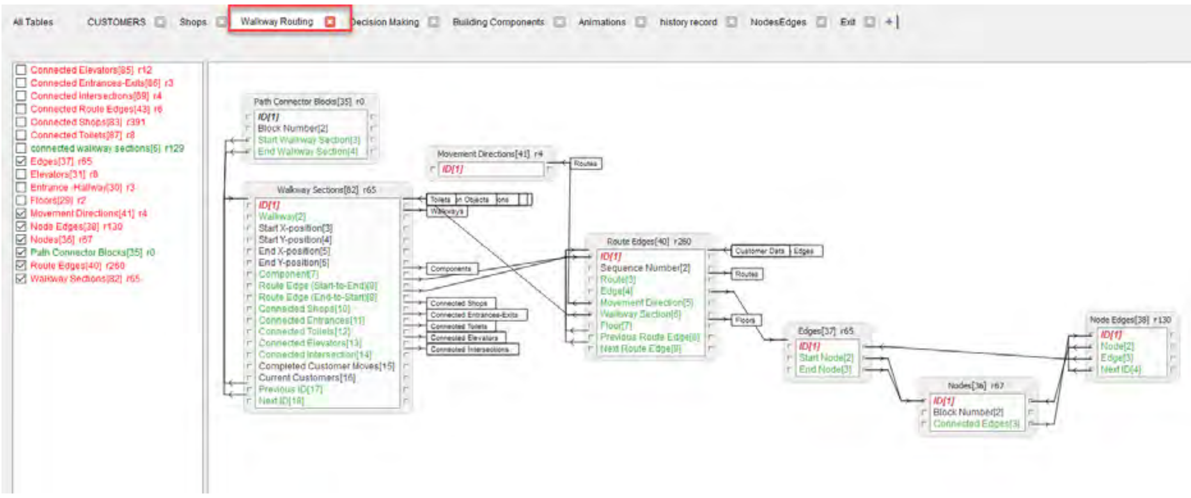


Figure 5-10: Database Structure of Walkway

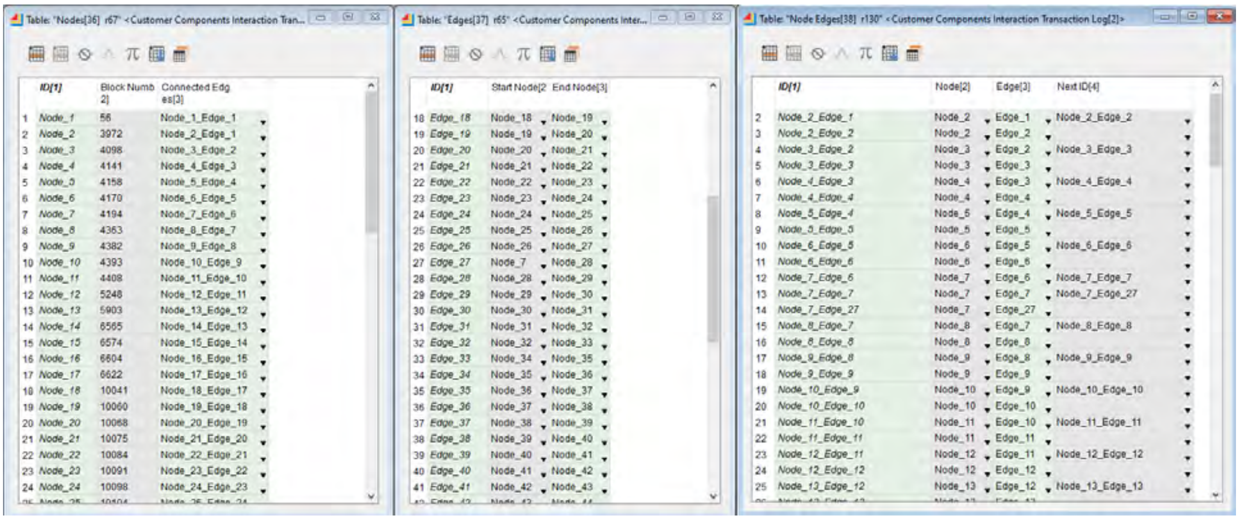


Figure 5-11: Nodes, Edges, Node Edges Table in Database Structure

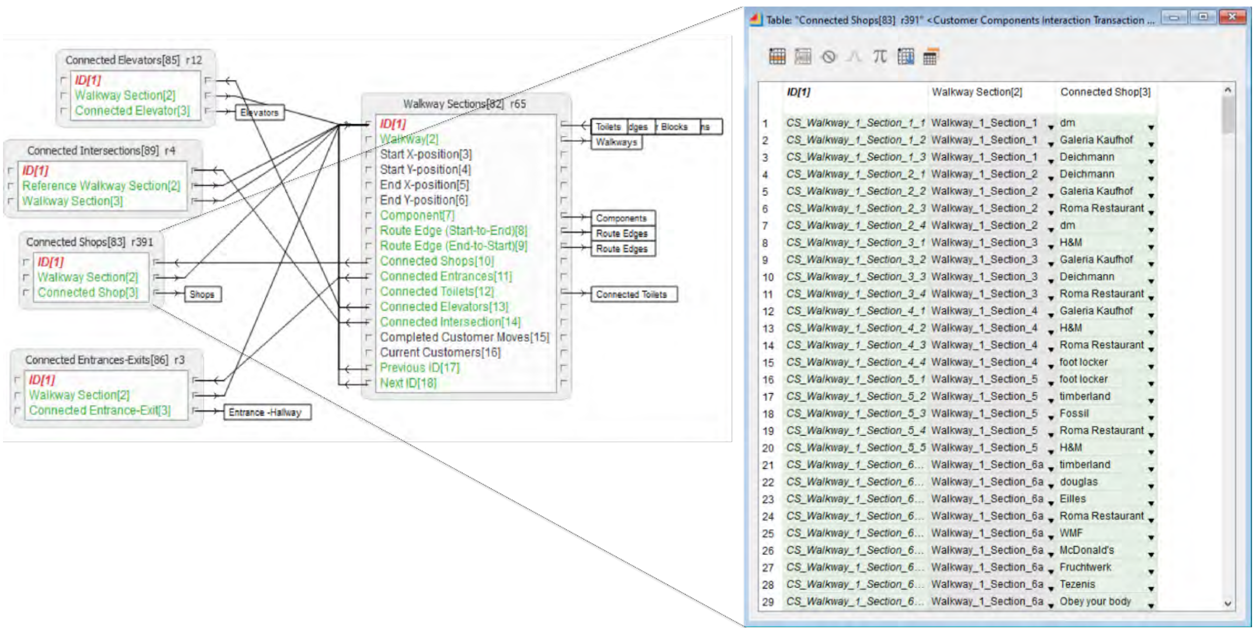


Figure 5-12: Table of Walkway Sections and connected Components in Database Structure

5.3.3 Shops

5.3.3.1 Shops Table in Database

In this shopping mall, each shop on EG and OG is recorded in the Shops Table in the Database, as shown in Figure 5-13 and Figure 5-14. Also, Figure 5-15 indicates the relations between the Parent/Child tables related to Shops Table. The Shops table contains over 10 Fields, such as Name, Categories, Floor, Customer visits. All information can be accessed within the model using Read and Write blocks and Equation blocks.

Table: "Shops[5] r108" <Customer Components Interaction Transaction Log[2]>

	Name[1]	Shops Vector[2]	Catch Block Number[3]	Location Type[4]	Floor[5]	Customer Decisions[6]	Highest Decision Score[7]	Customer Visits[8]	Y-position[9]	X-position[10]
1	dm	SV_dm	1610	Beauty/Health/Optic	EG	5818	1970	87	114,00	130,00
2	Deichmann	SV_Deich...	1047	Bags/Shoes	EG	9134	3109	165	262,00	122,00
3	H&M	SV_H&M	1311	Mode	EG	9949	3057	198	434,00	118,00
4	foot locker	SV_foot lo...	30891	Sports/Outdoor	EG	6649	2011	150	558,00	114,00
5	timberland	SV_timbe...	13252	Bags/Shoes	EG	23028	3753	246	650,00	110,00
6	douglas	SV_douglas	1847	Mode	EG	21729	3375	232	746,00	114,00
7	Hallhuber	SV_Hallh...	1944	Mode	EG	9058	1462	123	854,00	115,00
8	street one	SV_street ...	2018	Mode	EG	4241	860	65	974,00	114,00
9	Herzog & Bräuer	SV_Herzo...	2095	Mode	EG	6342	1186	101	1098,00	112,00
10	Bel Hair	SV_Bel Hair	2175	Service	EG	4234	702	62	1186,00	113,00
11	Jewelier Christ EG	SV_Jewel...	2368	Jewelry/Gifts	EG	4208	784	77	1278,00	114,00
12	Swarovski	SV_Swar...	2442	Jewelry/Gifts	EG	6220	1021	105	1394,00	115,00
13	X-LARGE Pop	SV_X-LAR...	2530	Mode	EG	7658	1282	105	1522,00	118,00
14	Andreas Krebs	SV_Andre...	2635	Mode	EG	4232	657	69	1626,00	118,00
15	PUMA	SV_PUMA	2729	Sports/Outdoor	EG	6306	1460	173	1738,00	116,00
16	Cafe Rischart	SV_Cafe ...	2823	Fast Food	EG	972	285	68	1782,00	166,00
17	orsay	SV_orsay	2917	Mode	EG	6163	1602	167	1926,00	118,00
18	Hunkemöller	SV_Hunk...	3011	Mode	EG	6011	1741	195	2018,00	116,00
19	Tchilo	SV_Tchilo	580	Groceries	EG	5982	1676	178	2110,00	118,00
20	Pimkie	SV_Pimkie	3105	Mode	EG	5954	1381	129	2210,00	120,00
21	Tally Weijl	SV_Tally ...	3185	Mode	EG	6980	1164	102	2302,00	116,00
22	Gamestop	SV_Game...	443	Electronic/Telecommunication	EG	5045	657	42	2402,00	118,00
23	Runner's Point	SV_Runn...	24806	Sports/Outdoor	EG	3828	767	54	2510,00	120,00

Figure 5-13: Shops Table in DB part 1

mean shopping time[11]	stdDev shopping time[1	Minimum Purchase Am	Maximum Purchase Amount[14]	Most Likely Purchase Amount[15]	Minimum Purchase Probability[16]	Maximum Purchase Probability[17]	Door Component[18]
12,00	2,25	0,00	100,00	25	0,00	0,60	COMP_door_dm
22,00	2,50	0,00	200,00	50	0,00	0,10	COMP_door_Deichmann
12,00	5,00	0,00	200,00	80	0,00	0,30	COMP_door_H&M
12,00	5,00	0,00	300,00	80	0,00	0,10	COMP_door_foot locker
22,00	3,75	0,00	200,00	80	0,00	0,10	COMP_door_timberland
12,00	5,00	0,00	200,00	50	0,00	0,10	COMP_door_douglas
12,00	3,25	0,00	300,00	50	0,00	0,10	COMP_door_Hallhuber
7,00	5,00	0,00	300,00	50	0,00	0,10	COMP_door_street one
42,00	15,00	0,00	300,00	50	0,00	0,10	COMP_door_Herzog & Bräuer
12,00	5,00	0,00	300,00	50	0,00	0,10	COMP_door_Bel Hair
12,00	5,00	0,00	3000,00	300	0,00	0,02	COMP_door_Jewelier Christ EG
12,00	2,50	0,00	2000,00	200	0,00	0,02	COMP_door_Swarovski
7,00	2,25	0,00	300,00	50	0,00	0,10	COMP_door_X-LARGE Pop
12,00	2,50	0,00	300,00	50	0,00	0,10	COMP_door_Andreas Krebs
22,00	2,00	0,00	200,00	50	0,00	0,10	COMP_door_PUMA
12,00	2,50	0,00	50,00	10	0,00	0,50	COMP_fast food_Cafe Rischart
12,00	2,50	0,00	200,00	50	0,00	0,10	COMP_door_orsay
12,00	5,00	0,00	200,00	50	0,00	0,10	COMP_door_Hunkemöller
17,00	4,75	0,00	200,00	50	0,00	0,10	COMP_door_Tchilo
22,00	2,50	0,00	200,00	40	0,00	0,10	COMP_door_Pimkie
22,00	3,75	0,00	200,00	40	0,00	0,10	COMP_door_Tally Weijl
22,00	5,00	0,00	200,00	50	0,00	0,10	COMP_door_Gamestop

Figure 5-14: Shops Table in DB part 2

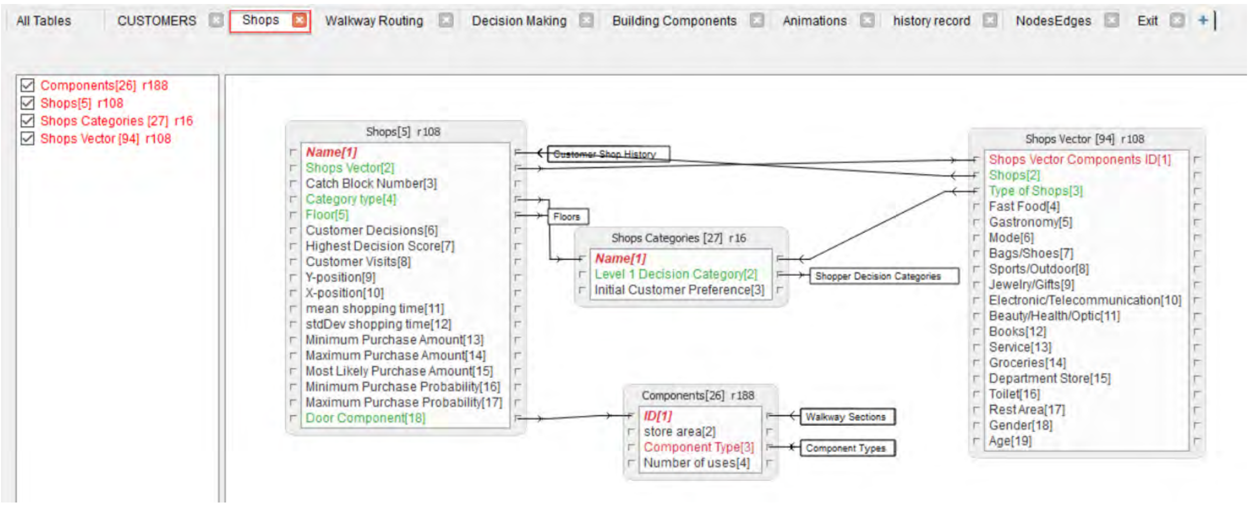


Figure 5-15: ExtendSim – Shops Database Structure

5.3.3.2 Fields Description in Shops Table

The most important field parameters are listed in Table 5-3 below.

Table 5-3: Description of fields in Shops Table

Field	Input/output	description
Customer Decision	Output	How many times the store has been calculated as one of the options.
Highest Decision	output	How many times a shop get the min. ED and becomes the potential best selection.
Customer Visits	output	Total number of customer visits.
Y-Position/X-Position	input	The x-, y-coordinates of the shop.
Mean/stdDev shopping time	input	Mean value and Std. Dev shopping time of a customer in a shop.
Min./Max. Purchase Amount	input	The min. and max. purchase amount of a customer in a shop
Max. purchase probability	input	The max. probability of a customer purchasing in a shop.
Door component	Parent/child	The interacted door of a shop.

The customer shopping time in each shop is set with a normal distribution and randomly assigned to each customer. The mean values and standard deviations are assumed based on store categories and shopping experiences. Figure 5-17 shows an example of Edeka store, which has a random customer delay using a normal distribution. What is more, the shopping time spent in each shop will be associated with the total maximum shopping time assigned to each customer as an attribute and is recorded in the Customer Data Table. The maximum shopping time is one of the conditions for a customer to exit the mall.

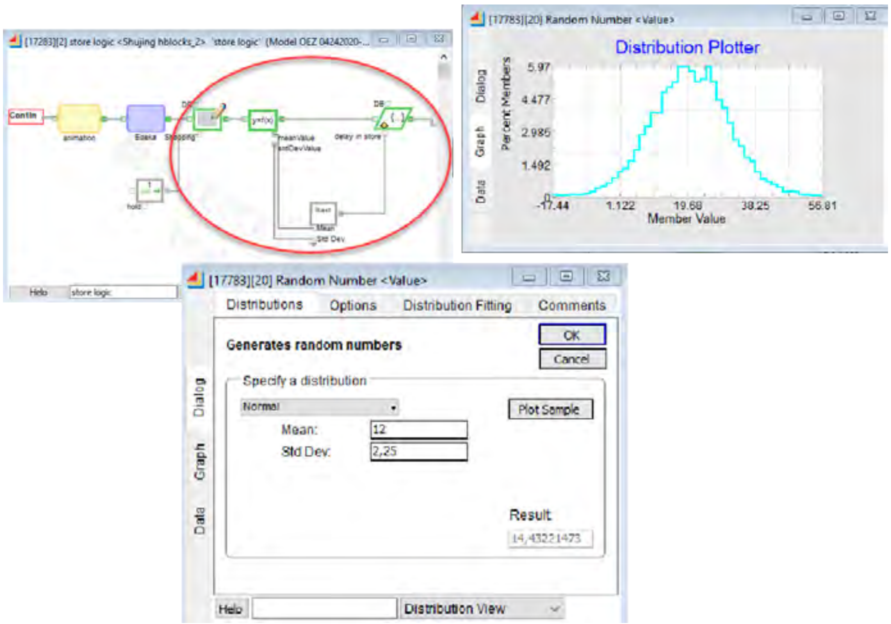


Figure 5-16: Random distribution of the delay in a shop

Furthermore, notice that sometimes the number of Highest Decision Score is not equal to the number of Customer Visits in the table because of the introduction of the parameter “max. ED threshold”, which is used to exclude some of the shops with a relatively large ED value. For example, Edeka now has the smallest Euclidean distance value 1.1 among five connected shops, but it is not selected, as the value exceeds the maximum Euclidean Distance set in the Model Parameter Table as shown in Figure 5-17. This represents the real shopping scenario when none of the shops meets the customer’s preference, the customer will continue walking instead.

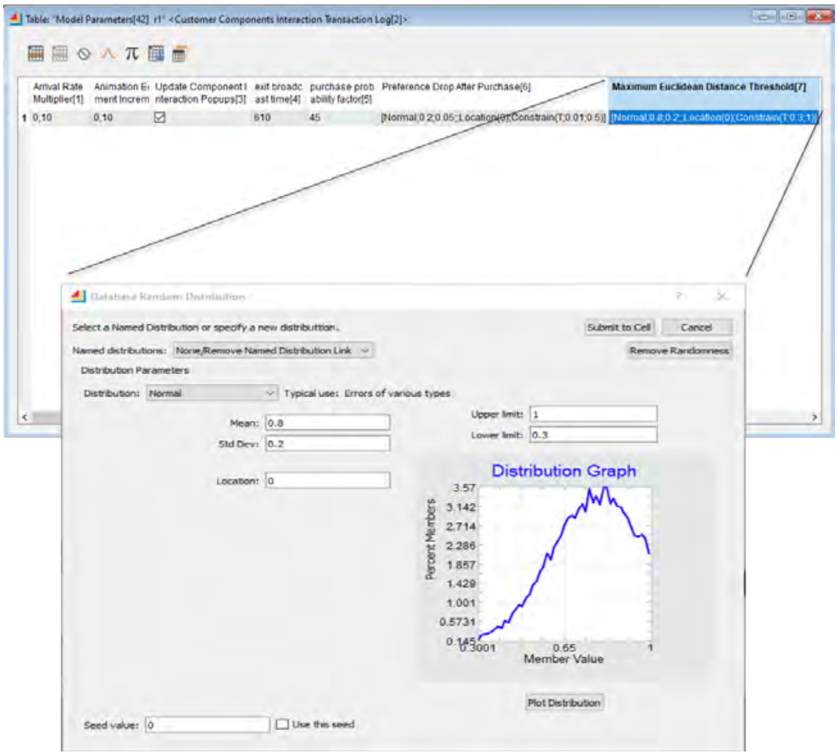


Figure 5-17: Parameter- Maximum Euclidean Distance Threshold in Model Parameter Table

5.3.3.3 Shops Vector Table

The Shops Vector Table (see Figure 5-18) in the database is one of the most important tables for the customer's decision-making logic and will be explained in the next chapter in detail.

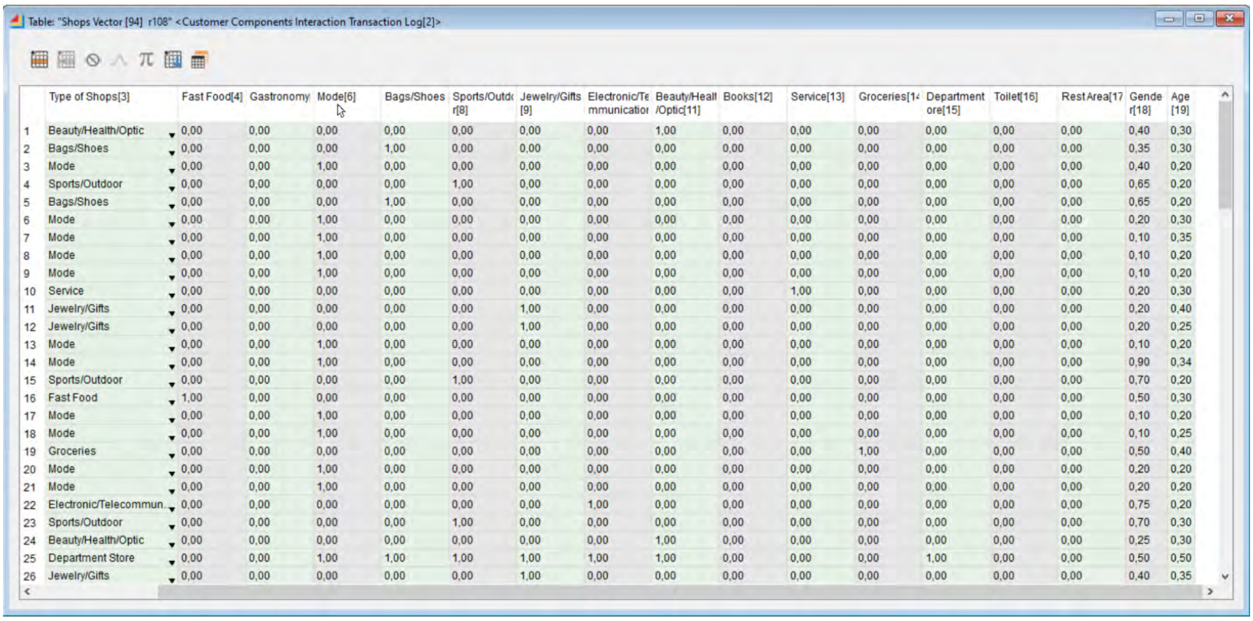


Table: "Shops Vector [94] r108" <Customer Components Interaction Transaction Log[2]>

	Type of Shops[3]	Fast Food[4]	Gastronomy	Mode[6]	Bags/Shoes	Sports/Outdoor[8]	Jewelry/Gifts [9]	Electronic/Telecommunication	Beauty/Health/Optic[11]	Books[12]	Service[13]	Groceries[14]	Department Store[15]	Toilet[16]	RestArea[17]	Gender[18]	Age [19]
1	Beauty/Health/Optic	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,30
2	Bags/Shoes	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,35	0,30
3	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,20
4	Sports/Outdoor	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,65	0,20
5	Bags/Shoes	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,65	0,20
6	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,30
7	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,35
8	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,20
9	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,20
10	Service	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,20	0,30
11	Jewelry/Gifts	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,40
12	Jewelry/Gifts	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,25
13	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,20
14	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,90	0,34
15	Sports/Outdoor	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,70	0,20
16	Fast Food	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,30
17	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,20
18	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,25
19	Groceries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,50	0,40
20	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,20
21	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,20
22	Electronic/Telecommun...	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,75	0,20
23	Sports/Outdoor	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,70	0,30
24	Beauty/Health/Optic	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,30
25	Department Store	0,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	1,00	0,00	0,00	0,50	0,50
26	Jewelry/Gifts	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,35

Figure 5-18: Shops Vector in DB

5.3.3.4 Increment of customer visits of a shop and shops visited of a customer

There are two equation blocks with customer's shopping logic programmed in the Store logic Hblock (see Figure 5-19):

1. increment of the number of customer visits in the shop and accordingly the number of shops visited of the customer
2. the customer purchase decision.

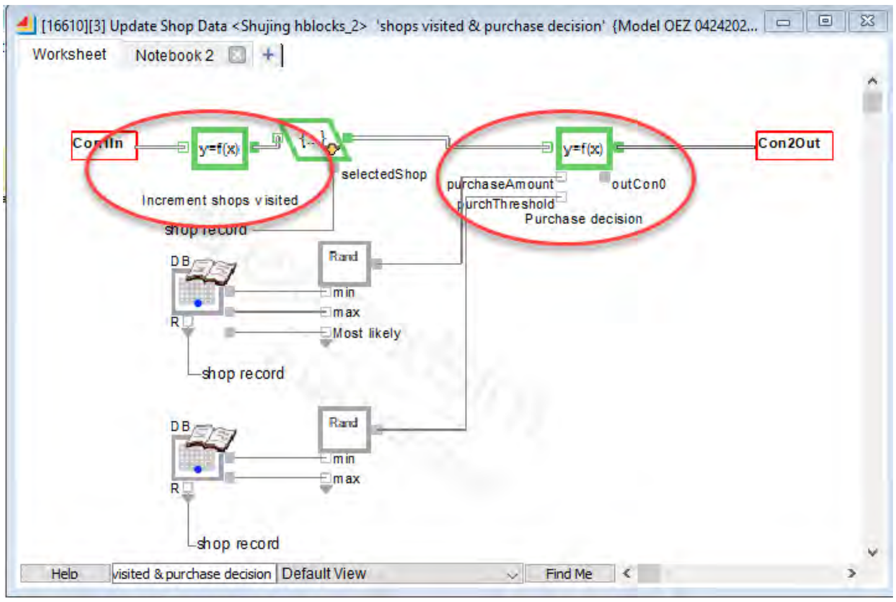


Figure 5-19: Shops visited and purchase decision logic in the store logic Hblock

5.3.3.4.1 Increment of the number of shops customer visited and the number of customer visits in a shop

Each time a customer visits a shop, the record is updated in “number of shops visited” in the Customer Table in DB, as well as the number of customer visits in the Shops Table in DB. This is performed in the Equation(I) block, and the codes are attached in appendix A.

5.3.3.4.1.1 Purchase decision

The purchase decision is also another factor that influences customer’s preferences dynamically in the process of shopping and thus affects their further shopping behaviour.

Purchase amount and Purchase threshold

Two parameters are connected to the input connector of the Equation block, purchase amount and purchase threshold, whose values are specified by two random distributions respectively (see Figure 5-20 and Figure 5-21 below).

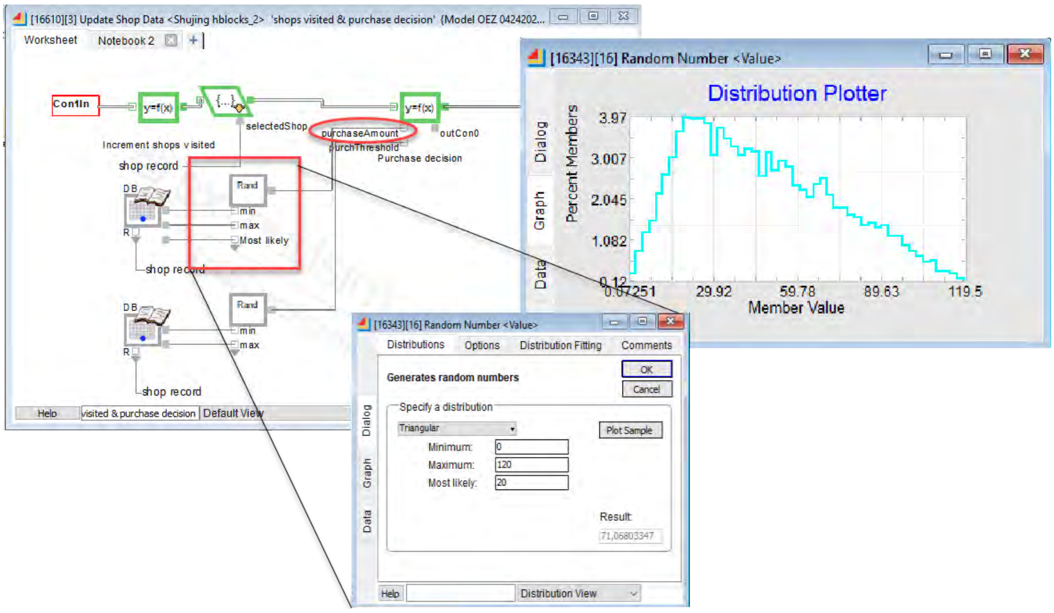


Figure 5-20: Random Number block connected to Purchase Amount in Purchase decision Equation block in Edeka

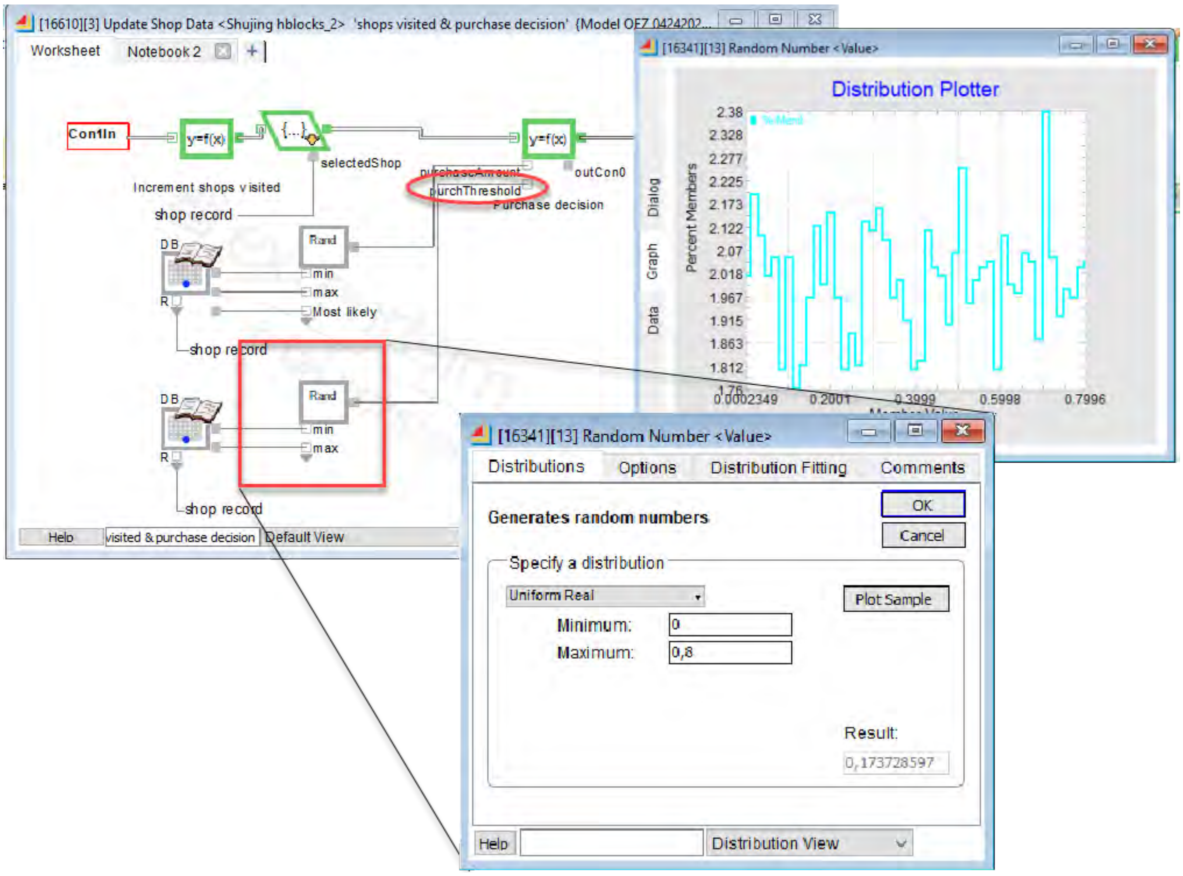


Figure 5-21: Purchase threshold Random Number block in Purchase decision Equation block in Edeka

The figures above are an example in Edeka (Grocery Store), the purchase amount is set with a Random number block, triangular distribution with a minimum value of 0, maximum value of 120, and most likely value 20. The minimum value 0 means a customer visits the shop but didn't make a purchase. The purchase threshold is specified with a uniform real distribution, with a minimum value of 0 and a maximum value of 0.8. As in real life, most people make a purchase in a grocery store, and therefore, it has a relatively higher maximum purchase threshold.

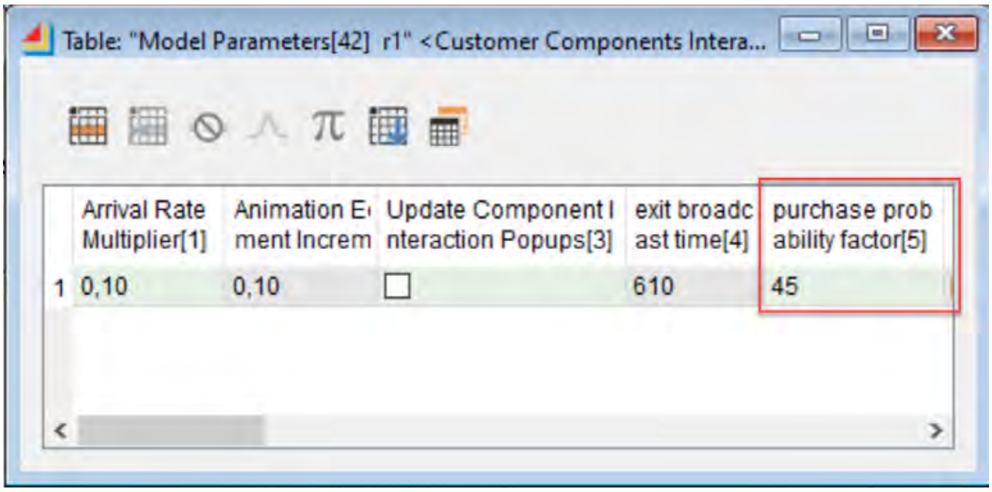
Purchase probability factor

Moreover, the customer's purchase probability is also dynamically changing over the shopping time. For instance, in the first period of time, customers tend to make fewer purchases than after shopping for some time in the mall. A factor that influences the probability of purchase (see Figure 5-22) is therefore introduced to slow down the purchase probability in the first *X* minutes of shopping. It is represented by a formula that is a function of time in the mall as follows:

$$purchaseProbability = shopProbability \times Factor$$
$$Factor = minimum(TimeInMall / X,\ 1)$$

Factor: ranges from 0 to 1
TimeInMall: time spent in the mall
X: purchase probability factor (see Figure 5-22)

Equation 5: Purchase probability equation applied in ExtendSim



	Arrival Rate Multiplier[1]	Animation E ment Increm	Update Component I nteraction Popups[3]	exit broadc ast time[4]	purchase prob ability factor[5]
1	0,10	0,10	☐	610	45

Figure 5-22: Purchase probability factor in Model Parameters table in DB

In other words, the probability factor increases over time till it reaches a maximum value of 1, *X* can be custom determined in the model depending on needs. This is very helpful when a customer's purchase behaviour or sales performance of a shop is of research interest.

Reduction of preference

Once a customer has purchased in a shop, the preference for the same category shops decreases accordingly. This makes the preference for each shop category dynamically change.

All the above makes the customer purchase decision in two steps:

1) Check if a customer will make a purchase based on the adjusted purchase probability
2) If the customer makes a purchase, determine the purchase amount and reduce the customer's preference for this category.

The purchase amount of a customer is recorded and updated in the corresponding table in the database. The codes in the Equation block can be seen in appendix A.

5.4 Customer

As mentioned in section 1.3.3, the identification and quantification of the customer decision-making process can be extremely complex. In this model, the following factors are considered:

- Gender
- Age group
- Preference for each category of shops or facilities in the mall
- Shopping time
- Total number of shops visited

5.4.1 Attributes

Attributes provide information such as unique properties and characteristics about items i.e. customers. In this model, attributes of customers are set using the Set block in the Entrance Setup Hierarchical block as represented in Figure 5-23, including

-Gender

-Age groups
-number of shops visited
-current floor.

Gender and age groups, as seen, are connected to a Random Number block respectively, while the number of shops visited is connected to a constant value block to initialize the value of customer shops visited. When they first enter the mall, the shops visited history is all set to a constant value 0. The current floor is connected to Popups blocks linked with a Floor Table from the Database indicating the current floor where the customer is located.

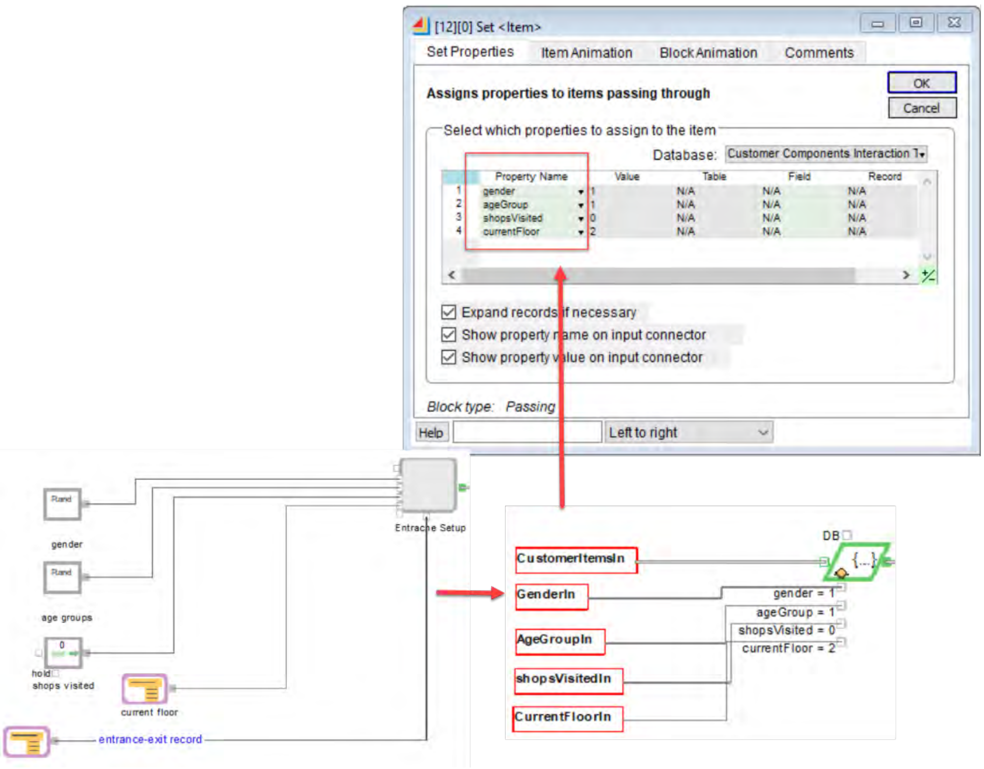


Figure 5-23: Customer's Attributes Set block

Gender

To specify that customers are generated in a specific ratio, a Random Number block is added to the "Entrance setup" Hblock in the model (see Figure 5-24). The values are linked with a Table "Gender Probabilities" from DB.

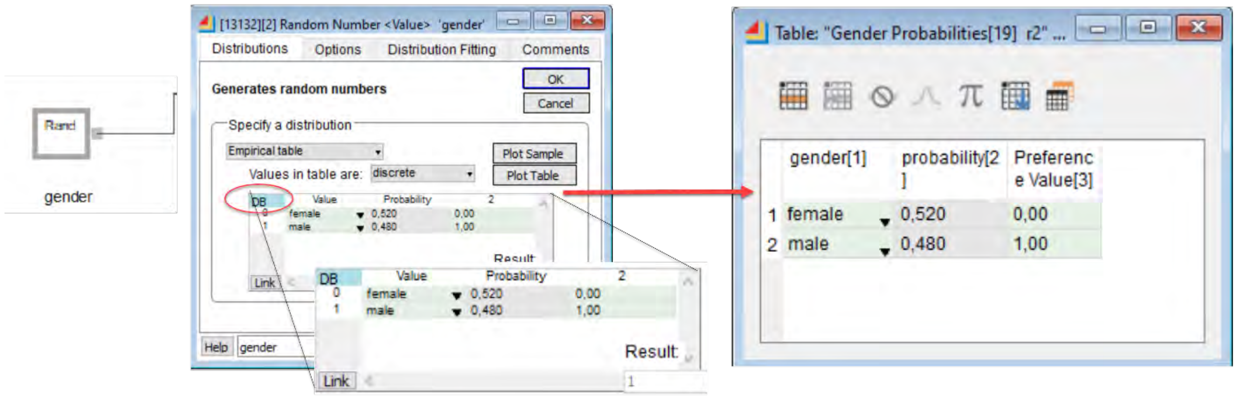


Figure 5-24: Random Number block of gender attribute and the linked Table in Database

Age

As mentioned earlier, the age of customers is divided into several groups ranging from 16 to over 60 years old, same as the Gender attribute, Age is also set using a Random Number block linked with the DB (see Figure 5-25).

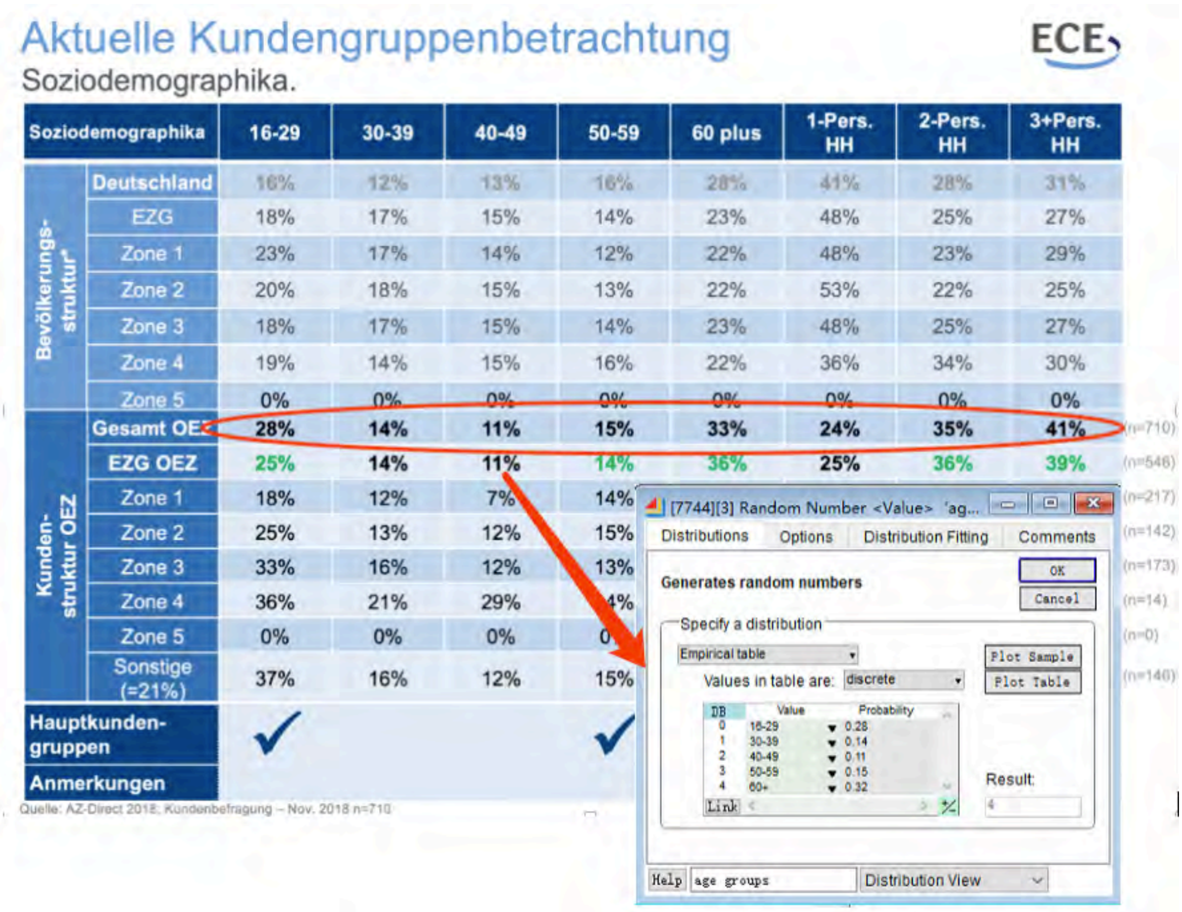


Figure 5-25: Customer age groups structure

Current Floor

Current floor attribute is set with a popup menu, which enables to select from two floors (see Figure 5-26).

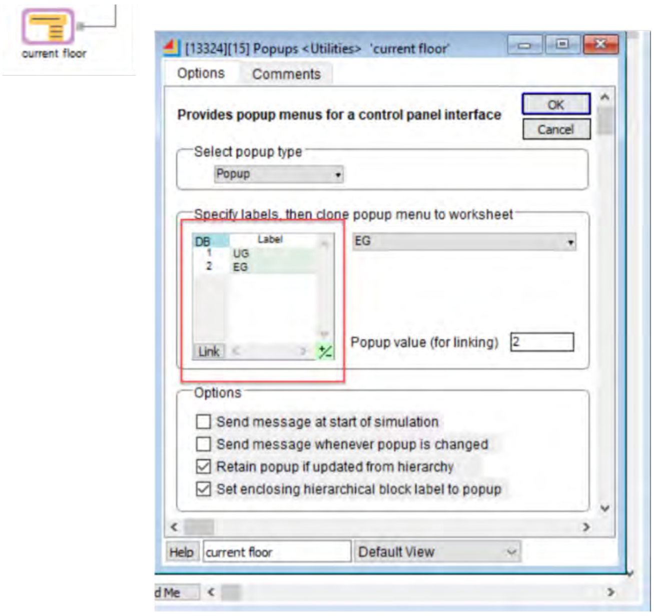


Figure 5-26: Current floor attribute setup

6 Customer Movement and Decision-Making in a Shopping Mall

Five different states of the customer in the shopping mall are identified in the model:

1. Walking on the walkway section
2. Shopping in a shop
3. Using toilet
4. On an elevator
5. Exited

6.1.1 Flow Diagram of Customer Movement

The construction of a flow diagram using blocks to present the problems' operations and resources is the key to discrete event modelling.

The flow diagram in Figure 6-1 indicates the main logic of customer movement in the mall. And Figure 6-2 shows the customer movement Hblock in ExtendSim, which matches the flow chart. The flow diagram includes four main phases:

customer arrival » walking in the mall » decision-making » activities in the mall » exit

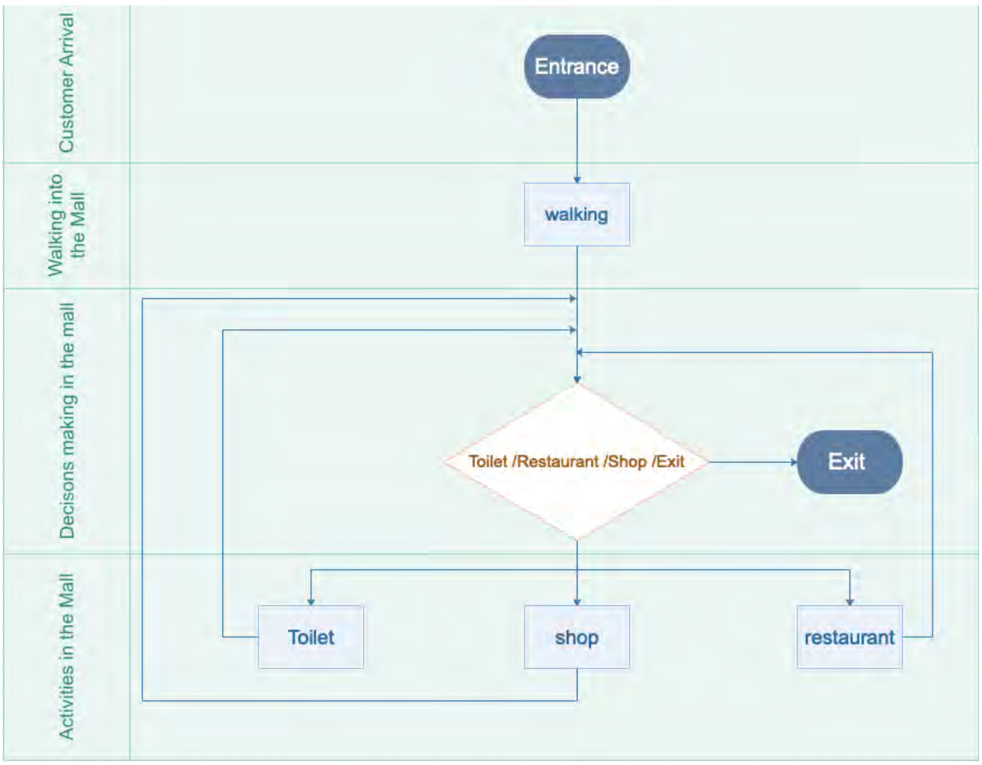


Figure 6-1: Flow Chart of the Model

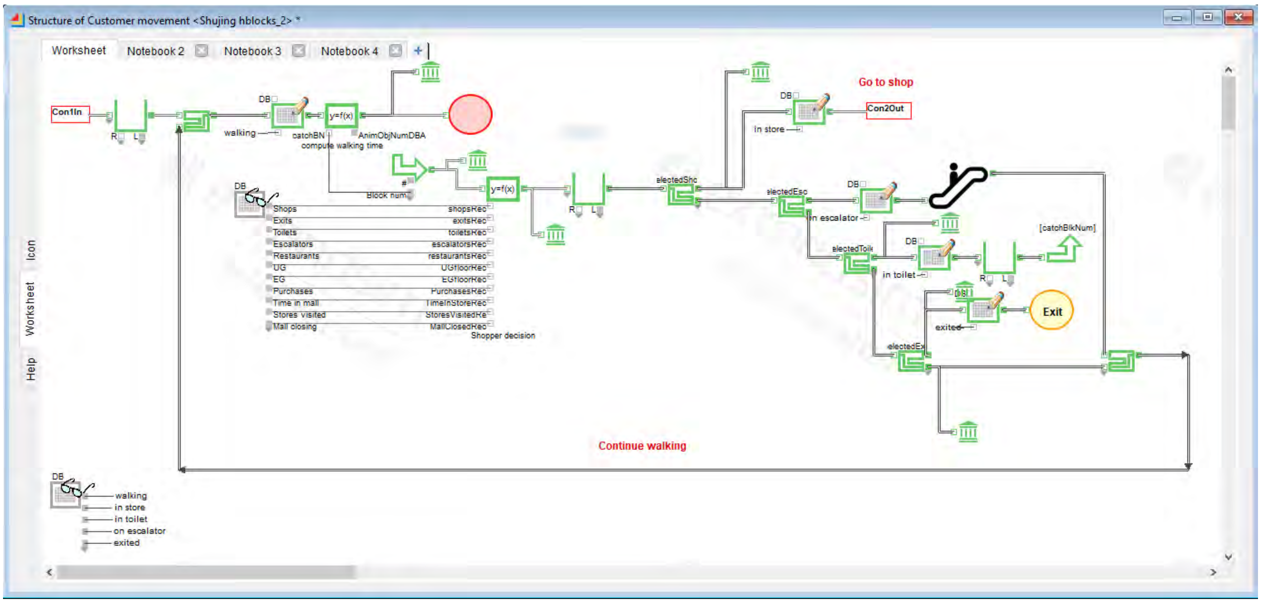


Figure 6-2: Customer Movement Hblock in ExtendSim

6.1.2 Exit

The Exit block automatically counts and passes items out of the simulation. When customers reach one of the conditions, they will exit the mall.

In this model, customers will exit the mall, if one of the conditions is fulfilled:

- Total time spent shopping reaches the maximal shopping time of the customer.
- Total shops visited reaches the customer's maximal number of shops to visit.
- the shopping mall is closed soon, here if the current time reaches the mall broadcast time in the 610 min, which is 20 min before the mall is closed.

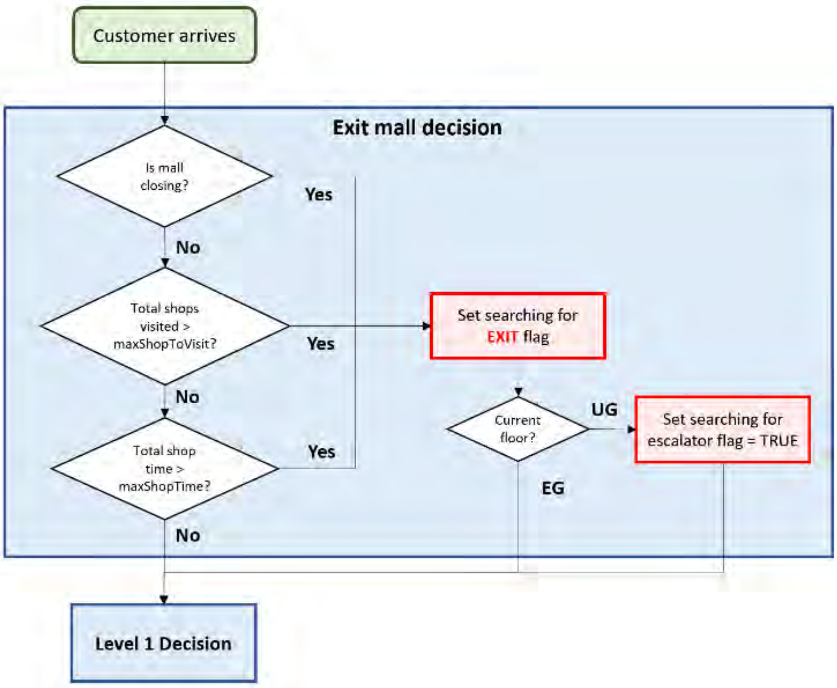


Figure 6-3:Flow Diagram of Exit Decision Logic

6.1.2.1 Determining the boundary parameters of max. purchase value, shopping time and number of shops visited

As discussed earlier, each customer was assigned a maximum shopping time when they enter the mall. Before any decision is made, a system will always check if a customer achieves one of the constraints, which leads to a customer exit from the mall.

Accordingly, the customer's boundary values of shopping time, purchase value and the total number of shops visited are set through appropriate distributions in an Equation block in Entrance Setup Hblock. The detail values of the parameters in the distributions are shown in the table below:

Table 6-1: Customer Data Setup – Distributions and Parameters setting

Nr.	Item	distribution	Min.	Max.	Most likely
1	Max. purchase value	Triangular	50	3000	200
2	Max. shopping time	Uniform Integer	5	30	/
3	Max. shops visited	Uniform Real	20	300	/

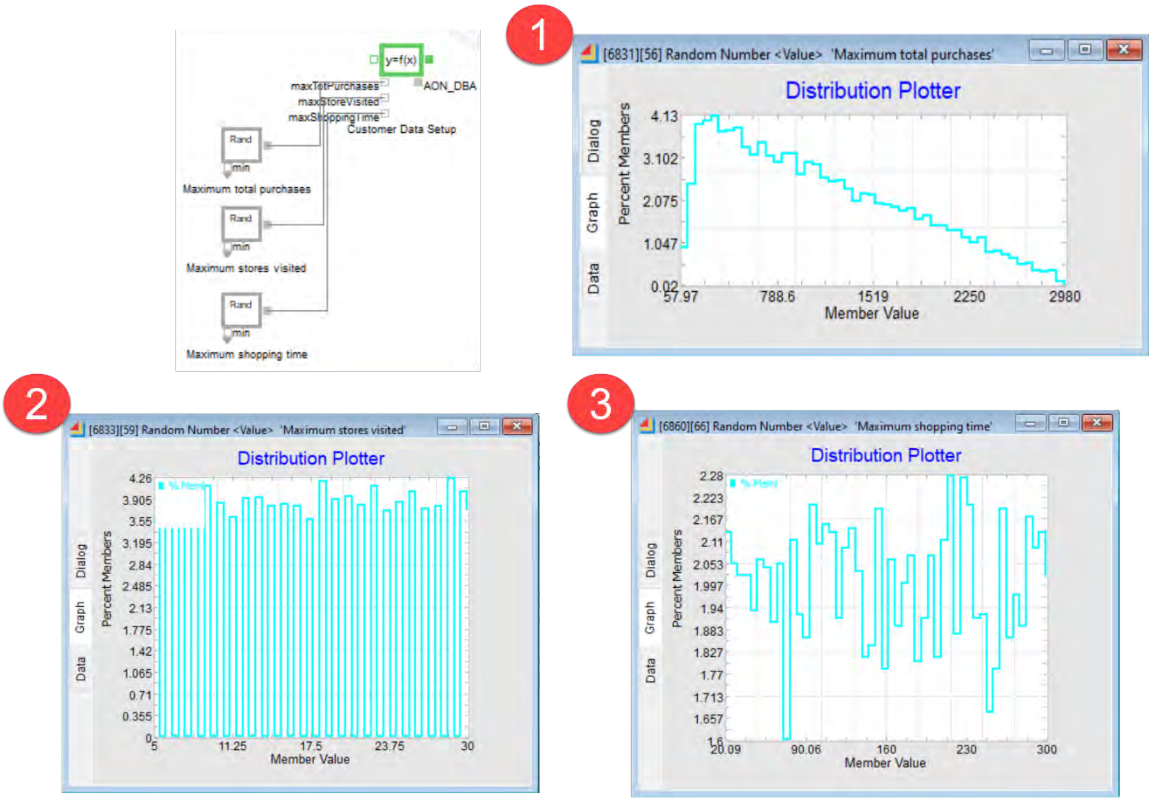


Figure 6-4: Graphs of the three distributions

6.1.2.2 Model parameter – exit broadcast time

The shopping mall closes at 20:00, which is a 630min simulation time; often, the broadcast starts to warn the customers shopping in the mall to prepare and leave the mall before it is closed. A parameter called broadcast time set at 610min is defined in the Model Parameter Table in the Database, meaning the customers will be forced to start to exit the shop when the simulation time reaches 610min.

The Logic in the Equation block will check the following:

If (simulationEndTime – broadcastTime) > currentTime, then EXIT mall.

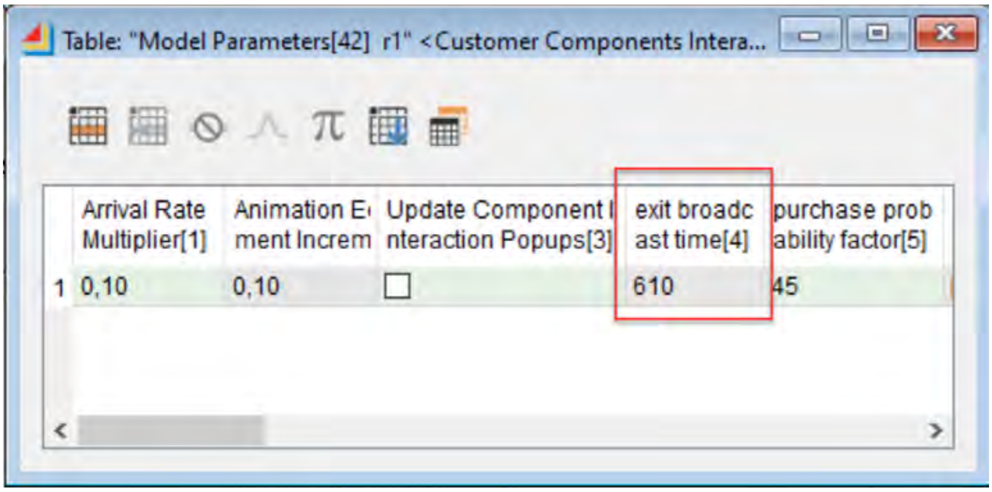


Figure 6-5: Exit Broadcast Time in Model Parameter Table in Database

6.1.3 Logic of Using Elevator

According to this specific layout in the shopping mall, most of the restaurants located on the underground floor (UG) while all the entrances on the ground floor (EG). Which means, a customer has to use an escalator if:

- in EG and needs to go to a restaurant in UG;
- in UG and needs to exit the mall through the main entrances in EG.

6.2 Two Level Decision-Making

To determine how a customer moves in a mall, a two-level decision-making method is applied.

6.2.1 First Level Decision-Making

In the first level, Each customer has four factors assigned:

- preferences for food
- preference for a toilet
- preference for shops
- preference for an exit

Here customers make decisions from a relatively higher level. This is due to that customers often tend to put physical needs such as hunger or need of using toilets in priority rather than shopping. This means customers might go to a restaurant or toilet in the middle of shopping. Once a customer has no strong desire to eat or use toilets or exit the mall, the next level of decision-making would be shopping. The logic is represented in Figure 6-6.

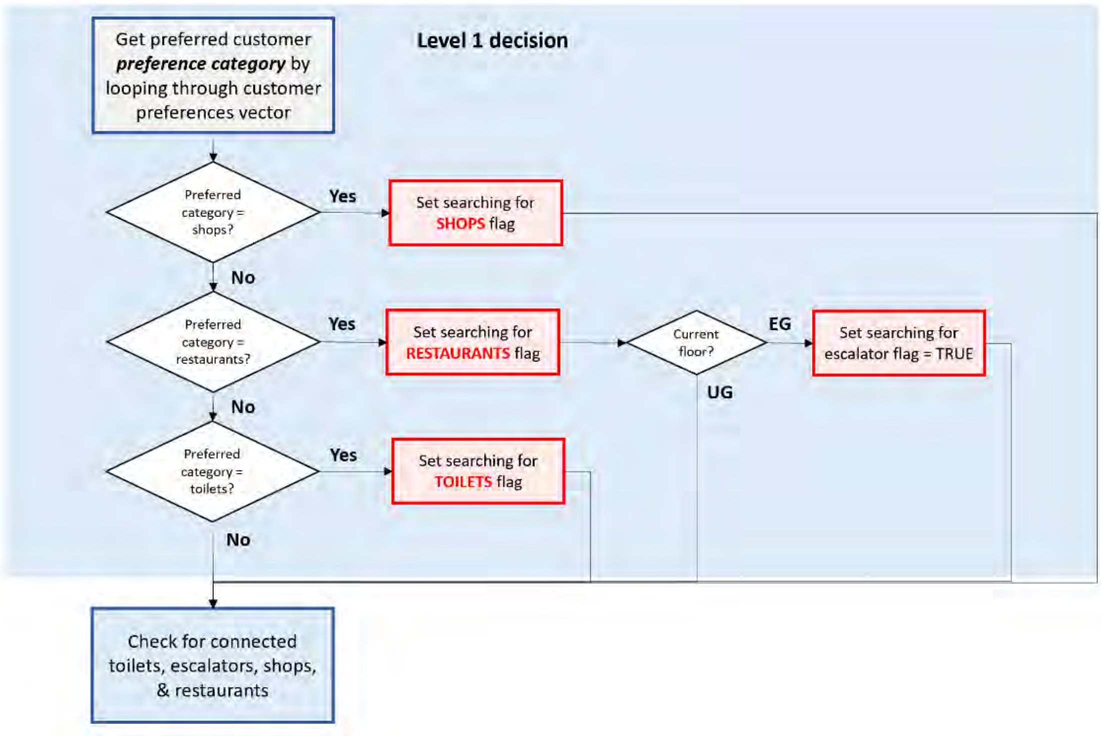


Figure 6-6: Flow Diagram of Level-1 Decision Making

Each loop of a customer's decision-making processes of a customer is based on:

- the options available at the end of each walkway section
- the factors of preferences for different needs, the one with the highest value shall be the decision made in the first level
- the specific need and preferences can be dynamically updated over time based on their shopping history

Vector of Customer's Preference in Level 1 Decision-Making

In this model, each customer has a preference vector composed of Shop, Exit, Restaurant, Toilet, and Escalator for the first level decision-making process.

V_i *(Shop, Exit, Restaurant, Toilet)*

The first -level decision is made by comparing the preferences, the customer chooses the one with the largest value and performs accordingly.

The values of each vector element are initialized when the model runs.

6.2.2 Level 2 Decision Making

In the second level decision-making process, the theory of Euclidean Distance Algorithm is applied to select the best selection among the options.

Each customer has a customer vector *p*, and each shop has a shop vector *q*. The vector components include the preferences of each category of shops, such as shoes, mode, cosmetics. In addition, some other factors, such as target gender or age group of a shop shall be introduced to distinguish shops in the same categories. For two shops in the same category, age and gender would be the crucial factors that influence the customeer's final decision.

Customer's Decision Vector

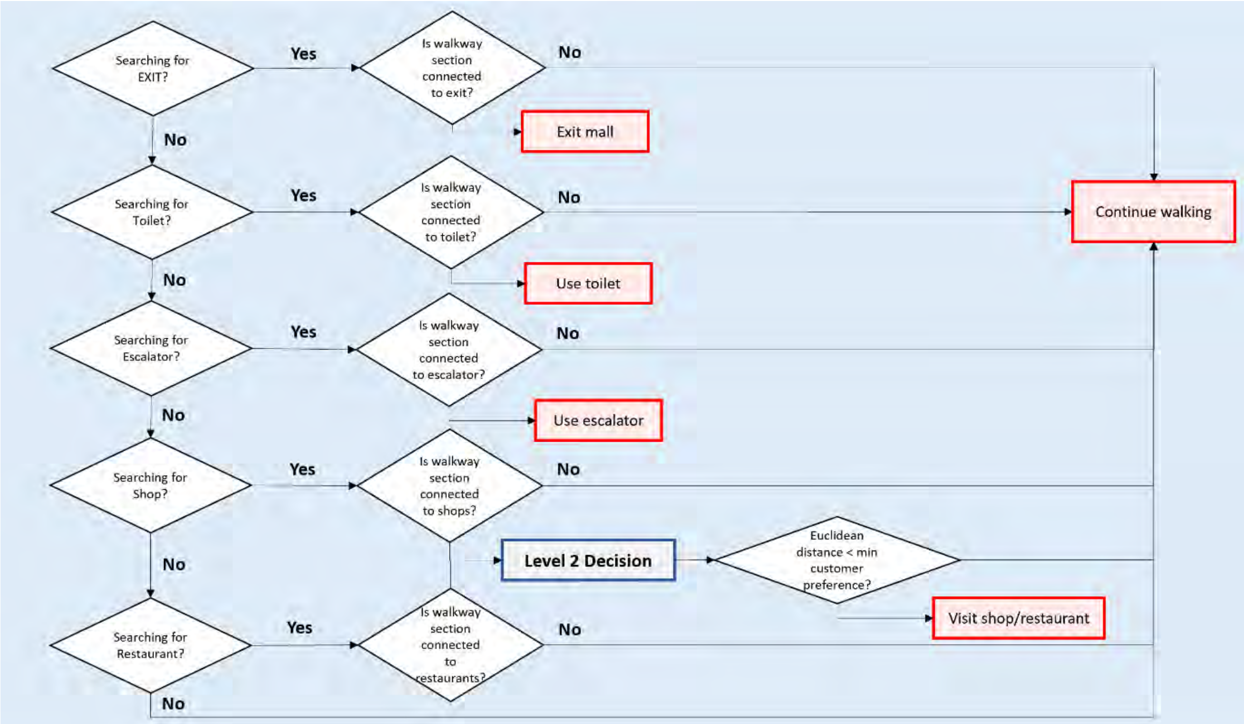


Figure 6-7: Flow Diagram of Level-2 Decision-Making Logic

6.3 Customer Decision-Making

While a customer makes decisions during shopping in the mall, both quantitative and qualitative criterion need to be considered, Euclidean Distance is a very useful technique for dealing with decision-making problems when many factors are to be considered. [63]

6.3.1 Identification of Euclidean Vector

As introduced in section 1.3, the Euclidean Distance algorithm is used to measure the matching degree between different shops and the customer. Therefore, it is essential to identify which factors are considered in the customer vector and shop vector first.

6.3.1.1 Customer Vector $\underset{p}{\rightarrow}$

Each customer has a vector that represents their needs or preferences for different categories of goods in the mall $\underset{p}{\rightarrow}$. In addition, some demographical factors such as gender, age are also considered in the vector influencing customer's shopping strategy.

[63] Merigó, J. M.; Casanovas, M.: Induced Aggregation Operators in the Euclidean Distance and Its Application in Financial Decision Making. Expert Systems with Applicaations. 383(6), 2011, P.7603-7608.

Hence, the customer vector is composed of the preferences for different categories of shops and attributes of the person:

$$\vec{p}=\begin{pmatrix} p_1 \\ p_2 \\ \vdots \\ p_{n-2} \\ p_{n-1} \\ p_n \end{pmatrix}=\begin{pmatrix} preference\ for\ fast\ food \\ preference\ for\ gastronomy \\ \vdots \\ preference\ for\ toilet \\ age \\ gender \end{pmatrix}$$

Equation 6: Customer Vector

n is the total number of the vector components that considered in the model, including:

p_1: customer's preference for Fast food
p_2: customer's preference for Gastronomy
p_3: customer's preference for Mode
p_4: customer's preference for Bags/Shoes
p_5: customer's preference for Sports/Outdoor
p_6: customer's preference for Jewelry/Gifts
p_7: customer's preference for Electronic/Telecommunication
p_8: customer's preference for Beauty/Health/Optic
p_9: customer's preference for Books
p_{10}: customer's preference for Service
p_{11}: customer's preference for Groceries
p_{12}: customer's preference for Department Store
p_{13}: customer's preference for Toilet
p_{14}: Age, attribute assigned to the customer
p_{15}: Gender, attribute assigned to the customer.

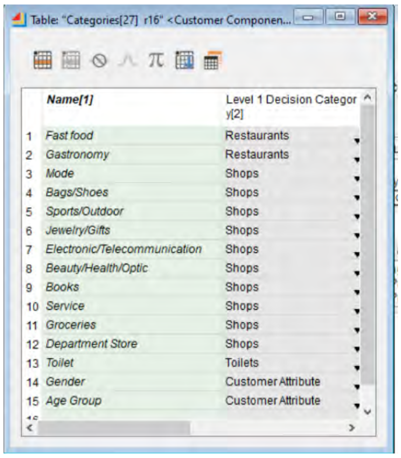


Table: "Categories[27] r16" <Customer Componen...

	Name[1]	Level 1 Decision Category[2]
1	Fast food	Restaurants
2	Gastronomy	Restaurants
3	Mode	Shops
4	Bags/Shoes	Shops
5	Sports/Outdoor	Shops
6	Jewelry/Gifts	Shops
7	Electronic/Telecommunication	Shops
8	Beauty/Health/Optic	Shops
9	Books	Shops
10	Service	Shops
11	Groceries	Shops
12	Department Store	Shops
13	Toilet	Toilets
14	Gender	Customer Attribute
15	Age Group	Customer Attribute

Figure 6-8: Vector parameters in DB

6.3.1.2 Shop Vector $\vec{q}$

Each shop has a vector $\vec{q}$ describing to what extent the shop will meet the need of the customer or is similar to what a customer expected.

As different shops have different target consumer group, for example, Douglas, as a cosmetic store, aims at young to middle age female customers rather than male customers. H&M Men are, on the other hand, positioned as men-oriented, whereas grocery shops and restaurants have little difference in target customer groups regarding their age or gender.
Hence, the shop vector is described as follow:

$$\vec{q}=\begin{pmatrix} q_1 \\ q_2 \\ \vdots \\ q_{n-2} \\ q_{n-1} \\ q_n \end{pmatrix}=\begin{pmatrix} supply\ for\ Fast\ food \\ supply\ for\ gastronomy \\ \vdots \\ supply\ for\ toilet \\ age \\ gender \end{pmatrix}$$

Equation 7: Shop Vector

q_1: customer's preference for Fast food
q_2: customer's preference for Gastronomy
q_3: customer's preference for Mode
q_4: customer's preference for Bags/Shoes
q_5: customer's preference for Sports/Outdoor
q_6: customer's preference for Jewelry/Gifts
q_7: customer's preference for Electronic/Telecommunication
q_8: customer's preference for Beauty/Health/Optic
q_9: customer's preference for Books
q_{10}: customer's preference for Service
q_{11}: customer's preference for Groceries
q_{12}: customer's preference for Department Store
q_{13}: customer's preference for Toilet
q_{14}: Age, target age group of the shop
q_{15}: Gender, target gender group of the shop

6.3.2 Initialization of Parameter Values

6.3.2.1 Parameter Values of Customer Vector

After the determination of the factors in the *customer vector,* the next step is to assign values to the vector.

Preference value for different types of shop
According to *central limit theorem* (**CLT**), when independent random variables are added, their properly normalized sum tends toward a normal distribution, as there are a large number of customers visiting the mall, their preferences are seen as independent variables and follow a normal distribution in the model.

As to the mean value and standard deviation value of the normal distribution of each preference, they are based on research and convey conducted by many scholars. For example, a survey was conducted by Hu and Jasper, when a customer asked "What kind of shops do you visit most often in malls?" the most visited by our respondents is, by far, the department stores, mentioned by 20 out of 24 respondents. Second is clothing specialty stores (11 out of 24 respondents), followed by craft stores and book stores (4 out of 24 respondents). [64]

Additionally, another questionnaire was finished by Widiyani in a shopping mall. The results are listed in Figure 6-9 below. The number of different types of shops visited, which refers to the customer preference for different types of shops.

[64] Hu, Haiyan; Jasper, Cynthia R.: A Qualitative Study of Mall Shopping Behaviors of MatureConsumers. Journal of Shopping Center Research. 2007, P.28.

Type of stores	Number of visits	%
Apparel-and-accessories	472	24.04
Media-and-special interest	226	11.51
Health-beauty	96	4.89
General-merchandise*	177	9.02
Food	308	15.69
Furnishing	67	3.41
Eating-places	479	24.4
Entertainment-and-education	138	7.03
Size	1963	100

* LM has no general-merchandise stores

Type of facilities	Number of visits	%
Financial	180	27.03
Public service	486	72.97

Figure 6-9: Types of Stores and Facilities Visited (N=670)[65]

Based on the statistics and shopping experience, the mean value and standard deviation of the distribution are determined in the table below:

Table 6-2: Initialization of preference value

p_i	***description***	***[Distribution; mean; Std. dev.]***
p_1	customer's preference for Fast food	[Normal;0.2;0.35]
p_2	customer's preference for Gastronomy	[Normal;0.1;0.35]
p_3	customer's preference for Mode	[Normal;0.7;0.25]
p_4	customer's preference for Bags/Shoes	[Normal;0.6;0.3]
p_5	customer's preference for Sports/Outdoor	[Normal;0.65;0.2]
p_6	customer's preference for Jewelry/Gifts	[Normal;0.4;0.3]
p_7	customer's preference for Electronic/Telecommunication	[Normal;0.5;0.3]
p_8	customer's preference for Beauty/Health/Optic	[Normal;0.65;0.2]
p_9	customer's preference for Books	[Normal;0.4;0.3]
p_{10}	customer's preference for Service	[Normal;0.4;0.3]
p_{11}	customer's preference for Groceries	[Normal;0.65;0.2]

65 Widiyani: Shopping Behavior in Malls. Eindoven: Technische Universiteit Eindhoven. 2018, P. 108.

p_{12}	customer's preference for Department Store	[Normal;0.65;0.25]
p_{13}	Need for Toilet	[Normal;0.1;0.3]
p_{14}	Age	Given probability
p_{15}	Gender	Given probability

From p_1 to p_{13} are the preferences for each type of store as well as the need for toilet. All values range from 0 to 1. Each customer is assigned with a random value of preference for a particular shop category upon arrival. A bigger mean value indicates that most customers will have more preference for that type of store and vice versa. The standard deviation means how different customer's preferences are from each other. For example, the initial value of preference for gastronomy follows a normal distribution with a mean value of 0.1 and Std. Dev of 0.35, the distribution graph is shown in Figure 6-10.

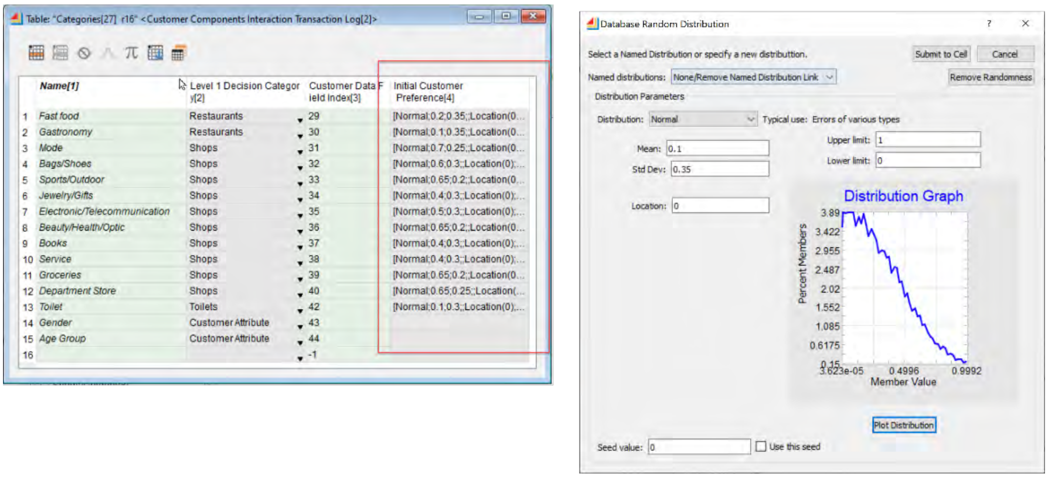


Figure 6-10: Initial value of Customer Preference for each store category

Initial Value of Attributes

-Age Parameter

According to Table 3-2, Uniform Real describes a real value that is likely to fall anywhere within a specified range. As known, age groups are divided into four groups that range from 19 to 60+. As the values are always limited within 0-1. Assume age from 0 to100 accords with a value from 0.1 to 1. Use a Uniform Real distribution, with minimum and maximum value according to the age range. For example, in Figure 6-11, customers from 16 to 29 years old, are having an initial value assigned randomly from 0.16 to 0.29.

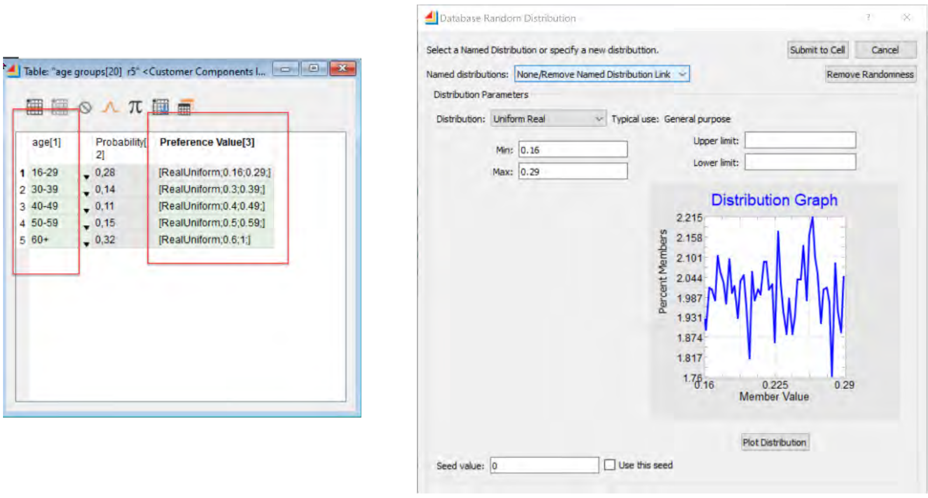


Figure 6-11: Value Assignment of Age Parameter

-Gender Parameter

Set female equals 0 and male 1. When a man arrives, he gets a value of 1 in the vector.

Customer Vector Values in the DB

A table with the required fields for Customer Vector is auto-generated by adding logic to the corresponding Equation block, and the values of records can also be randomly populated dynamically based on the determined distribution (see Figure 6-12).

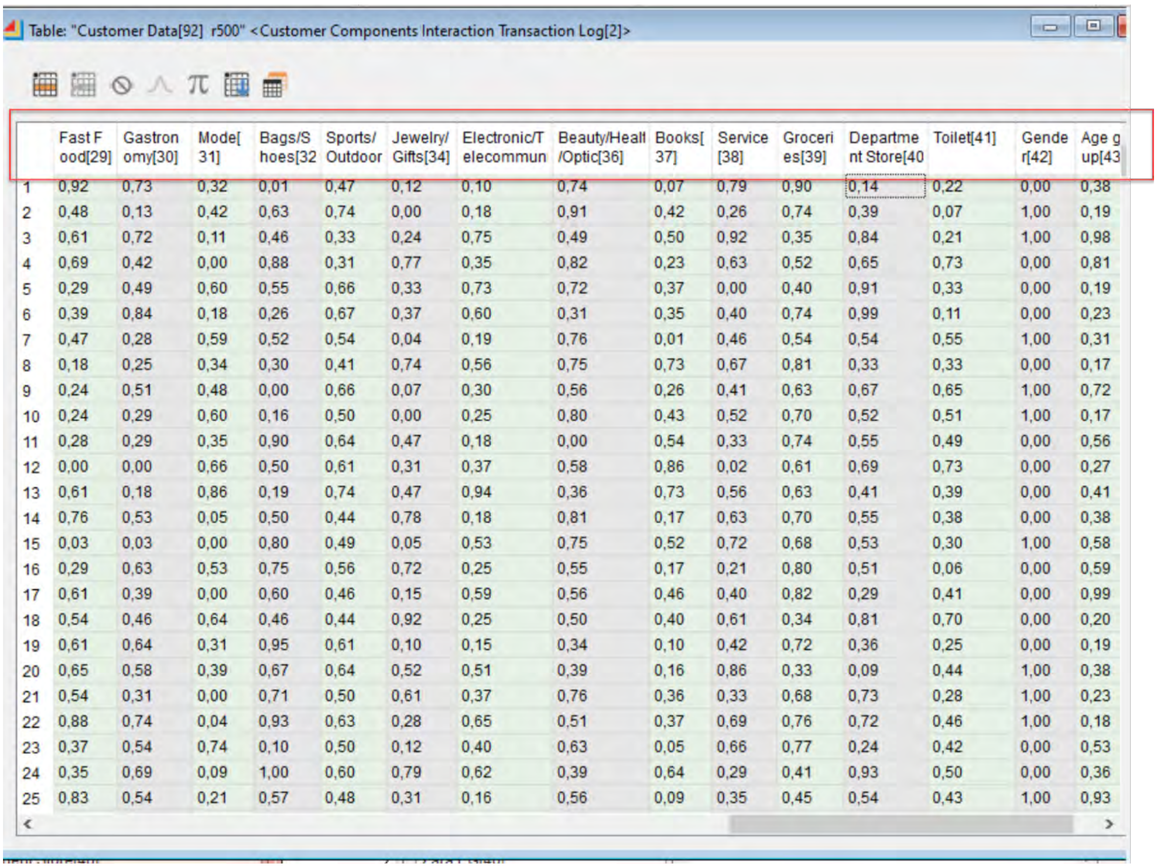


Table: "Customer Data[92] r500" <Customer Components Interaction Transaction Log[2]>

	Fast Food[29]	Gastronomy[30]	Mode[31]	Bags/Shoes[32	Sports/Outdoor	Jewelry/Gifts[34]	Electronic/Telecommun	Beauty/Healt/Optic[36]	Books[37]	Service[38]	Groceries[39]	Department Store[40	Toilet[41]	Gender[42]	Age group[43
1	0,92	0,73	0,32	0,01	0,47	0,12	0,10	0,74	0,07	0,79	0,90	0,14	0,22	0,00	0,38
2	0,48	0,13	0,42	0,63	0,74	0,00	0,18	0,91	0,42	0,26	0,74	0,39	0,07	1,00	0,19
3	0,61	0,72	0,11	0,46	0,33	0,24	0,75	0,49	0,50	0,92	0,35	0,84	0,21	1,00	0,98
4	0,69	0,42	0,00	0,88	0,31	0,77	0,35	0,82	0,23	0,63	0,52	0,65	0,73	0,00	0,81
5	0,29	0,49	0,60	0,55	0,66	0,33	0,73	0,72	0,37	0,00	0,40	0,91	0,33	0,00	0,19
6	0,39	0,84	0,18	0,26	0,67	0,37	0,60	0,31	0,35	0,40	0,74	0,99	0,11	0,00	0,23
7	0,47	0,28	0,59	0,52	0,54	0,04	0,19	0,76	0,01	0,46	0,54	0,54	0,55	1,00	0,31
8	0,18	0,25	0,34	0,30	0,41	0,74	0,56	0,75	0,73	0,67	0,81	0,33	0,33	0,00	0,17
9	0,24	0,51	0,48	0,00	0,66	0,07	0,30	0,56	0,26	0,41	0,63	0,67	0,65	1,00	0,72
10	0,24	0,29	0,60	0,16	0,50	0,00	0,25	0,80	0,43	0,52	0,70	0,52	0,51	1,00	0,17
11	0,28	0,29	0,35	0,90	0,64	0,47	0,18	0,00	0,54	0,33	0,74	0,55	0,49	0,00	0,56
12	0,00	0,00	0,66	0,50	0,61	0,31	0,37	0,58	0,86	0,02	0,61	0,69	0,73	0,00	0,27
13	0,61	0,18	0,86	0,19	0,74	0,47	0,94	0,36	0,73	0,56	0,63	0,41	0,39	0,00	0,41
14	0,76	0,53	0,05	0,50	0,44	0,78	0,18	0,81	0,17	0,63	0,70	0,55	0,38	0,00	0,38
15	0,03	0,03	0,00	0,80	0,49	0,05	0,53	0,75	0,52	0,72	0,68	0,53	0,30	1,00	0,58
16	0,29	0,63	0,53	0,75	0,56	0,72	0,25	0,55	0,17	0,21	0,80	0,51	0,06	0,00	0,59
17	0,61	0,39	0,00	0,60	0,46	0,15	0,59	0,56	0,46	0,40	0,82	0,29	0,41	0,00	0,99
18	0,54	0,46	0,64	0,46	0,44	0,92	0,25	0,50	0,40	0,61	0,34	0,81	0,70	0,00	0,20
19	0,61	0,64	0,31	0,95	0,61	0,10	0,15	0,34	0,10	0,42	0,72	0,36	0,25	0,00	0,19
20	0,65	0,58	0,39	0,67	0,64	0,52	0,51	0,39	0,16	0,86	0,33	0,09	0,44	1,00	0,38
21	0,54	0,31	0,00	0,71	0,50	0,61	0,37	0,76	0,36	0,33	0,68	0,73	0,28	1,00	0,23
22	0,88	0,74	0,04	0,93	0,63	0,28	0,65	0,51	0,37	0,69	0,76	0,72	0,46	1,00	0,18
23	0,37	0,54	0,74	0,10	0,50	0,12	0,40	0,63	0,05	0,66	0,77	0,24	0,42	0,00	0,53
24	0,35	0,69	0,09	1,00	0,60	0,79	0,62	0,39	0,64	0,29	0,41	0,93	0,50	0,00	0,36
25	0,83	0,54	0,21	0,57	0,48	0,31	0,16	0,56	0,09	0,35	0,45	0,54	0,43	1,00	0,93

Figure 6-12: Customer Vector Table in DB

6.3.2.2 Parameter Values of Shop Vector

q_i is the value that indicates to which extent the shop can meet customer's preferences. The value of this parameter will be either 0 or 1. Only the preference for the specific category to which the shop belongs gets a value of 1. Otherwise, the value equals 0. For most of the shops in the mall, they only provide specific categories of goods except department stores such as Galeria, Karstadt. However, this might cause that the department store is always with a higher Euclidean Distance result which is not realistic. Hence, each category shall be considered separately in a department store, and only the one with the smallest value will be selected and compared to the results of other shops for the final decision.

e.g., dm belongs to category Beauty/health, therefore only q_8 equals 1; set age group with a value of 0.3, and gender value to be 0.3, meaning DM tends to slightly attract more female customers around 30 years old. The value depends on the positioning of the target consumer group of the store.

$$\overrightarrow{q^{dm}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.3 \\ 0.3 \end{pmatrix}$$

Equation 8: An example of Shop Vector of DM

Table: "Shops Vectors[94] r107" <Customer Components Interaction Transaction Log[2]>

	Shops Vector Components ID[1]	Shops[2]	Type of Shop[3]	Fast Food[4]	Gastronomy[5]	Mode[6]	Bags/Shoes[7]	Sports/Outd… r[8]	Jewelry/Gifts [9]	Electronic/Te… mmunicatio…	Beauty/Healt… /Optic[11]	Books[12]	Service[13]	Groceries [14]	Department Store[15]	Toilet[16]
1	SV_dm	dm	Beauty/He…	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00
2	SV_Deichmann	Deichmann	Bags/Shoes	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	SV_H&M	H&M	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	SV_foot locker	foot locker	Sports/Ou…	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5	SV_timberland	timberland	Bags/Shoes	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	SV_douglas	douglas	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
7	SV_Hallhuber	Hallhuber	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
8	SV_street one	street one	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
9	SV_Herzog & Br…	Herzog & Bräuer	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10	SV_Bel Hair	Bel Hair	Service	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
11	SV_Jewelier Chr…	Jewelier Christ…	Jewelry/Gifts	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12	SV_Swarovski	Swarovski	Jewelry/Gifts	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13	SV_X-LARGE Pop	X-LARGE Pop	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	SV_Andreas Krebs	Andreas Krebs	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	SV_PUMA	PUMA	Sports/Ou…	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
16	SV_orsay	orsay	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17	SV_Hunkemöller	Hunkemöller	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
18	SV_Tchilo	Tchilo	Groceries	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00
19	SV_Pimkie	Pimkie	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
20	SV_Tally Weijl	Tally Weijl	Mode	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
21	SV_Gamestop	Gamestop	Electronic…	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00
22	SV_Runner's Point	Runner's Point	Sports/Ou…	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23	SV_City Parfüme…	City Parfümerie	Beauty/He…	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00
24	SV_Karstadt	Karstadt	Departme…	0,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	0,00	0,00	1,00	0,00
25	SV_Euroshop	Euroshop	Jewelry/Gifts	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Figure 6-13: Overview of Shops Vector in DB

There are also many other factors that also have impacts on the customer's decision making in their shopping. Due to the limited time, only the parameters above are considered in this model. Other factors could be, for example:

-The rest shopping time
-distance
-income
-Perception of customer and attraction of shop, etc.

6.3.3 Determination of the Next Target Shop

The Decision Logic of selecting a shop to visit from the shops connected to the walkway section where the customer is currently on:

1) Compute the Euclidean Distance of each connected shop
2) Compute the minimum Euclidean Distance of all connected shops
3) Decide if the minimum Euclidean Distance is below the threshold value

6.3.3.1 Euclidean Distance algorithm

$$\text{dist}=\sqrt{\sum_{i=1}^{n}(p_i-q_i)^2}$$

Equation 9: Euclidean distance equation

The option with the minimal Euclidean Distance will be the one selected as the next shopping destination. However, sometimes even the shop with the minimum value does not meet customer's preferences. To avoid this, a threshold value is introduced to help the shopper eliminate the selection when the result is out of the threshold range, the logic in the model is as below:

If Min Euclidean Distance > Max Threshold, do NOT go into shop.

6.3.3.2 Customer Shop History

It is very helpful to record a history of all shops a customer visited and made a purchase in, and for the use of the verification and validation of the finished model in the end, as well as for the further logic in other parts of the model as input variables. The Customer Shop History Table is updated automatically whenever a customer visits a shop, the records include the entry and exit time of a customer visiting a store (see Figure 6-14).

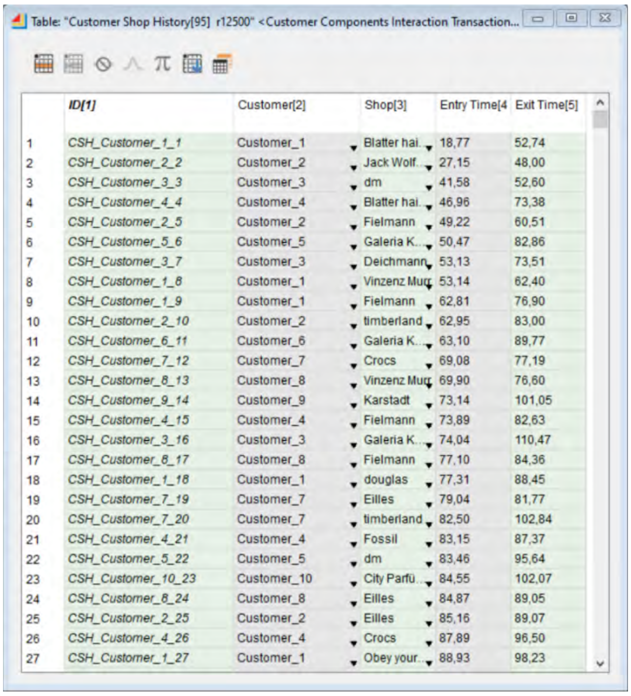


Table: "Customer Shop History[95] r12500" <Customer Components Interaction Transaction...

	ID[1]	Customer[2]	Shop[3]	Entry Time[4	Exit Time[5]
1	CSH_Customer_1_1	Customer_1	Blatter hai...	18,77	52,74
2	CSH_Customer_2_2	Customer_2	Jack Wolf...	27,15	48,00
3	CSH_Customer_3_3	Customer_3	dm	41,58	52,60
4	CSH_Customer_4_4	Customer_4	Blatter hai...	46,96	73,38
5	CSH_Customer_2_5	Customer_2	Fielmann	49,22	60,51
6	CSH_Customer_5_6	Customer_5	Galeria K...	50,47	82,86
7	CSH_Customer_3_7	Customer_3	Deichmann	53,13	73,51
8	CSH_Customer_1_8	Customer_1	Vinzenz Murr	53,14	62,40
9	CSH_Customer_1_9	Customer_1	Fielmann	62,81	76,90
10	CSH_Customer_2_10	Customer_2	timberland	62,95	83,00
11	CSH_Customer_6_11	Customer_6	Galeria K...	63,10	89,77
12	CSH_Customer_7_12	Customer_7	Crocs	69,08	77,19
13	CSH_Customer_8_13	Customer_8	Vinzenz Murr	69,90	76,60
14	CSH_Customer_9_14	Customer_9	Karstadt	73,14	101,05
15	CSH_Customer_4_15	Customer_4	Fielmann	73,89	82,63
16	CSH_Customer_3_16	Customer_3	Galeria K...	74,04	110,47
17	CSH_Customer_8_17	Customer_8	Fielmann	77,10	84,36
18	CSH_Customer_1_18	Customer_1	douglas	77,31	88,45
19	CSH_Customer_7_19	Customer_7	Eilles	79,04	81,77
20	CSH_Customer_7_20	Customer_7	timberland	82,50	102,84
21	CSH_Customer_4_21	Customer_4	Fossil	83,15	87,37
22	CSH_Customer_5_22	Customer_5	dm	83,46	95,64
23	CSH_Customer_10_23	Customer_10	City Parfü...	84,55	102,07
24	CSH_Customer_8_24	Customer_8	Eilles	84,87	89,05
25	CSH_Customer_2_25	Customer_2	Eilles	85,16	89,07
26	CSH_Customer_4_26	Customer_4	Crocs	87,89	96,50
27	CSH_Customer_1_27	Customer_1	Obey your...	88,93	98,23

Figure 6-14: Table of Customer Shop History in Database

6.4 Dynamic Parameter of Vector $\underset{P}{\rightarrow}$

In the process of shopping, vector *p* and *q* will be updated based on their shopping history and customer strategies. Some of the vector components p_i and q_i are changing dynamically with different strategies over time.

6.4.1 Dynamic Update of Preference for Toilet

Vector components are dynamically changing during the simulation run. This is due to the customer's strategy in the shopping mall. For instance, if the need for toilets dominates other needs, customers will go straight forward to a toilet without considering other selections. After the use of the toilet, the need for using toilets will be reset to 0 and slowly increase over time when the customer continues to shop. The last visit to a toilet is recorded in DB, and a preference increment formula is programmed in the Equation Block:

Δ(Toilet preference difference)=(current time-last use time)/toilet preference numerator
Which can be described as:

$$\Delta y=(t-t_0)/x$$

Δy	increment of need for toilet
x	variable parameter controlling
t	current time
t_0	the last time using toilet

Equation 10: Toilet preference increment

This means when the current time is equal to last use time, the preference is reset to 0, the increment increases over time until the preference reaches the maximal value again, and so on.

6.4.2 Dynamic Update of Preference for Restaurants

Similarly, the preference for restaurants changes with the same logic, with the preference value reset to 0 after eating, then the need for food increases again over time as follow:

$$\Delta y=(t-t_0)/x$$

Δy	restaurant preference increment
x	variable parameter controlling
t	current time
t_0	the last time eating in a restaurant

Equation 11: Food preference increment

6.4.3 Dynamic Update of Preference for Different Categories Shops

A parameter called "preference drop after purchase" is defined, indicating that based on the purchase history of the customer, the preference for the specific category will decrease a particular amount depending on the parameter determined of the random distribution. See the figure below.

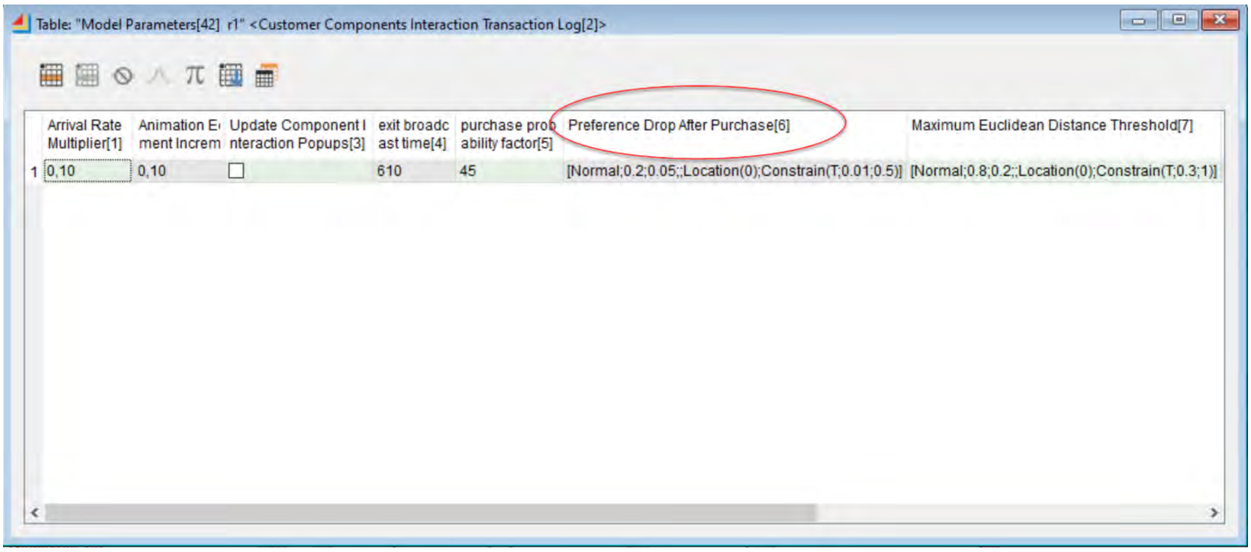


Figure 6-15: Model Parameter Table- Preference Drop after Purchase

7 Quantification of Usage Intensity

After all the logic of the customer’s movement implemented in the model, it is now possible to track the number of uses of building components or building products in the mall.

When a building component or product interacts with a customer in the mall, a record in the table “Components” in DB will be updated accordingly (see Figure 7-1). The component Hblock tracks the interactions that occur for specific components. Each time an item passes through the Component Interaction block, it will increment the usage count by 1 for the record corresponding to a specific component.

In this model, five different types of building components or building products and some special facilities of interest will be recorded, including:

- Use of doors of shops
- Use of elevators
- Use of entrances/exits
- Use of toilets
- Use of walkway sections

Other typical consumable products such as HVAC system and lights in the mall, which are unify controlled by the management center of the shopping mall, are not associated with customer behavior, and therefore not included in the model. The table of all research objects is shown below:

Table 7-1: List of research objects and quantitative uits in the model

Customer activities	Interacted object	Quantitative criteria (unit)
Entering/exiting	Door of entrances/exits	Number of uses/day
Walking on walkway	Walkway sections	People/day
Shopping in a store	Door of each shop	People/day or door open times/day
Taking elevator	Elevator	People/day
Using toilets	Door of toilets	People/day
eating	Door of restaurants	People/day

Notes: Each visit of a customer includes entering and exiting the shop, the number of uses of a door is therefore twice the number of visits.

The Components table in DB recording number of uses of different components is shown in Figure 7-1.

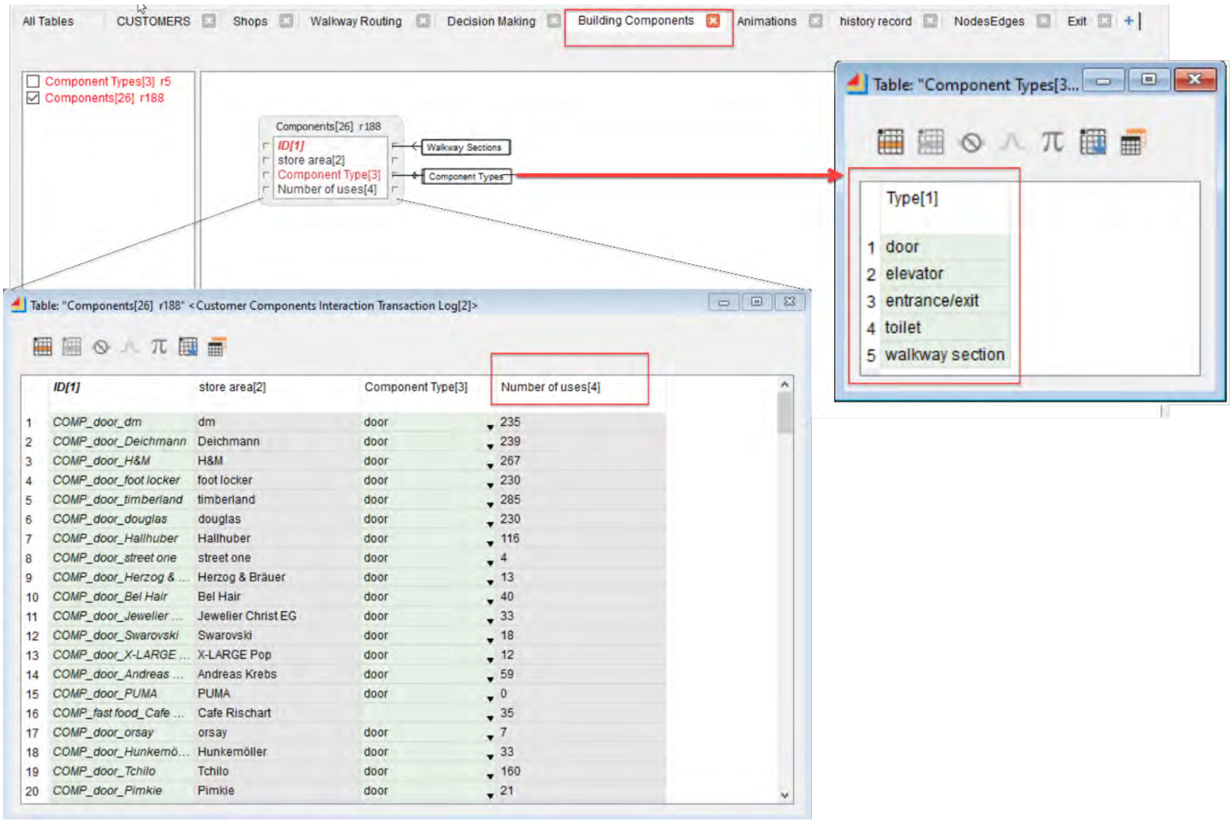


Figure 7-1: Components Table and Component Type Table in Database

7.1 Usage of Doors

Doors are one of the main building products that are frequently used in a shopping mall. Mostly, its frequency of usage depends on the number of visitors. The number of uses is recorded and automatically updated during the simulation run in the Components table, which is related to a parent table Component Type from which the certain components to be recorded can be selected.

The Component Hblock is to track where a specific object is used.

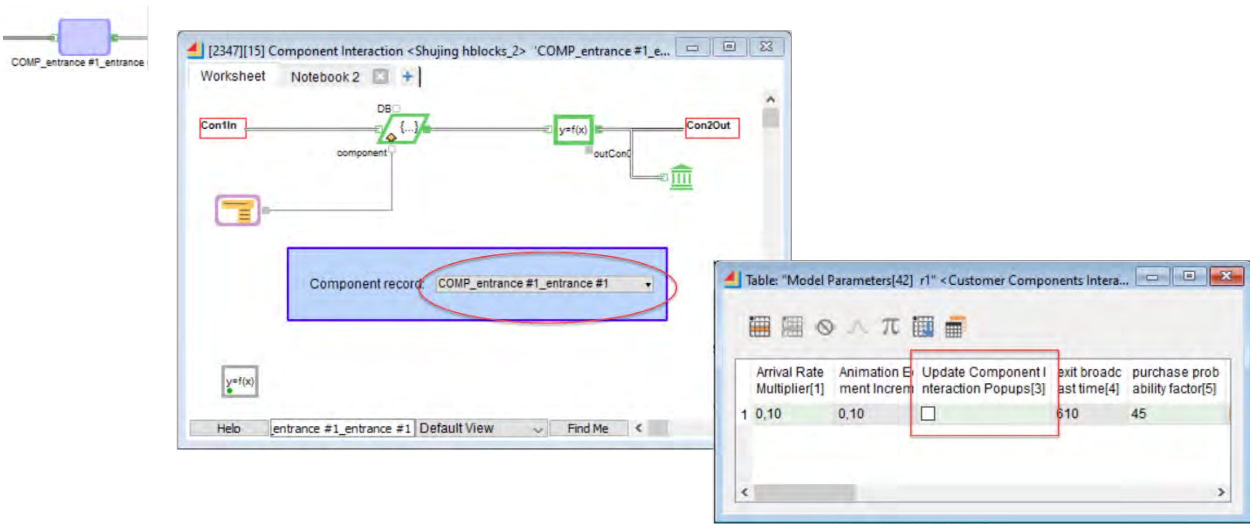


Figure 7-2: Example of Component Hierarchical block with popup menu auto-updated

7.1.1 Usage of Doors of Each Shop

The customer shop visits history is recorded in the database, for example, in the DM shop, the components interaction Hblock is placed at the beginning of the shop's item flow to represent customer's entries and at the end of the shop's item flow to represent customer exits from the shop (see Figure 7-3). Thus, each visit contributes a door use increment of 2.

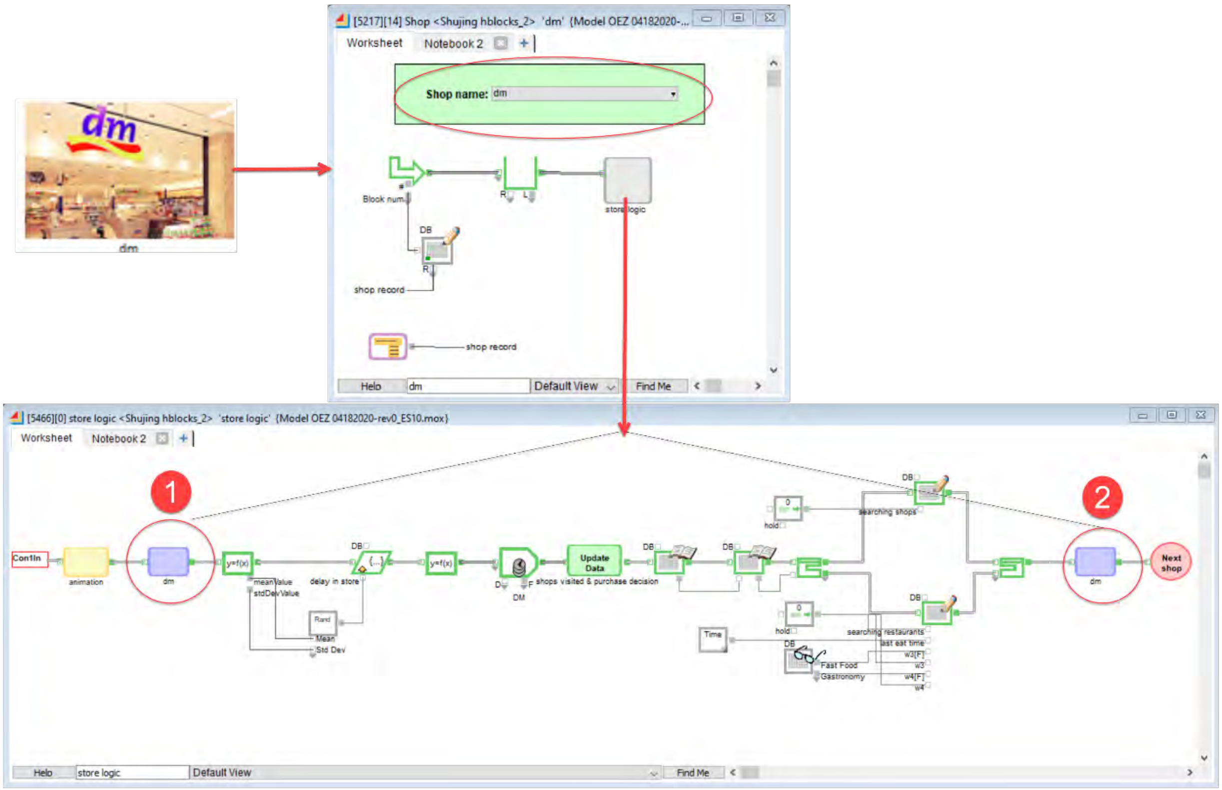


Figure 7-3: Components Hblock in DM as an example

When the customer leaves the current shop and goes to the next destination, it will cause the customer loop through the model to make the next decision (Figure 7-4).

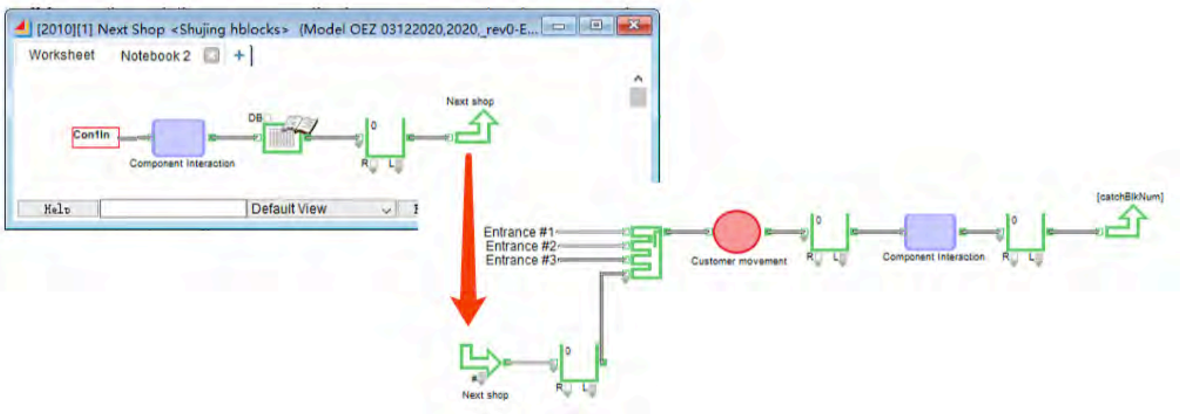


Figure 7-4: Next Shop Hblock

7.1.2 Usage of Entrances/Exits Doors

The three entrances/exits in the model are located respectively in the west, south, and east on the ground floor. As explained in the last section, for the use of the main doors at entrances/exits, the same Components Interaction Hblocks is set after the Create Block. As presented in the following figure, the number of uses of Entrance doors in the Database is updated whenever a customer arrives at a certain Entrance.

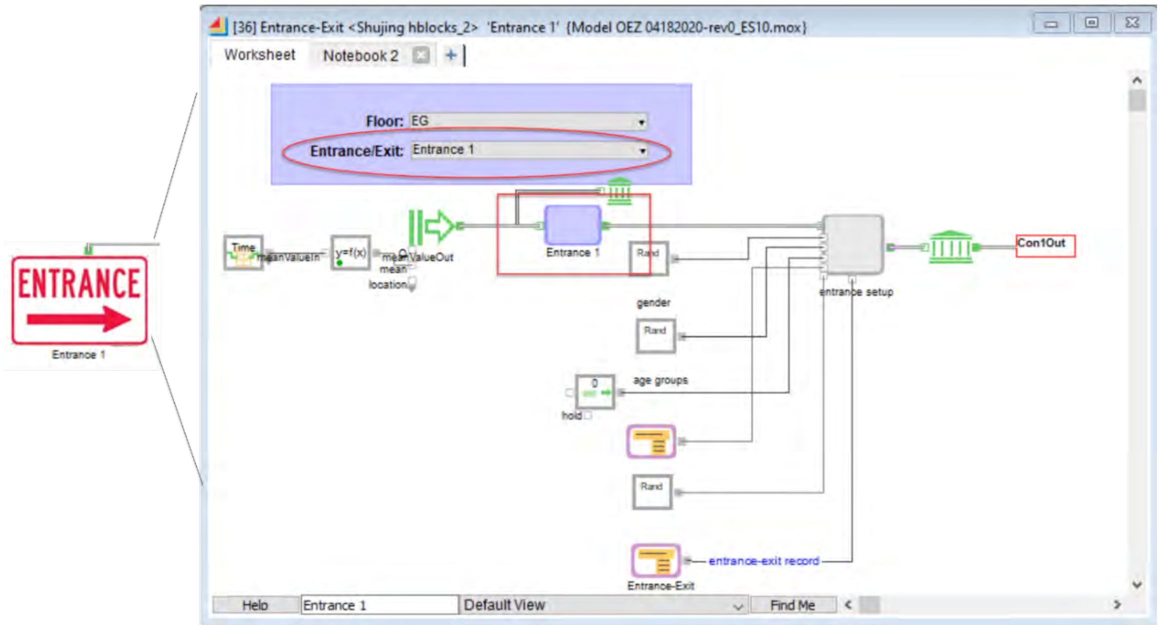


Figure 7-5: Entrance Door Usage

7.2 Usage of Elevator

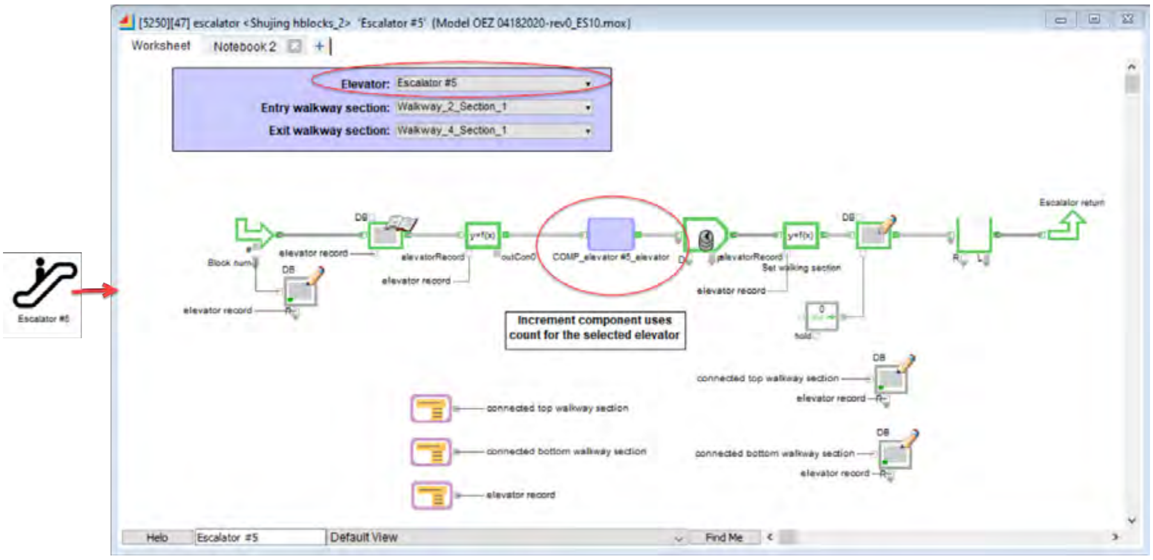


Figure 7-6: Usage of Elevator

7.3 Usage of HVAC

HVAC system is centralized managed by the mall management center, the run time of the HVAC system in the mall is consistent with the opening time of the shopping mall. From 9:30 to 20:00.

7.4 Usage of Floor

In addition to the record of door use of each shop and other equipment, the usage intensity of each walkway section is also automatically populated by tracking each customer's shopping history and walking path instead of using the Component Hblock as other building components.

7.5 Simulation Run and Results

7.5.1 Simulation Run

After building and testing the model with ExtendSim blocks, the simulation time and the granularity of the results need to be set for the simulation run. Simulation time is an abstraction of real time. Depends on the size and complexity of the model the simulation time varies from each other. As the simulation clock advances, the model translates the model block logic, database content and relations, executes the resulting dynamic system behavior and outputs the results. If the model is valid, the outputs of the simulation will reflect the performance or behaviour of the real system as expected.[66]

[66] Imagine That Inc: ExtendSim User Reference. Ausgabe 2020, S. 6.

7.5.2 Export Table data

Data Import Export block enables to transfer data between internal and external data sources and targets, by simply specifying the data source needed from the DB and the target file, for example, an Excel spreadsheet (see Figure 7-7). The Exel file will be automatically opened to import data when the model runs and export data when the simulation run finishes.

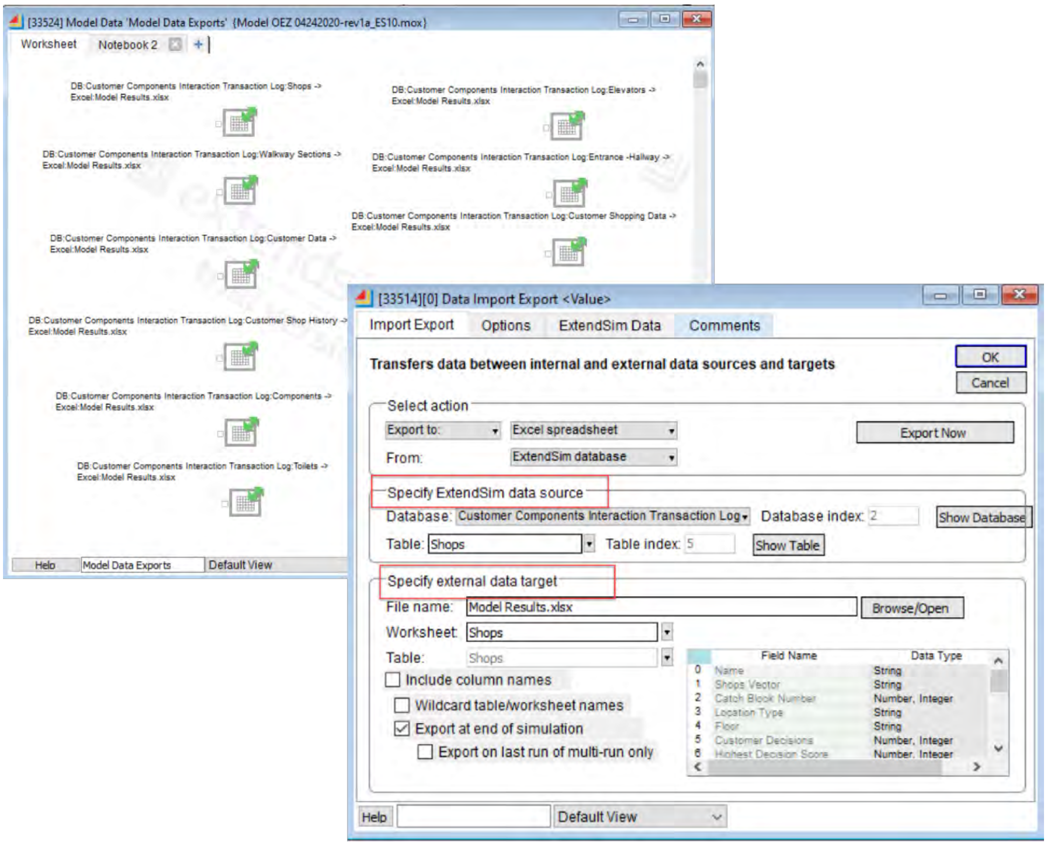


Figure 7-7: Model Data Hblock for Exporting data to Exel spreadsheet

7.5.3 Parameters and Simulation Results

To observe the results more ealily, a chart block is used to graphically plot high level results generated during the simulation run. The simulation results are based on all the assumptions and input variables explained in previous chapters and are listed in the following tables in this section. These variables are named “original variables”. The results of different scenarios with different input variables shall be compared with the simulation results using original variables.

7.5.3.1 Input variables

-TBA

Table 7-2: Input variables of TBA of Entrances

Time	Entrance 1	Entrance 2	Entrance 3
/	Interval(min)	Interval(min)	Interval(min)
9:30-11:00	0.2	0.5	0.5
11:00-14:00	0.02	0.02	0.035
14:00-17:00	0.04	0.07	0.07

17:00-18:00	0.03	0.05	0.05
18:00-19:40	2	2	2
19:40-20:00	-	-	-

-Age

Table 7-3: Input variables of age groups distribution

age	probability
16-29	0.28
30-39	0.14
40-49	0.11
50-59	0.15
60+	0.32

-Gender

Table 7-4: Input variables of gender distribution

gender	probability
female	0.52
male	0.48

-Other parameters

Table 7-5: Other important model parameters

Parameter	distribution		values
Max. shopping time	Triangular	(Min;max;most likely)	(30;360;120)
Max.shop visited	Triangular	(Min;max;most likely)	(3;20;5)
Interarrival multiplier	/	constant	0.1
ED threshold	Normal	(Mean;Std.Dev.)	(0.8;0.2)
Exit broadcast time	/	constant	610
Toilet preference numerator	/	constant	30000
Restaurant preference numerator	/	constant	20000
Delay in each shop	Normal	(Mean;Std.Dev.)	See Shops Table

7.5.4 Simulation Results

Given the input variables and two different model runs, the results plotter (a) and (b) are shown as follows. Figure 7-8 indicates the plotters of simulation results using a DB Line Chart block and Exel plotter based on the records exported from ExtendSim. The left plotter includes the trace of number of customers in the toilet, on elevator, in shops and the usage of entrances/exits at a point in time.

The high points of total customers in the mall as well as the customer in shops can be found around 14:00. The reason could be the setup of the customer TBA schedule. The distribution of shops visits, namely the door use of each shop has a relatively reasonable distribution based on the order of magnitude and shopping experience.

Figure 7-9 represents the scatter chart of each walkway section, with each walkway in a different color. As can be seen, with a customer traffic of 4000 in the mall, the number of some of the walkway section use are twice the customer traffic, meaning customers pass through some walkway section multiple times. Most of the walkway sections have a number of use over half of the total customer traffic.

Plotters of (b) are showing a similar distribution to (a)

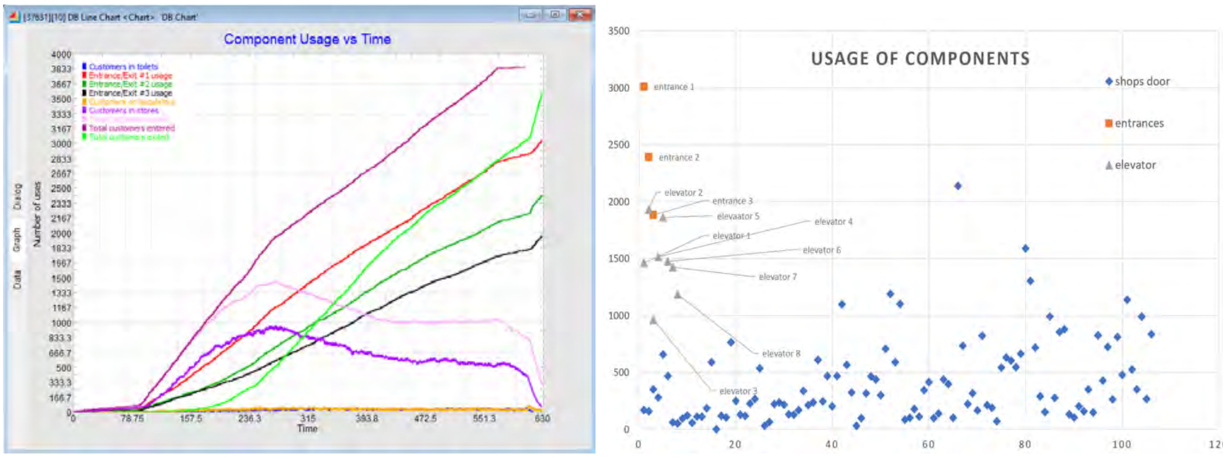


Figure 7-8: (a) Output plotter and shop visits scatter chart(multiplier=0.1, daily customer traffic c.a. 4000 people, Max.ED threshold=Norm(0.8;0.2)

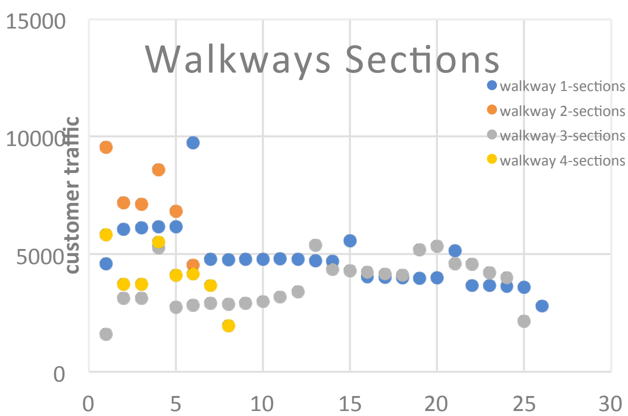


Figure 7-9: (a) Scatter chart of simulation results – Walkways Sections

(b)

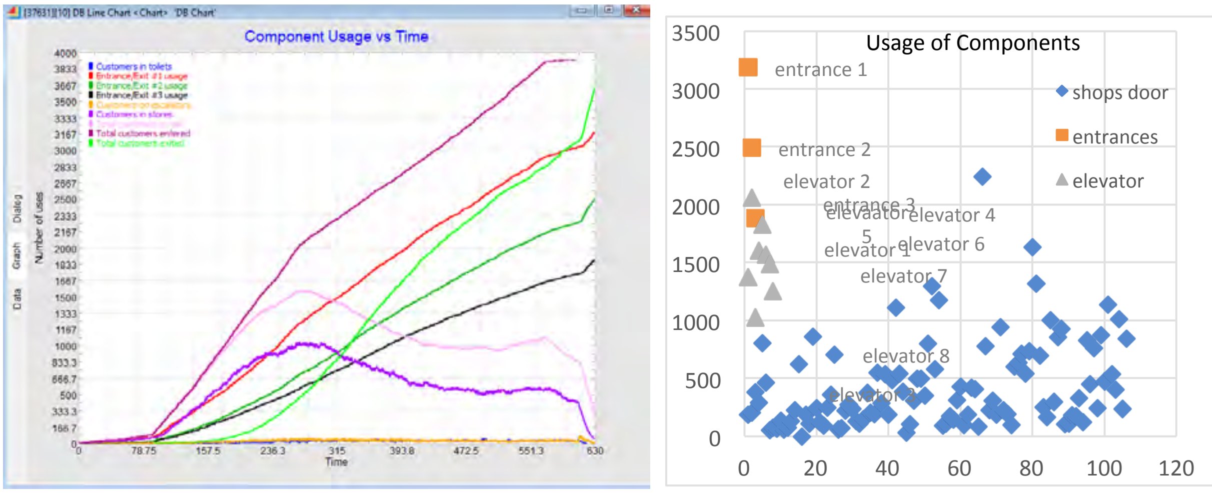


Figure 7-10: (b) Output plotter and shop visits scatter chart(multiplier=0.1, daily customer traffic c.a. 4000 people, Max.ED threshold Norm=(0.8;0.2)

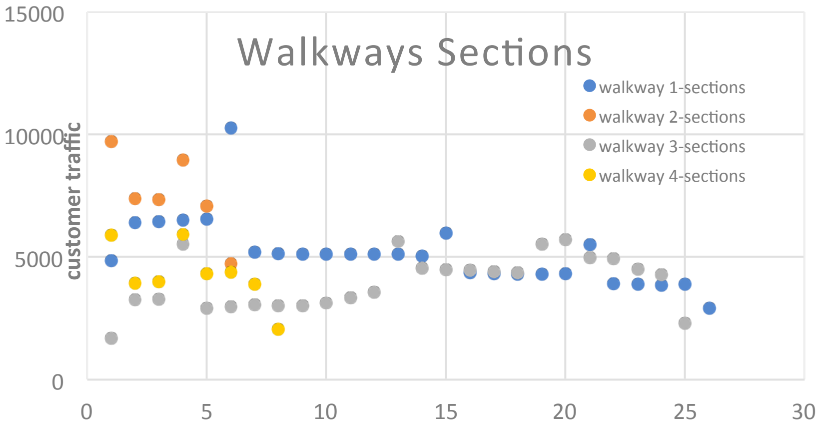


Figure 7-11: (b) Scatter chart of simulation results – Walkways Sections

8 Model Verification and Validation

Model verification is the process of reviewing a model to make sure that all model portions are operating as expected. This could be done by modelling in stages and running the model during the model building process.

8.1 Model Verification and Validation

The verification of the simulation is to compare the model results to what is expected. This is also one of the processes of debugging in ExtendSim. It is a necessary step to detect problems in the model.

8.1.1 Validation process

By analyzing the simulation results in plotters or tables, some problems can be found in the early stage of modelling. For example, after a run, the simulation outputs do not meet the expected results in the real system. Stress test of parameters is necessary and useful to find the factors influencing the result and thus correct the model.

Debugging and model validation can be very time-consuming depends on the complexity of the model. As this model includes a large number of data in the DB, and it has various of logic programmed in several different Equation blocks, which are updated during the debugging process. The final results explained in the last section indicates that this model is now reflecting the outputs relative close to the results expected.

The next section discusses the output analysis that needed to be conducted after the model validation.

9 Simulation Output Analysis

9.1 Terminating Simulation

From the aspect of outputs analysis, discrete event can be divided into terminating simulation and nonterminating simulation. The method to collect outputs data of two different simulations is different. Terminating simulation has a natural endpoint, whereas non-terminating has no obvious end time.

9.2 Output Sensitivity Analysis with Scenario Manager Block

9.2.1 Goal of sensitivity analysis

After gaining the outcome from the simulation run, it is necessary to observe which particular parameters have more impact on model results. Sensitivity analysis enables to investigate the effect of changing one or more parameter values upon an area of interest. Generally, sensitivity analysis is where multi-dimensional scenarios can be explored with different combinations of variables assumed. In this model, the factors that influence the usage intensity of building components, i.e., the customer flow is of interest.

9.2.2 Scenario Manager

9.2.2.1 Scenario Manager Block and Scenario DB

Scenario Manager Block

Scenario analysis provided the possibility to examine the outcome of different model configurations systemically and strategically. ExtendSim facilitates scenario analysis through the Scenario Manager block (Value library) to control all aspects of the analysis, and more importantly, to gain insight into why the system behaves the way it does and how it can be improved and managed.

Scenario DB

When a Scenario Manager block is added to the model, a database named Scenario DB is automatically created and is where the factors and results for the scenarios are stored.

9.2.2.2 Setup Scenario Manager

As seen in Figure 9-1, the Scenario Manager has tabs for Factors, Responses, Scenarios, and Export. It allows referencing either dialogue variables as factors or database factors.

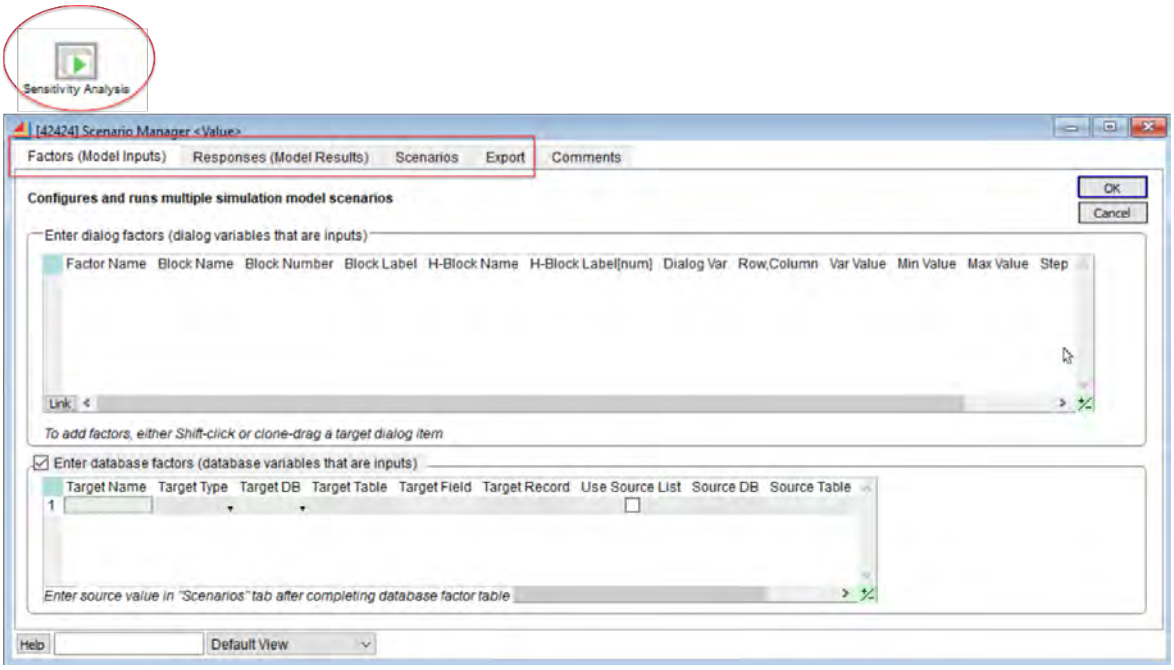


Figure 9-1: Dialogue of Scenario Manager block

9.2.2.2.1 Identification of factors and responses

Factors are the model inputs that are to be included in the analysis. The research goal is to study the usage of building components and building products in the mall, which is directly influenced by the customer levels. Some of the factors in the model are not as important to the outputs. Therefore, only the critical factors are included, as shown in Table 9-1.

The responses are the same as the Components table in DB.

In addition, the third factor - interarrival multiplier can be used as a factor controlling the total customer traffic of a mall, which indirectly represent the scenarios in shopping malls in different scales.

Table 9-1: Factors and Values

No.	Factor		Distribution	Values
1	Max. shopping time	Triangular	(Min;max;most likely)	(30;360;120) (50;390;150) (10;300;90)
2	Max.shops visited	Triangular	(Min;max;most likely)	(3;20;5) (6;40;10) (9;60;15)
3	Interarrival multiplier	/	/	0.05, 0.1, 0.5
4	ED threshold	Normal	(Mean;Std. Dev.)	(0.8;0.2) (0.7;0.15) (0.6;0.1)

To evaluate the possible combinations requires 81 replications, i.e., scenarios (3×3×3×3×3 levels). Each scenario can be run multiple times to capture the variation in the results between two runs. As this model is relatively large and takes over 20 min for each run, therefore, only one run for each scenario will be implemented. Due to the limitations, only part of the scenarios is analyzed.

9.3 Simulation Results Comparison

When the model is running correctly as expected, the last step is to analyze the results after running for one or multiple times as needed.

To investigate the impact of each factor on the outputs, different scenarios are compared and analyzed by changing the parameter values.

9.3.1 Scenario Analysis

9.3.1.1 Factor - Interarrival Multiplier

In this section, scenarios results will be analyzed by changing the interarrival multiplier. The input factors are shown in Table 9-2.

Table 9-2: Values of model factors – Interarival multiplier

Parameter	distribution		values
Max. shopping time	Triangular	(Min;max;most likely)	(30;360;120)
Max.shop visited	Triangular	(Min;max;most likely)	(3;20;5)
Interarrival multiplier	**/**	**constant**	**0.05/0.1/0.7**
ED threshold	Normal	(Mean;Std.Dev.)	(0.8;0.2)

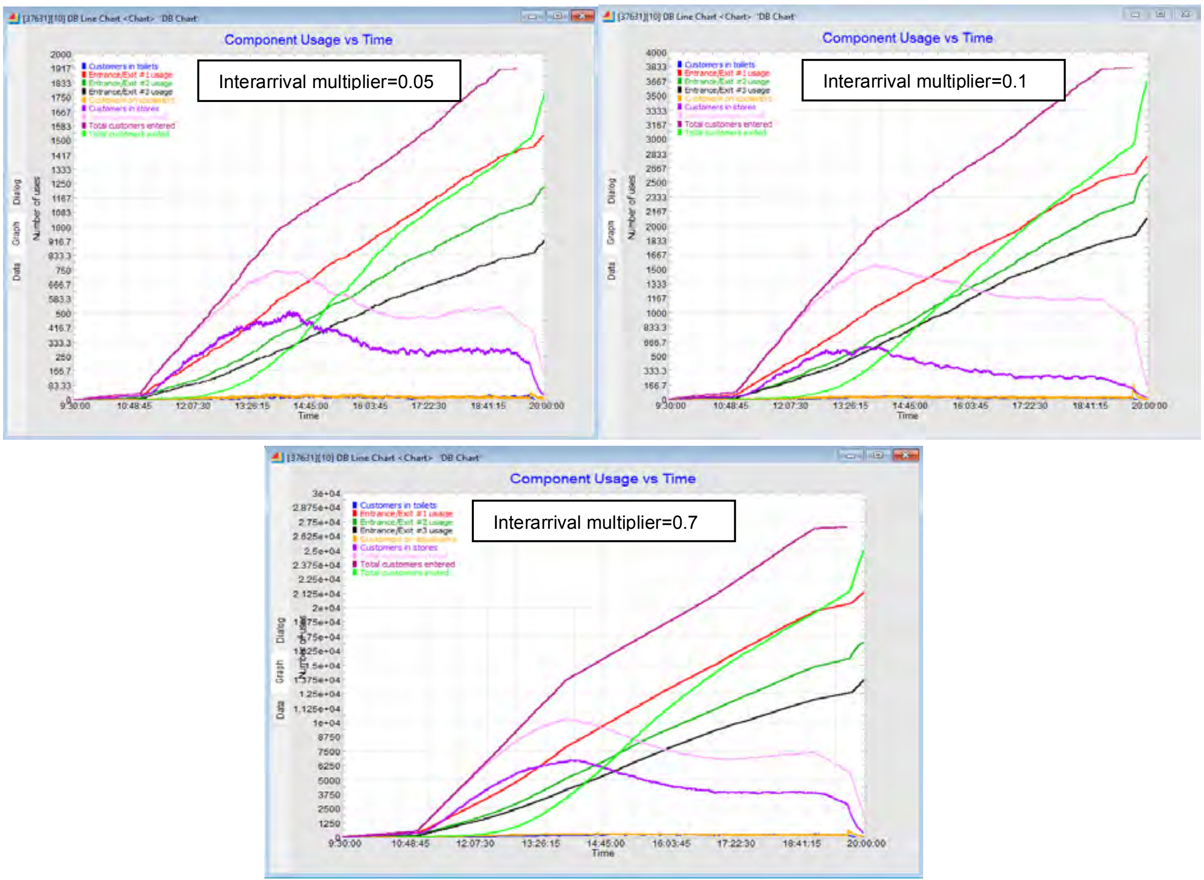


Figure 9-2: Output plotters in ExtendSim comparison(multiplier=0.05/0.1/0.7, max.ED threshold:Norm(0.8;0.2))

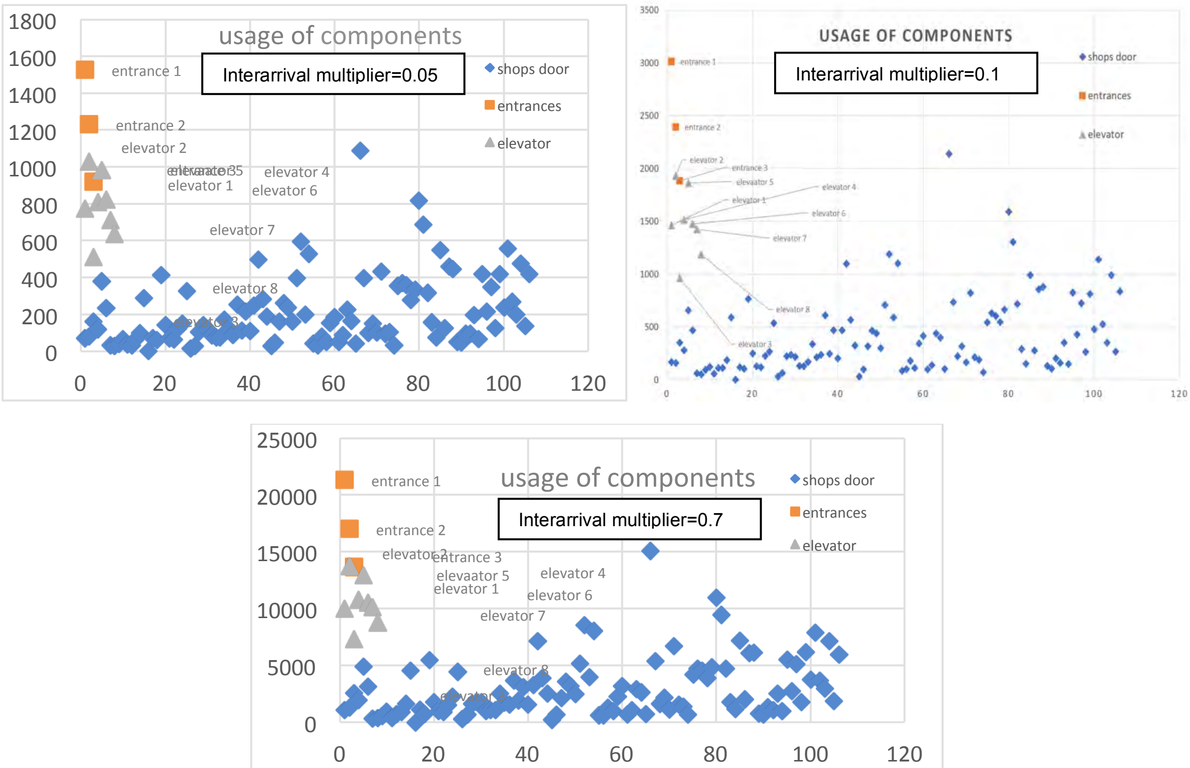


Figure 9-3: Output plotters of components usage comparison(multiplier=0.05/0.1/0.7, max.ED threshold:Norm(0.8;0.2))

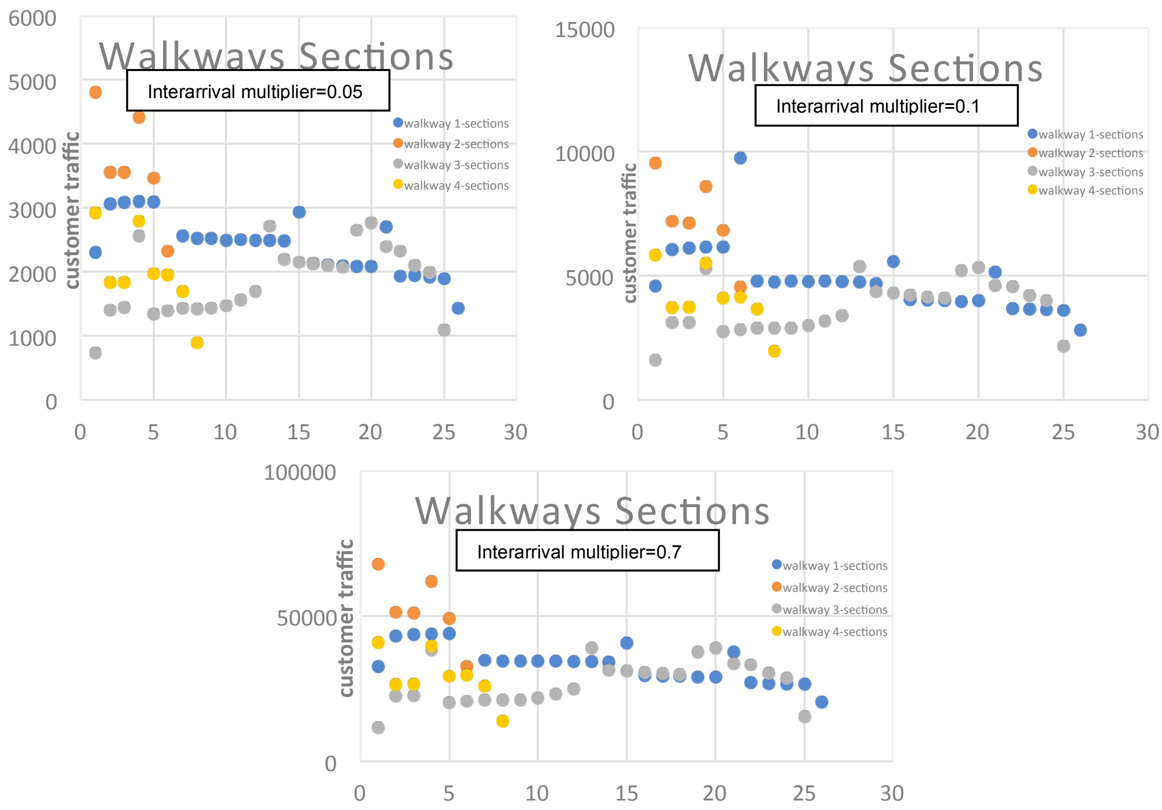


Figure 9-4: Output plotters of walkway usage comparison(multiplier=0.05/0.1/0.7, max.ED threshold:Norm(0.8;0.2))

As can be seen in the figures above, the interarrival multiplier shows a significant impact on the simulation results on the y-axis. The results are following similar curve trends, which indicate that the mall with larger human traffic has a relatively higher shop visit rate compared to the one with much smaller customer flow. It is apparent that the number of customer arrivals in a mall can be one of the most important factors influencing the usage of the objects in the mall.

9.3.1.2 Factor - ED Threshold

To shorten the simulation run, the interarrival multiplier is set to 0.05, and the simulation results from different ED threshold values shall be compared in this section. In Table 9-3 are the input factor values.

Table 9-3: Values of model factors – ED threshold

Parameter	distribution		values
Max. shopping time	Triangular	(Min;max;most likely)	(30;360;120)
Max.shop visited	Triangular	(Min;max;most likely)	(3;20;5)
Interarrival multiplier	/	constant	0.05
ED threshold	**Normal**	**(Mean;Std.Dev.)**	**(0.8;0.2);(0.7,0.15);(0.6,0.1)**

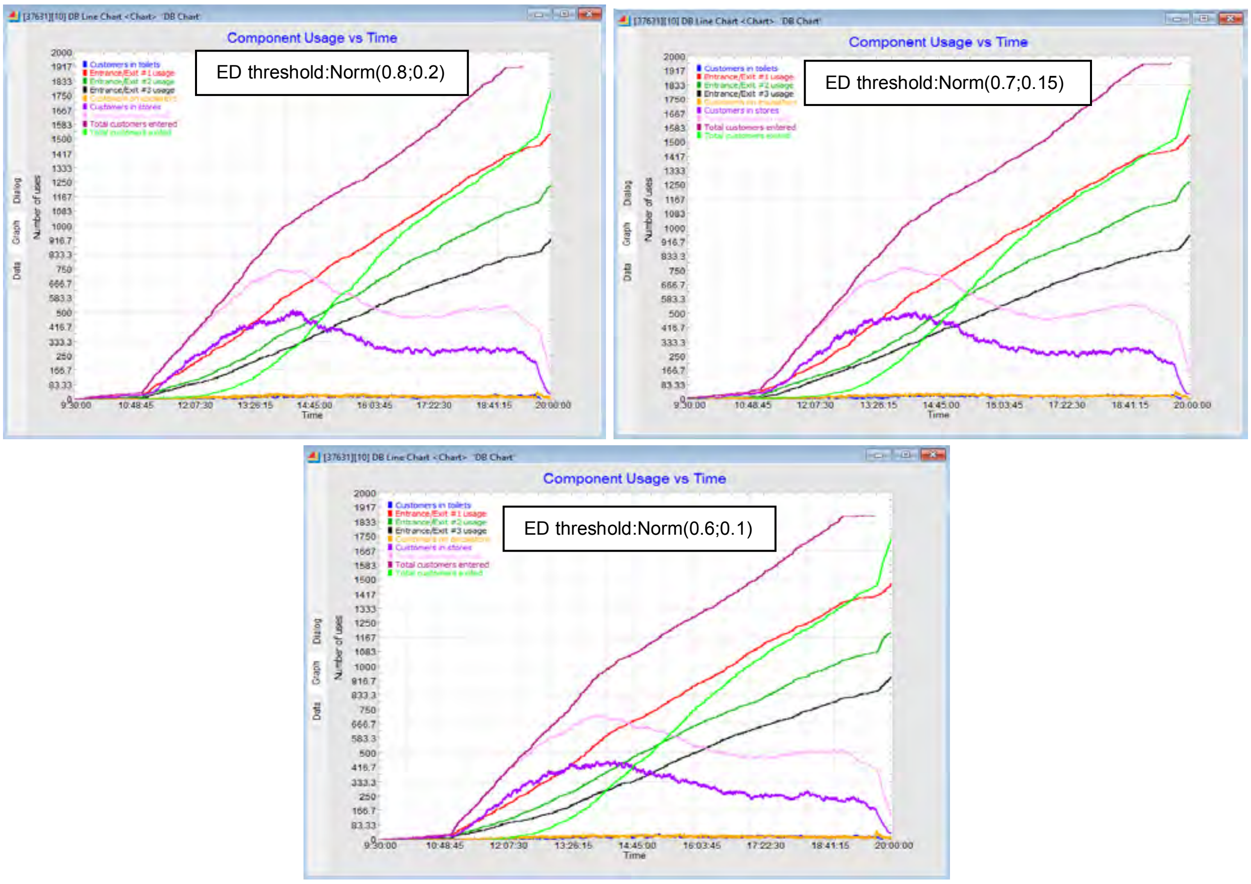


Figure 9-5: Output plotters in ExtenSim comparison(multiplier=0.05, Max.ED threshold=Norm(0.8;0.2)/(0.7,0.15)/(0.6,0.1))

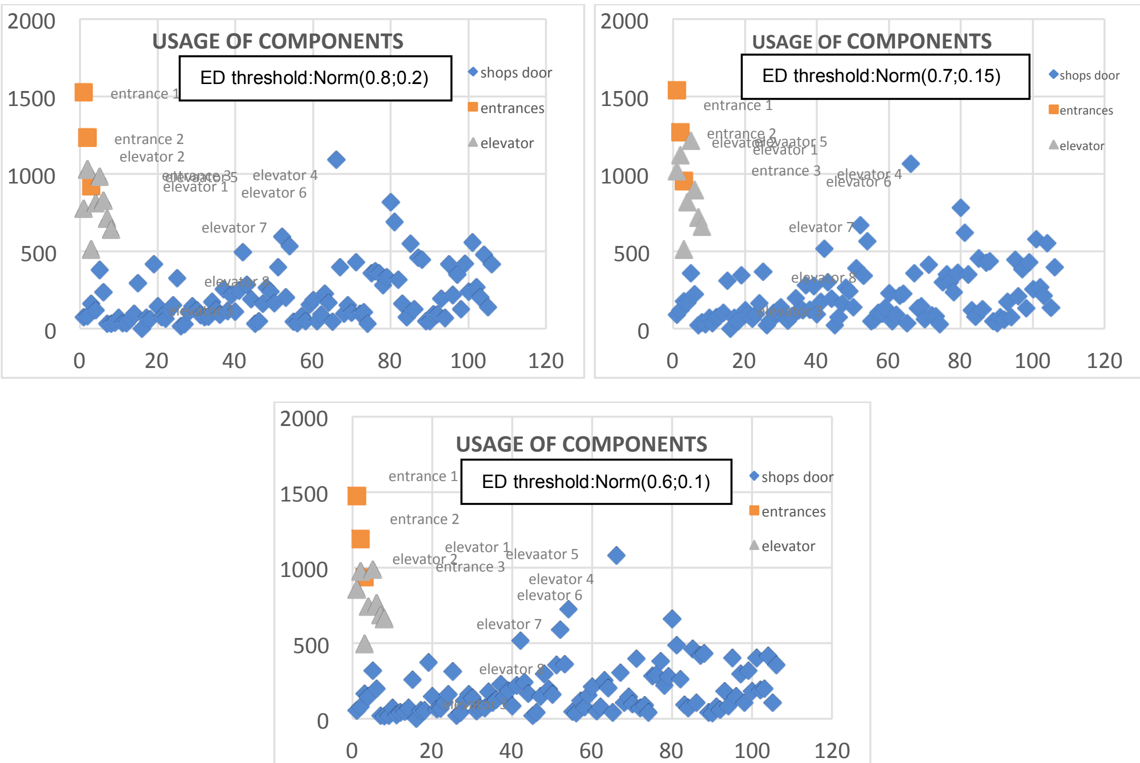


Figure 9-6: Output plotters of components usage comparison (multiplier=0.05, Max.ED threshold=Norm(0.8;0.2)/(0.7,0.15)/(0.6,0.1))

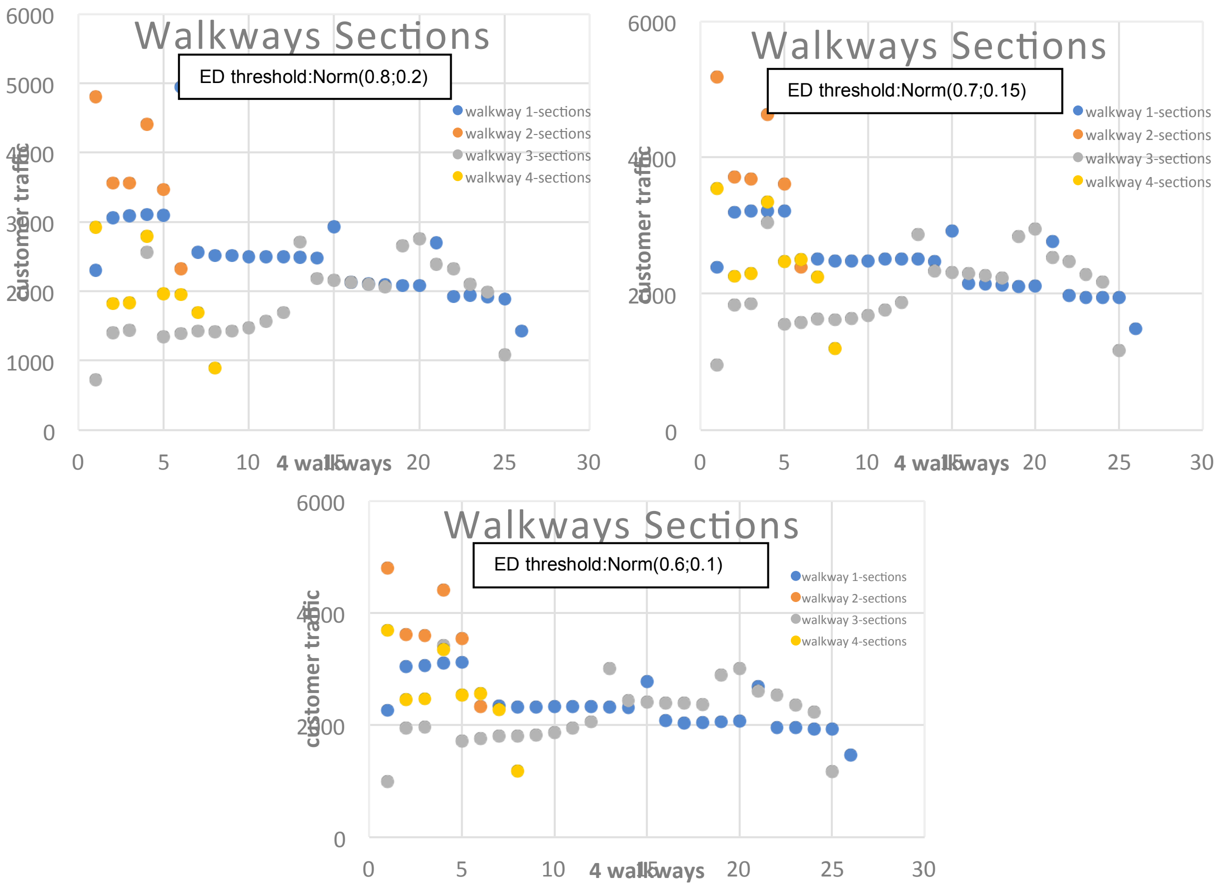


Figure 9-7: Output plotters of walkway usage comparison(multiplier=0.05, Max.ED threshold=Norm(0.8;0.2) /(0.7,0.15)/(0.6,0.1))

The observations are based on the condition that other parameters remain unchanged. As seen from the three figures above. No remarkable changes are found. For the trace graph comparison in Figure 9-5, as the ED threshold only has an influence when customers are making decisions after evaluating all the shops, if the ED threshold value is smaller, the probability that a customer will visit the shop with the smallest value decreases and vice versa. A slight decrease in the purple trace - total customers in stores can be seen because a smaller ED threshold eliminates several potential options from the final decision.

9.3.1.3 Factor - Maximum Shopping Time

Table 9-4: Values of model factors – max. shopping time

Parameter	**distribution**		**values**
Max. shopping time	**Triangular**	**(Min;max;most likely)**	**(30;360;120); (50;390;150) (10;300;90)**
Max.shop visited	Triangular	(Min;max;most likely)	(3;20;5)
Interarrival multiplier	/	constant	0.05
ED threshold	Normal	(Mean;Std.Dev.)	(0.8;0.2)

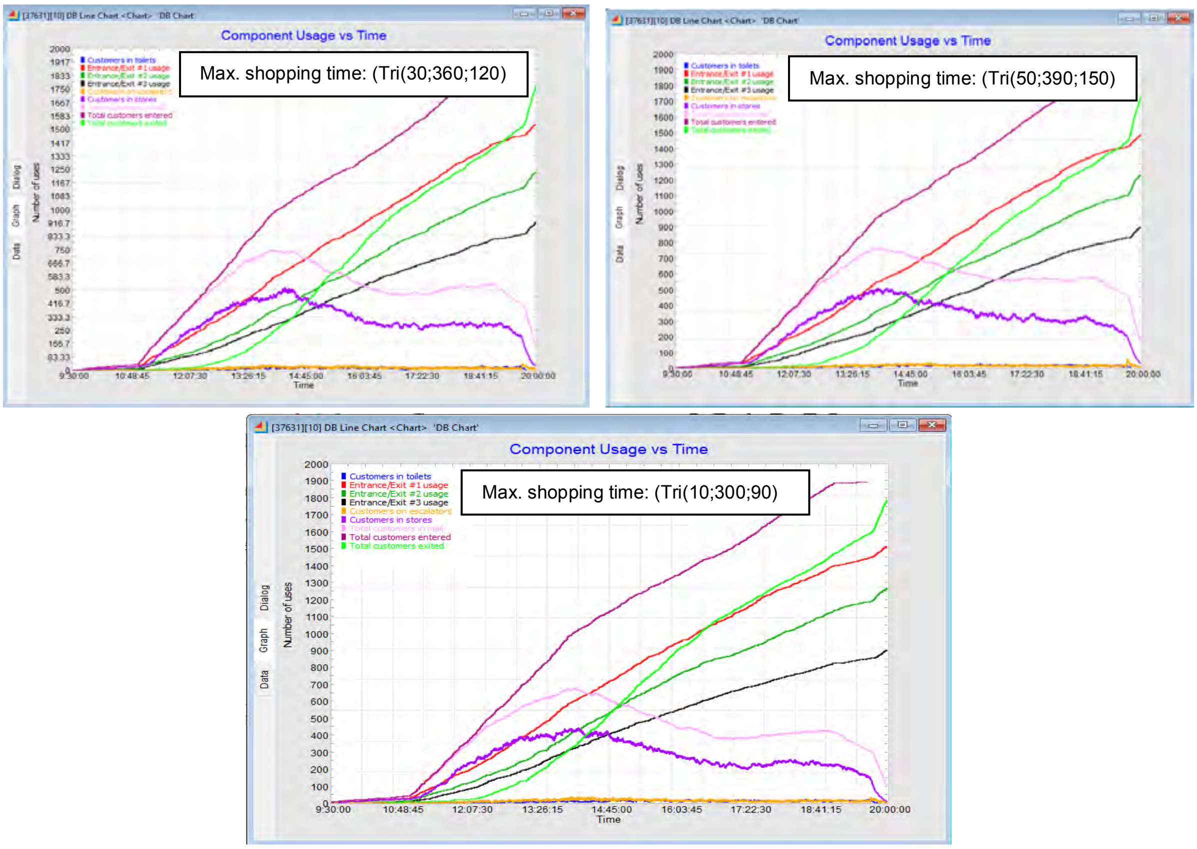


Figure 9-8: Output plotters in ExtenSim comparison(multiplier=0.05, Max.ED threshold=Norm(0.8;0.2), max.shopping time: Tria(30;360;120)/(50;390;150)/(10;300;90))

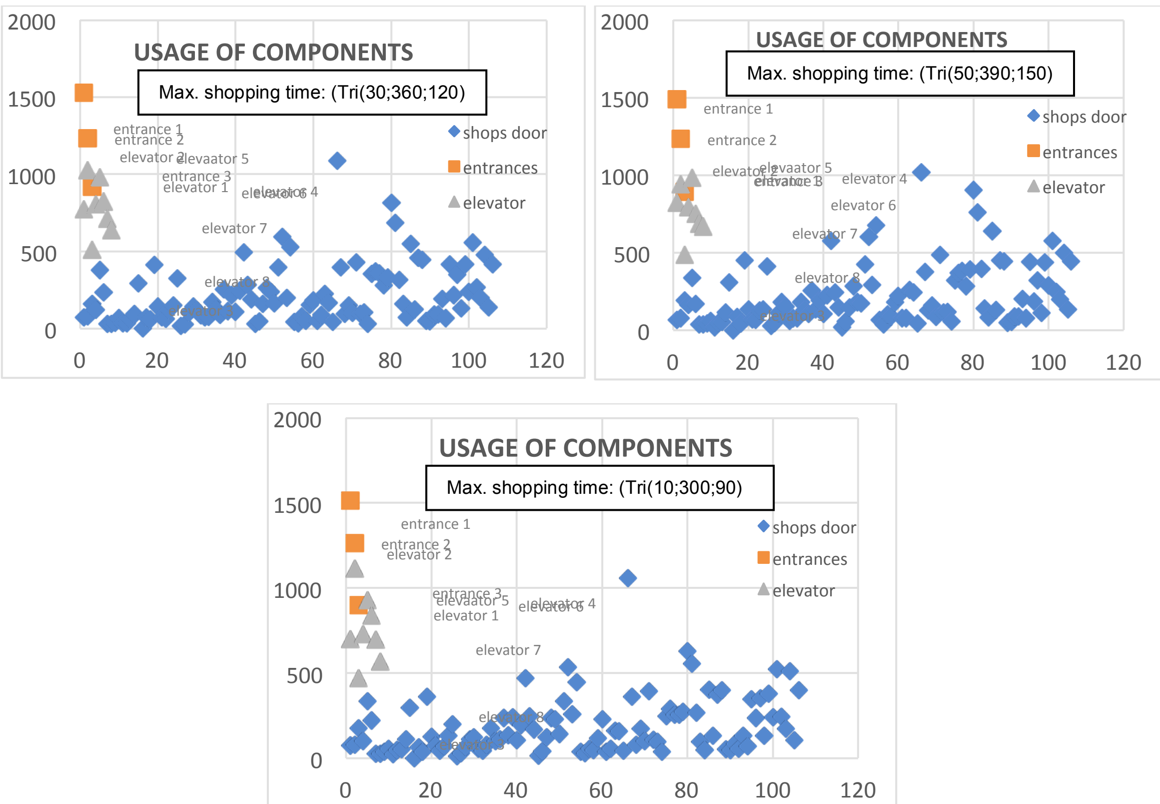


Figure 9-9: Output plotters of components usage comparison (multiplier=0.05, Max.ED threshold=Norm(0.8;0.2), max.shopping time: Tria(30;360;120)/(50;390;150)/(10;300;90))

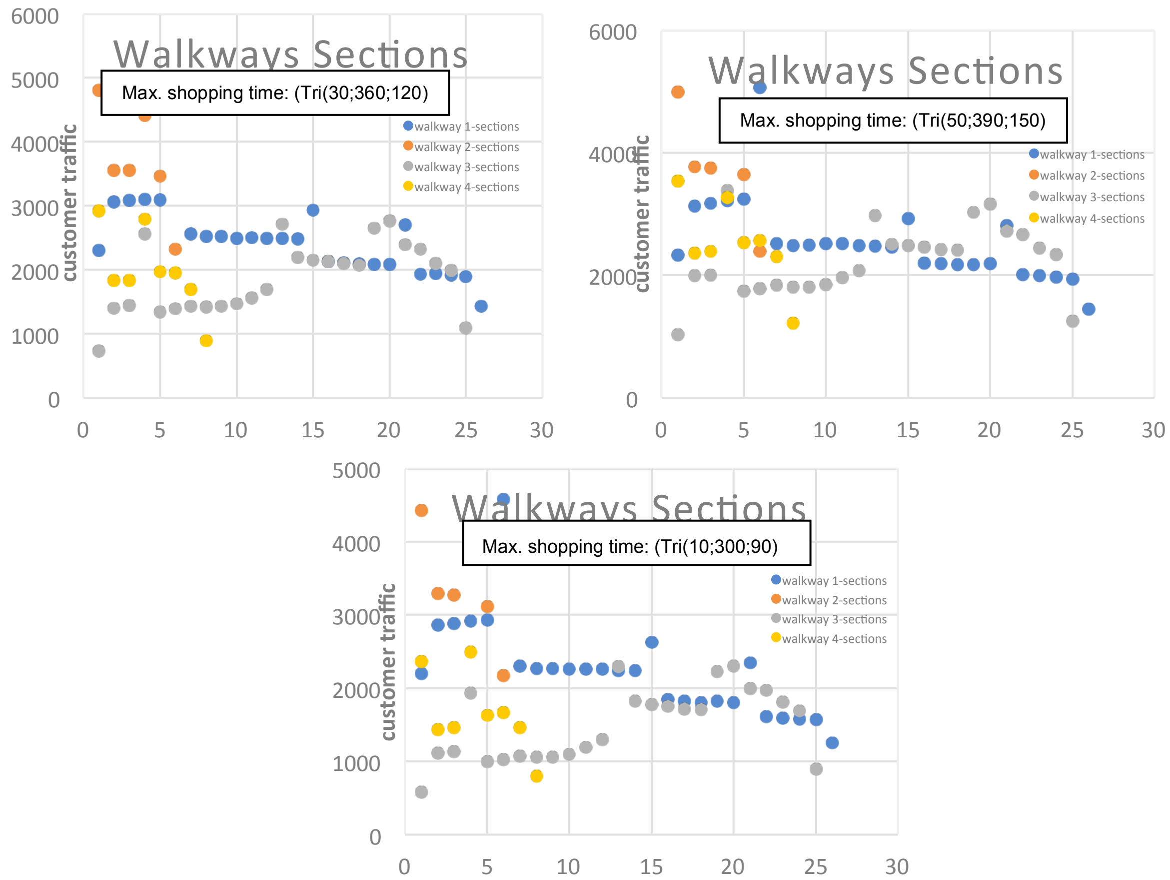


Figure 9-10: Output plotters of walkway usage comparison(multiplier=0.05, Max.ED threshold=Norm(0.8;0.2), max.shopping time: Tria(30;360;120)/(50;390;150)/(10;300;90))

Under the condition that only max. Shopping time is changed while other parameters remain the same, the curve of customers in stores with the smallest max. Shopping time is overall lower than the curves in the other scenarios. The same results can be derived from Figure 9-9 and Figure 9-10, while most of the values lying between 200 and 400 when customers have shorter shopping time, the other results are spread around 400.

The results in this section are not all-inclusive, a number of statistics generated by the model in Exel Sheet as well as in DB are suggested for further study.

The Scenario Manager block keeps track of multiple what-if models that are pre-configured before the model is run. It provides the functionality to change variable information automatically and generate scenario reports by assigning a named scenario to each combination of variables that are to be examined. This is very practical and simple to apply. However, due to the stochastic nature of the system, the outputs are randomly given, which can lead to misjudgments. To gain more accurate conclusions, further statistical analysis is required.

10 Conclusion and Further Work

10.1 Limitations of the Model

Lack of Data

Although some of the statistics of OEZ were provided by the management centre, there are a large number of parameters that are not accessible and thus have to be assumed in the model, which limits the accuracy of the model. The logic in the model can be improved significantly, if information such as the popularity of the shop, the promotion activities are accessible, more factors that influence customer's decisions can be quantified and considered in the vector.

Feasibility Limitation

A flow of customers is hard to predefine or predict as they have intelligence, memory, social interaction, contextual and spatial awareness, and the ability to learn.

Time constraints

Due to the time constraints, it is hard to include all the details in the system, as it simulates a real-life scenario is a shopping mall, which is relatively complex, and a large number of parameters are involved. However, the model can always be refined when needed.

Hardware Limitations

As no simulation tool is perfect, ExtendSim is a great software, especially on simulation commercial or industrial systems. However, there are also some limitations using ExtendSim, for example, from one store to another shop, a customer can be easily "thrown" to the next node, but how a customer reaches the destination is not easy to illustrate. It costs a lot of time and programming efforts.

10.2 Conclusion

Simulation is indispensable for understanding, analyzing, and predicting the behaviour of complex and large-scale systems. It is useful to gain a better understanding of the functioning of existing systems and to help design new systems by predicting their behaviour before they are built.[67]

Despite the limitations mentioned above, the main factors are considered in the model, and most processes are assigned with specific logic to create a model as much close to reality as possible. The dynamics of user-space relationships within the shopping mall can be observed and exposed, and the interactions between the customers and building components and products, as well as in some special facilities in the building shall be represented accordingly.

[67] Imagine That Inc: *ExtendSim User Guide.* 2013, P. 104.

Moreover, ExtendSim provided excellent tools for statistical analysis and visualization and adding randomness easily.

Generally, many factors have an impact on the life span of the components in a building, such as product quality and maintenance. From the simulation results of the model in different scenarios, the usage of building components and products mainly depends on the total number of the consumers in the mall, who have interactions with the objects. The logic of how customers make-decisions inside the mall has a limited effect on the usage of the components when considering a large sample size.

However, this model shows a general sample of how customers behave in a shopping mall based on available data and assumptions as well as logical algorithms added to the model. With more detailed real data, it can accurately reveal and simulate the real-world scenarios. Simulation in this area is of great meaning, as it is applicable and scalable for further application areas including not only shopping mall design optimization, but also mall management operation optimization, etc.

10.3 Further Work

This thesis intends to serve as a start point of finding a new way to quantify the usage intensity regarding building components or products in a building by simulation. There is a great deal of further work to be performed and eventually improve model accuracy.

1. Shortest Path Algorithm combining with routing solutions can be assigned to customers.

2. Interaction between customers, the capacity of each store can be set based on real scenarios. For example, a balk logic should be added to restaurants or toilets, etc.

3. As this shopping mall has its own unique layout, many shopping malls have multiple floors with more walkway intersections and are much more complex to simulate. More logic will need to be programmed.

4. Statistics Analysis based on the data exported from the Scenario Manager Block, a more detailed parameter test can be further analyzed.

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Appendix

Appendix A

A.1 ExtendSim Code

A.1.1 Increment of the Number of Customer Visits and Shop Visited

Include: C:\Users\shuji\OneDrive\Documents\ExtendSim10\Extensions\EQE_Model OEZ 04242020-rev1a_ES10.mox[11808].h*

```
//Output Variables
//----------------------------------------------
//    1.) shopsVisited  (Type = Attribute)
//    2.) route  (Type = Attribute)
//END: Equation Variables
//************************************************
integer customerVisits, numShopsVisited;
integer DBIdx, TIdx, ShopsVisitedFIdx;
integer CustomerShopHistoryTIdx, ExitTimeFIdx;
real DBA;

// Update the number of shops visited by this customer

DBIdx = DBDatabaseGetIndexFromAddress(shopsVisitedDBA);
TIdx = DBTableGetIndexFromAddress(shopsVisitedDBA);
ShopsVisitedFIdx = DBFieldGetIndexFromAddress(shopsVisitedDBA);
DBA = DBAddressReplaceIndex(shopsVisitedDBA, 4, customerRecord);
numShopsVisited = DBDataGetAsNumberUsingAddress(DBA);
DBDataSetAsNumberUsingAddress(DBA, numShopsVisited + 1);


// Read the current number of customer visits to this store

customerVisits = DBDataGetAsNumber(DBIndex, ShopsTIdx, custVisitsFIdx, selectedShop);

// Increment count of customer visits to this store by 1

DBDataSetAsNumber(DBIndex, ShopsTIdx, custVisitsFIdx, selectedShop, (customerVisits + 1));

shopsVisited++;
route = 1;  // force shopper to make their exit decision in the shopper movement section of the model

// Update the customer's exit time from this store in the customer shop history table
CustomerShopHistoryTIdx = DBTableGetIndexFromAddress(exitTimeDBA);
ExitTimeFIdx = DBFieldGetIndexFromAddress(exitTimeDBA);
DBA = DBAddressReplaceIndex(exitTimeDBA, 4, custSHRecord);
DBDataSetAsNumberUsingAddress(DBA, currentTime);
```

Appendix A- 1: Increment of Customer Visits and Shops Visited

A.1.2 Purchase Decision and Update of customers preference for shopping

Include: C:\Users\shuji\OneDrive\Documents\ExtendSim10\Extensions\EQE_Model OEZ 04242020-rev1a_ES10.mox[13499].h

```
//**********************************************
integer firstCategoryFIdx;
integer dBIdx, CustomerDataTIdx, categoryPreferenceFIdx, locationTypeRecord, parentArray[3];
real maxPDBA, totPDBA, entTimeDBA, DBA;
real maxPurchases, totPurchases, entryTime;
real purchaseThreshold, currentPreferenceLevel;
string locationName;

maxPDBA = DBAddressReplaceIndex(maxPurchaseDBA, 4, customerRecord);
totPDBA = DBAddressReplaceIndex(totPurchaseDBA, 4, customerRecord);
entTimeDBA = DBAddressReplaceIndex(entryTimeDBA, 4, customerRecord);
DBA = DBAddressReplaceIndex(locationTypeDBA, 4, selectedShop);
locationTypeRecord = DBDataGetParentUsingAddress(DBA, parentArray);
DBA = DBAddressReplaceIndex(locNameDBA, 4, locationTypeRecord);
locationName = DBDataGetAsStringUsingAddress(DBA);
dBIdx = DBDatabaseGetIndexFromAddress(maxPurchaseDBA);
CustomerDataTIdx = DBTableGetIndexFromAddress(maxPurchaseDBA);
// Get the field index in the Customer Data table for this location category preference
firstCategoryFIdx = DBFieldGetIndex(dBIdx, CustomerDataTIdx, "Fast Food");
categoryPreferenceFIdx = DBFieldGetIndex(dBIdx, CustomerDataTIdx, locationName);

// Increment count of times customer has been to this store
DBA = DBAddressReplaceIndex(custShopDataDBA, 4, customerRecord);
DBA = DBAddressReplaceIndex(DBA, 3, (selectedShop + 1));
DBDataSetAsNumberUsingAddress(DBA, (DBDataGetAsNumberUsingAddress(DBA) + 1));

maxPurchases = DBDataGetAsNumberUsingAddress(maxPDBA);
totPurchases = DBDataGetAsNumberUsingAddress(totPDBA);
entryTime = DBDataGetAsNumberUsingAddress(entTimeDBA);

// Purchase threshold calculation
//______________________________
//
//  Make purchase threshold value a function of how long customer has been in the store. This
//  value starts out being 1 when customer first enters the mall and gradually becomes the smaller until it equals
//  the purchase threshold value for the particular store
//
purchaseThreshold = min2(1, purchThreshold / max2(.0001, min2((currentTime - entryTime) / purchProbFactor, 1)));
if (randomReal() > purchaseThreshold)
{
    if (totPurchases < maxPurchases)
    {
        // Make the purchase
        DBDataSetAsNumberUsingAddress(totPDBA, (totPurchases + purchaseAmount));

        // Reduce the customer's preference for this category
        currentPreferenceLevel = DBDataGetAsNumber(dBIDx, CustomerDataTIdx, categoryPreferenceFIdx, customerRecord);
        currentPreferenceLevel = max2(0, currentPreferenceLevel - preferrenceDrop);
        DBDataSetAsNumber(dBIDx, CustomerDataTIdx, categoryPreferenceFIdx, customerRecord, currentPreferenceLevel);
    }

}
```

Appendix A- 2: Purchase Decision and Dynamic Preference for Shopping

A.1.3 Dynamic Strategy of Customer's Preference

Include: C:\Users\shuji\OneDrive\Documents\ExtendSim10\Extensions\EQE_Model OEZ 04242020-rev1a_ES10.mox[2].h

```
// Update customer dynamic preference values
DBA = DBAddressReplaceIndex(lastEatTimeDBA, 4, customerRecord);
lastEatTime = DBDataGetAsNumberUsingAddress(DBA);
currentPreferenceValue = DBDataGetAsNumber(DBIdx, CustomerDataTIdx, customerGastronomyFIdx, customerRecord);
currentPreferenceValue += (currentTime - lastEatTime) / RestaurantPrefN;
DBDataSetAsNumber(DBIdx, CustomerDataTIdx, customerGastronomyFIdx, customerRecord, currentPreferenceValue);

DBA = DBAddressReplaceIndex(lastEatTimeDBA, 4, customerRecord);
lastEatTime = DBDataGetAsNumberUsingAddress(DBA);
currentPreferenceValue = DBDataGetAsNumber(DBIdx, CustomerDataTIdx, customerFastFoodFIdx, customerRecord);
currentPreferenceValue += (currentTime - lastEatTime) / RestaurantPrefN;
DBDataSetAsNumber(DBIdx, CustomerDataTIdx, customerFastFoodFIdx, customerRecord, currentPreferenceValue);

DBA = DBAddressReplaceIndex(lastToiletTmDBA, 4, customerRecord);
lastToiletTime = DBDataGetAsNumberUsingAddress(DBA);
currentPreferenceValue = DBDataGetAsNumber(DBIdx, CustomerDataTIdx, customerToiletFIdx, customerRecord);
currentPreferenceValue += (currentTime - lastToiletTime) / ToiletPrefNum;
DBDataSetAsNumber(DBIdx, CustomerDataTIdx, customerToiletFIdx, customerRecord, currentPreferenceValue);

EGfloor = EGfloorRec;
UGfloor = UGfloorRec;

searchingForExitDBA = DBAddressReplaceIndex(searchExitDBA, 4, customerRecord);
searchingForRestaurantDBA = DBAddressReplaceIndex(searchRestDBA, 4, customerRecord);
searchingForEscalatorDBA = DBAddressReplaceIndex(searchEscalDBA, 4, customerRecord);
searchingForToiletDBA = DBAddressReplaceIndex(searchToiletDBA, 4, customerRecord);
searchingForShopDBA = DBAddressReplaceIndex(searchShopDBA, 4, customerRecord);
```

Appendix A- 3: Dynamic of Customer's Preference for Food and Toilet

A.1.4 Initialization and Creation Preference Vectors

Include: C:\Users\shuji\OneDrive\Documents\ExtendSim10\Extensions\EQE_Model OEZ 04242020-rev1a_ES10.mox[2].h

```

// Initialize preferences vectors
for (i=0;i<GetDimension(customerPreferences);i++)
{
    customerPreferences[i] = 0;
    shopPreferences[i] = 0;
}
// Build the shop's prefences vector
shopVectorRecord = DBDataGetParent(DBIdx, ShopsTIdx, shopsVectorFIdx, shopRecord, parentArray);
//numFields = DBFieldsGetNum(DBIdx, shopsVectorTIdx) - 2;    // don't use gender and age yet
numFields = DBFieldsGetNum(DBIdx, shopsVectorTIdx); // don't use gender and age yet
for (FIdx=ShopFastFoodFIdx;FIdx<=numFields;FIdx++)
{
    shopPreferences[FIdx - ShopFastFoodFIdx] = DBDataGetAsNumber(DBIdx, shopsVectorTIdx, FIdx, shopVectorRecord);
}

// Build the customer's prefences vector
shopVectorRecord = DBDataGetParent(DBIdx, ShopsTIdx, shopsVectorFIdx, shopRecord, parentArray);
numFields = DBFieldsGetNum(DBIdx, CustomerDataTIdx);
for (FIdx=customerFastFoodFIdx;FIdx<=numFields;FIdx++)
{
    customerPreferences[FIdx - customerFastFoodFIdx] = DBDataGetAsNumber(DBIdx, CustomerDataTIdx, FIdx, customerRecord);
}
```

Appendix A- 4: Creation and Initialization of Preference Vectors

A.1.5 Euclidean Distance Calculation

Include: C:\Users\shuji\OneDrive\Documents\ExtendSim10\Extensions\EQE_Model OEZ 04242020-rev1a_ES10.mox[2].h*

```
// Calculate the Euclidean distance of the vector

sumOfSquares = 0;
sumCustomerPreferences = 0;
numShopPreferences = 0;
for (i=0;i<(numFields - customerFastFoodFIdx + 1);i++)
{
    if (shopPreferences[i] > 0)
    {
        if ((numShopPreferences > 0) && (i < (customerGenderFIdx - customerFastFoodFIdx)))
        {
            squareResult = (customerPreferences[i] - shopPreferences[i])^2;
            if (squareResult < sumOfSquares)
                sumOfSquares = squareResult;

        }
        else
        {
            sumOfSquares += (customerPreferences[i] - shopPreferences[i])^2;
        }
        sumCustomerPreferences += customerPreferences[i] ;
        numShopPreferences++;
    }
}
EuclideanDistances[numConnectedShops][0] = sumOfSquares^.5;
EuclideanDistances[numConnectedShops][1] = shopRecord;
customerPreferenceScore = sumCustomerPreferences^.5;
numConnectedShops++;

connectedShops[RestaurantsCategoryIndex][connectedShoppingCategories[RestaurantsCategoryIndex]][0] = shopRecord;
locationTypeRecord = DBDataGetParent(dBIdx, ShopsTIdx, locTypeFIdx, shopRecord, parentArray);
DBA = DBAddressReplaceIndex(categoryDBA, 4, locationTypeRecord);
categoryRecordIndex = DBDataGetParentUsingAddress(DBA, parentArray);
connectedShops[RestaurantsCategoryIndex][connectedShoppingCategories[categoryRecordIndex - 1]][0] = shopRecord;

DBA = DBAddressReplaceIndex(statusDBA, 3, StatusFIdx + categoryRecordIndex);
DBA = DBAddressReplaceIndex(DBA, 4, customerRecord);
connectedShoppingCategories[categoryRecordIndex - 1]++;

```

Appendix A- 5: Euclidean Distance Vector Calculation

A.1.6 Two-level Decision-Making Logic

Include: C:\Users\shuji\OneDrive\Documents\ExtendSim10\Extensions\EQE_Model OEZ 04242020-rev1a_ES10.mox[2].h*

```
//  2-LEVEL Decision Making
// Level-1 Decision

DBDataSetAsParentIndex(dBIndex, CustomerDataTIdx, CurrentShopFIdx, customerRecord, 0);
CurrentShopFIdx = DBFieldGetIndexFromAddress(custDataDBA);

selectedShop = 0;
selectedEscal = 0;
selectedExit = 0;
selectedToilet = 0;
if (maxCategoryPreferenceIndex != -1)
{
    if (connectedShoppingCategories[maxCategoryPreferenceIndex] > 0)
    {
        continueWalking = false;
        if ((maxCategoryPreferenceIndex == shopsCategoryIndex) ||
            (maxCategoryPreferenceIndex == restaurantsCategoryIndex))
        {
        // Calculate the minimum Euclidean distance for all connected shops
            minEuclidianDistance = 1000;
            minEuclidianDistanceIndex = 0;
            numTiedShops = 1;
            for (i=0;i<numConnectedShops;i++)
            {
                if (breakForShop)
                    result = 1;
                if (EuclideanDistances[i][0] < minEuclidianDistance)
                {
                    minEuclidianDistance = EuclideanDistances[i][0];
                    minEuclidianDistanceIndex = i;
                    numTiedShops = 1;
                    tiedShops[numTiedShops-1] = i;
                    shopRecord = EuclideanDistances[minEuclidianDistanceIndex][1];
                }
                else if (EuclideanDistances[i][0] == minEuclidianDistance)
                {
                    numTiedShops++;
                    tiedShops[numTiedShops-1] = i;
                }
            }
            if (numTiedShops > 1)
            {
            //  Randomly pick one of the shops
                minEuclidianDistanceIndex = tiedShops[random(numTiedShops)];
                minEuclidianDistance = EuclideanDistances[minEuclidianDistanceIndex][0];
                shopRecord = EuclideanDistances[minEuclidianDistanceIndex][1];
            }
            numHighestScore = DBDataGetAsNumber(DBIdx, ShopsTIdx, highScoreFIdx, shopRecord);
            DBDataSetAsNumber(DBIdx, ShopsTIdx, highScoreFIdx, shopRecord, numHighestScore + 1);
//          if (maxToleratedEuclidDist >= minEuclidianDistance)
            if ((maxToleratedEuclidDist >= minEuclidianDistance) && (randomReal() > criticalRatio))
            {
            // Shopping decision made!!!
```

Figure A- 6: Two-Level Decision-Making

A.1.7 Update Shopping History

Include: C:\Users\shug\OneDrive\Documents\ExtendSim10\Extensions\EQE_Model OEZ 04242020-rev1a_ES10.mox[2].h*

```
                // Add new record to this customer's shopping history

                CustomerShopHistoryTIdx = DBTableGetIndexFromAddress(custShopHistDBA);
                CustomerFIdx = DBFieldGetIndexFromAddress(custShopHistDBA);
                IDFIdx = DBFieldGetIndexFromAddress(IDcshDBA);
                shopFIdx = DBFieldGetIndexFromAddress(shopCshDBA);
                entryTimeFIdx = DBFieldGetIndexFromAddress(entTimCshDBA);
                exitTimeFIdx = DBFieldGetIndexFromAddress(exitTimCshDBA);

                DBDataSetAsNumberUsingAddress(nxtCSHrecordDBA, (DBDataGetAsNumberUsingAddress(nxtCSHrecordDBA) + 1));
                customerShopHistoryRecord = DBDataGetAsNumberUsingAddress(nxtCSHrecordDBA);
                if (customerShopHistoryRecord > DBRecordsGetNum(DBIdx, CustomerShopHistoryTIdx))
                {
                    DBRecordsInsert(dBIndex, CustomerShopHistoryTIdx, 0, 500);
                }

                custSHRecord = customerShopHistoryRecord; // set the attribute value

                DBDataSetAsString(dBIndex, CustomerShopHistoryTIdx, IDFIdx, customerShopHistoryRecord, "CSH_" +
                    DBDataGetAsString(dBIndex, CustomerDataTIdx, 1, customerRecord) + "_" + customerShopHistoryRecord);

                DBDataSetAsParentIndex(dBIndex, CustomerShopHistoryTIdx, CustomerFIdx, customerShopHistoryRecord, customerRecord);
                DBDataSetAsParentIndex(dBIndex, CustomerShopHistoryTIdx, shopFIdx, customerShopHistoryRecord, shopRecord);
                DBDataSetAsNumber(dBIndex, CustomerShopHistoryTIdx, entryTimeFIdx, customerShopHistoryRecord, currentTime);
            }
        }
        else
        {
            continueWalking = true;
        }
    }
    else if (maxCategoryPreferenceIndex == EscalatorsCategoryIndex)
    {
```

Appendix A- 7: Customer Shop History Table Update

Appendix B

B.1 Statistics from OEZ

Group Social Demographical Structure of OEZ:

Aktuelle Kundengruppenbetrachtung
Soziodemographika.

	Soziodemographika	16-29	30-39	40-49	50-59	60 plus	1-Pers. HH	2-Pers. HH	3+Pers. HH	
Bevölkerungs-struktur*	Deutschland	16%	12%	13%	16%	28%	41%	28%	31%	
	EZG	18%	17%	15%	14%	23%	48%	25%	27%	
	Zone 1	23%	17%	14%	12%	22%	48%	23%	29%	
	Zone 2	20%	18%	15%	13%	22%	53%	22%	25%	
	Zone 3	18%	17%	15%	14%	23%	48%	25%	27%	
	Zone 4	19%	14%	15%	16%	22%	36%	34%	30%	
	Zone 5	0%	0%	0%	0%	0%	0%	0%	0%	
Kunden-struktur OEZ	**Gesamt OEZ**	**28%**	**14%**	**11%**	**15%**	**33%**	**24%**	**35%**	**41%**	(n=710)
	EZG OEZ	25%	14%	11%	14%	36%	25%	36%	39%	(n=546)
	Zone 1	18%	12%	7%	14%	48%	34%	35%	31%	(n=217)
	Zone 2	25%	13%	12%	15%	35%	18%	39%	42%	(n=142)
	Zone 3	33%	16%	12%	13%	25%	20%	36%	43%	(n=173)
	Zone 4	36%	21%	29%	14%	0%	21%	14%	64%	(n=14)
	Zone 5	0%	0%	0%	0%	0%	0%	0%	0%	(n=0)
	Sonstige (=21%)	37%	16%	12%	15%	21%	20%	29%	51%	(n=146)
Hauptkunden-gruppen		✓			✓	✓		✓	✓	
Anmerkungen										

Quelle: AZ-Direct 2018; Kundenbefragung – Nov. 2018 n=710
Die Basen der Kundenstruktur beziehen sich je einmal auf den Alterssplit bzw. einmal auf den Haushaltssplit
1

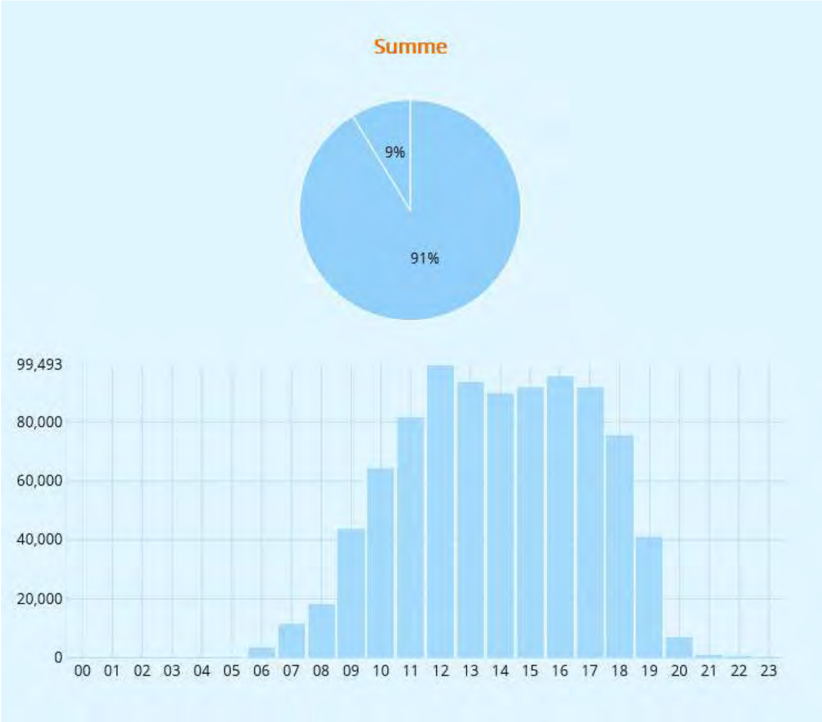
Appendix B- 1: Current Customer Group Age Distribution Structure in OEZ[68]

Kennzahlen der Wettbewerbsstandorte
Ergebnisse aus der Kundenbefragung und Externen-Passantenbefragung.

		Männlich	1 & 2 Pers. Haushalt	Alter	KFZ	Verweil-dauer*	Stamm-kunde	Zufrieden-heit	Durch schnittsbon*	
KB	OEZ	**46%**	**59%**	**47**	**42%**	**69**	**67%**	**2,0**	**122**	(n=710)
EPB (oder KB des ECE Centers)	München - Pasing Arcaden	44%	55%	42	13%	71	65%	2,1	80	(n=481)
	Freising - Fußgängerzone	38%	56%	42	32%	80	67%	2,8	52	(n=288)
	München - Riem Arcaden	37%	43%	34	20%	83	65%	2,1	69	(n=246)

Appendix B- 2: Customer Gender Ratio of OEZ[69]

[68] AZ-Direct 2018-[customer quenstionare], Kundenbefragung,10/2018
[69] Customer questionair 11/2018, external passanten questionair, Autumn, 2018.



Appendix B-3: Distribution of Daily Customer Traffic of OEZ in November 2019

Erklärung

Ich versichere an Eides Statt,

1. dass ich die Arbeit selbständig und ohne fremde Hilfe angefertigt habe,
2. dass ich alle Abschnitte, die wörtlich oder annähernd wörtlich aus einer Veröffentlichung entnommen sind, als solche kenntlich gemacht habe,
3. dass die Arbeit noch nicht veröffentlicht und auch noch keiner anderen Prüfungsbehörde vorgelegt worden ist,
4. dass ich keine Kopien von Softwareprogrammen des Lehrstuhls angefertigt habe und alle Programme, die mir zur Verfügung gestellt wurden, entweder zurückgegeben oder gelöscht habe.

Ich erkläre mich damit einverstanden, dass der Lehrstuhl für Bauprozessmanagement und Immobilienentwicklung die von mir hiermit vorgelegte Master's Thesis zur weiteren Bearbeitung bzw. Veröffentlichung verwenden kann.

....

(Unterschrift)