Generalized assignment problem to minimize emergency evacuation routing in Istanbul Grand Bazaar

İlkay Saraçoğlu*‡, Gül Yücel**

*Department of Industrial Engineering, Faculty of Engineering and Architecture, Istanbul Gelisim University, Turkey

** Department of Architecture, Faculty of Engineering and Architecture, Istanbul Gelisim University, Turkey

(isaracoglu@gelisim.edu.tr, gyucel@gelisim.edu.tr)

‡ Corresponding Author; İlkay Saraçoğlu, Industrial Engineering Dept., Faculty of Engineering and Architecture, Istanbul Gelisim University, Avcılar, Turkey, Tel: +90 212 422 70 00

isaracoglu@gelisim.edu.tr

Received: 14.06.2019 Accepted:20.08.2019

Abstract- In this study, the exit door assignment problem was discussed to determine routes with the shortest distance and least density for users of Istanbul Grand Bazaar in case of an emergency. The evacuation plan was considered as a Generalized Assignment Problem (GAP) which is a 0-1 mixed integer programming model. The components of the evaluation model consist of length, area, and user density as well as streets in the Grand Bazaar and their connection with the exterior. In the study, 12 gates in the Grand Bazaar which directly open onto roads and 15 nodal points among the junction points which are related to these gates were taken into consideration. A route is suggested with the aim of ensuring safe evacuation with minimum density and in the shortest time in any emergency case. The Grand Bazaar has more than one hundred thousand visitors daily depending on the season due to its characteristics of being the historical trade centre. Based on the study results, it is foreseen that there will be density at some gates in cases of emergency. Any evacuation plan in case of emergency must evaluate these routes and necessary physical precautions should be taken. At the same time, this evaluation may constitute the basis for improvement works devoted to the use of other gates.

Keywords *Generalized assignment problem, Emergency evacuation, Istanbul Grand Bazaar*

1. Introduction

Emergency evacuation at different scales from city to dwelling unit is crucial for the safety of life in any emergency case. The type and scale of disaster and settlement characteristics to be evacuated affect the selection of evacuation methods. Also, the type of hazard that leads to disaster affects the evacuation conditions and if these are also triggered by secondary disasters, safe evacuation conditions may become difficult. The fire risk following an earthquake may constitute a more serious case, along with the post-disaster structural damage and evacuation conditions. Physical aspects of routes such as geometry, width, and length are important for evacuation safety conditions with the user capacity. The historical city fabric, topographic conditions, building typology, scale and routes are some factors that affect safety conditions in emergency evacuation cases. Historical buildings also have similar problems. The horizontal and vertical circulation routes in new buildings include sufficient geometric design according to codes and standards. But historical buildings which consist of different type, typology and history, may have irrational circulation typology. Historical buildings need special solutions for the evacuation model due to special conditions. Due to weak features in terms of physical conditions, historical cities are at significant risk due to disasters, mainly earthquakes. The special conditions in historical buildings, necessary to protect cultural assets, involve special methods and processes in practice. The procedure for making large-scale historical buildings, used by a high number of users, safe may take a long time. It is also crucial to ensure the safety of individuals living in these buildings and develop fast and safe evacuation conditions for disasters which may occur. The historical bazaars and Han (inn) buildings may be given as examples of these types of buildings. Their scale, number of users, planning and structures appear to be a complicated problem.

In the second section, the literature including studies concerning emergency evacuation is discussed. In the third section, the generalized assignment model is explained. In the fourth section, the implementation model for the Grand Bazaar is considered while solution results are mentioned in the fifth section and finally the conclusion is explained in the last section of the study.

2. Literature Review

In terms of emergency evacuation, building complexes can be classified into three types (vertical, horizontal, and both): high-rise buildings have vertical characteristics, so escape routes can be provided by a number of stair ramps. Examples of horizontal architecture can be mentioned as fairgrounds and the examples of the Grand Bazaar. In these buildings, the number of doors is generally higher and access roads to the gates are located at greater distances. Structures such as stadiums are low-rise buildings that have horizontal and vertical structure characteristics in one place. Studies about single-story horizontal structures which have characteristics similar to the Istanbul Grand Bazaar architecture, which is the focus of this study, are examined.

The first study which was conducted with the aim of evacuating large indoor spaces and high-rise buildings in case of emergency mentioned in the literature was modelled by Francis [1]. Pursals and Garzon [2] developed a mathematical model which enables people to select the most convenient route. Kang et al. [3] implemented the method of assignment to last exit with the aim of evacuating a large shopping centre. One of two models that they developed allows for evacuation from different exit points by departmentalising the people based on linear programming, while other method allows for evacuation by directing each department to a single exit based on integer programming. Cuesta [4] conducted a study about the evacuation methodology of a single-floor manufacturing facility. They tested this suggested model with STEPS software which is a commercial application. Chen and Feng [5] used flow control algorithm for evacuation of a large indoor space. They considered the aspects of single narrow door, single wide door, multiple narrow doors, etc. by hand individually. Boonmee et al. [6] applied a facility location model to solve a wide range of emergency humanitarian logistics.

In some studies, the behaviour tendencies of people were analysed with simulations to discover which doors they head towards. Alighadr et al. [7] conducted a simulation study of behaviours of pedestrians for emergency evacuation in Tabriz historical bazaar. They found the maximum density by creating four experiment sets as two exit doors or single exit door by considering four different pedestrian numbers. In another study, Zhang et al. [8] investigated the behaviours of people in subway stations and decided the most convenient evacuation routes with simulation-based decision-making approach.

Mathematical models which will minimize the evacuation period were mostly established in studies about the evacuation problem in case of emergency. The simulation studies and the studies on behaviour tendencies of people in closed spaces in case of emergency are also reviewed. In this study, the emergency evacuation of people in Istanbul Grand Bazaar was considered based on a 0-1 mixed integer programming model.

3. Istanbul Grand Bazaar

The Grand Bazaar in Istanbul is a historical site located north of Beyazıt Square. The main building of the Grand Bazaar consists of Cevahir Bedesten (construction date 1455-1460) and Sandal Bedesten (construction date 1545-1550). The historical records reveal that the Grand Bazaar was damaged due to many earthquakes and fires since its establishment and many repairs were made devoted to fixing the damage [9-13]. Today, the Grand Bazaar maintains its function with two bedestens and 16 Han (inn) buildings, opened onto the bazaar which are interconnected with the surrounding roads within its historical urban fabric. The Grand Bazaar, which has maintenance and repair provisioned by a special law, is registered as a monumental structure and was added into the scope of urban renewal in 2007. The surveying, restitution and restoration projects for the Grand Bazaar which were completed in 2016 were performed by Fatih Municipality (Law No.5366), and today, according to the restoration project, roof and infrastructure renovation are completed.

The change in the bazaar's boundaries after disasters which occurred during history, the change of use in parallel with current conditions, and the maintenance-repair history of the Grand Bazaar which consists of structures with different qualities may be listed as sources of many problems experienced today. The construction deterioration and structural cracks which occurred locally in the street vault cover locally reveal the urgency for maintenance and repair [14,15]. In addition, the resolution of structural problems will be dealt with in the scope of restoration practices; and aspects such as location in the city, area, multiple ownership, structural specification of bazaar and maintaining its function and monumental building status will be effective throughout the restoration. According to Mortan and Küçükerman [16], the accumulation, historical and cultural assets specific to the Grand Bazaar span over five hundred years and its commercial commodity value (1.2 billion USD) shows the multi-dimensional aspect of the issue. All these conditions make the development of a safe evacuation plan urgent. The monumental building value of the Grand Bazaar is determinative for sensitivity of physical interventions which will be made. Therefore, conducting and developing a preliminary study devoted to determining the routes convenient to its physical features and evacuation conditions is prioritized. In this regard, the primary need is to determine the physical condition of current routes and exit doors used and the density of use in the bazaar.

The determination of escape routes which may be insufficient for the earthquake risk shall be considered within this scope. The sectoral distribution in the bazaar, the density of use, escape routes, and wideness and capacities of doors have a significant place in the determination of safe routes based on integrated analysis. The aim is to carry out studies to determine the routes which may be unsafe in terms of earthquakes and take emergency precautions.

3.1. Emergency evacuation planning and safe evacuation structure

Within the scope of emergency evacuation planning for the Grand Bazaar; the roads in the bazaar, road length and areas, user load/capacity, and exit doors are taken in consideration.

The Grand Bazaar has 21 gates (exit doors) with different specifications which are interconnected to the surrounding area (Figure 1, 2). There are 12 gates which directly open onto the street as well as seven gates which exit onto streets as a gateway by opening onto the Han building (inn) present in the bazaar.

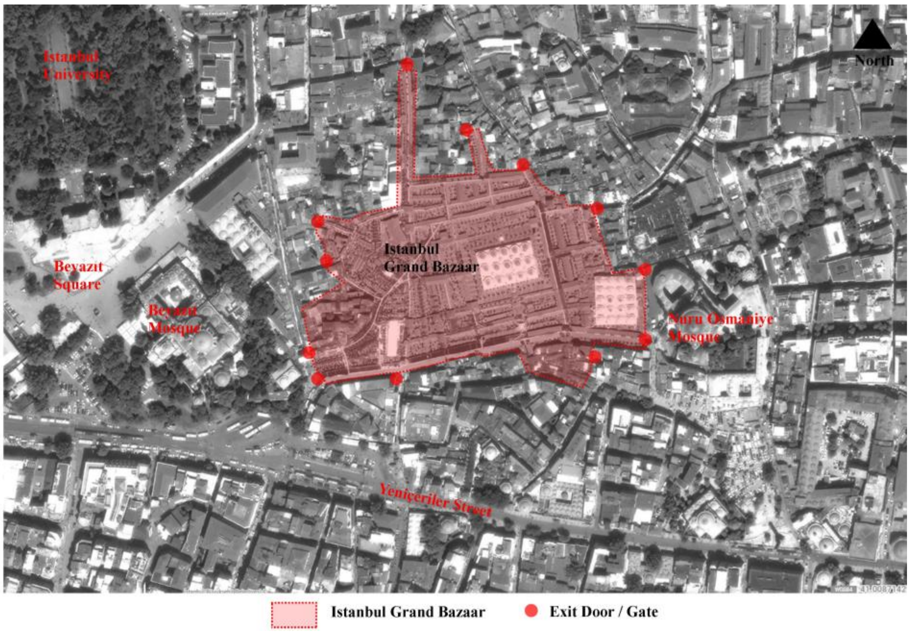

Fig. 1. The Grand Bazaar gate locations on satellite view.

Fig. 2. The Grand Bazaar gate/exit door examples, general view (D01, D05, D07, D16)

Fig. 3. The Grand Bazaar street views

The Han (inn) gate, named Yolgeçen, located on Yağlıkçılar Street which is currently closed was excluded from the evaluation. Two exits are in Kürkçüler Bazaar. All exits which ensure connections with surrounding streets all day are closed at the end of the day. In the study, the gates which are directly opened to streets were selected for evacuation in case of an emergency. The interconnected gates were excluded from the study.

The bazaar plan and map which was used in study was obtained from the municipality. The plan includes streets, shops, gates and bazaar surrounding information in metric form and digital format. The number of shops on streets were collected from the plan. All route information such as road size and width in the Grand Bazaar are taken from the plan as shown in Appendix 1. The physical information for gates is based on the study by Yücel and Arun [15].

3.2. Gates/Exit Doors and Density of Use

The user density of the Grand Bazaar gates was evaluated based on on-site observations made within by interviewing Grand Bazaar security teams and observations made for a specific period at every gate. The crowded gates in terms of density of use are gates Çarşıkapı (D05), Beyazıt (D07), Nuruosmaniye (D01), Mahmutpaşa (D18), Mercan (D16) and Örücüler (D14), respectively. The highest number of exits from the bazaar was made from Mahmutpaşa gate (D18). These densities are taken into consideration for the selection of gates which will be used for emergency evacuation. The relationship of main axes to which doors connect, with the city roads and the level of the topography have a significant effect on the density at these entries-exits. There is five metre level difference between the doors at Beyazıt (D07) and Nuruosmaniye (D01) and the doors at Çarşıkapı (D03) and Örücüler (D14) from uninterrupted ways. According to sea level, Yorgancılar gate (D11) is located at the highest elevation (52.99), while Mahmutpaşa gate (D18) is located at the lowest level (38.34 level). Figure 3 shows some of the Grand Bazaar street views.

3.3. User Capacity

The employees in the shops were considered as fixed population in the Grand Bazaar, while the daily visitors were taken as mobile-variable users or population. In this study, the street slope, sectoral gathering and structural specification were not taken into consideration.

4. Method

4.1. Generalized Assignment Problem (GAP) Model

The aim of study is to ensure the evacuation of persons from the closest point by assigning exit doors which ensure the least density and shortest distance in terms of safe evacuation. The studies which were conducted about assignment problems in the last 50 years were summarized by Pentico [17]. In the most well-known classical assignment problems, the lowest total assignment cost is found by coupling '*n*' job with '*m*' location exactly. For example; the assignment problems may be given as "activities to locations, jobs to machine, jobs to workers or workers to machines". In this assignment problem, one to one coupling was made. More than one job assignment to one machine or more than one facility assignment to one location is different from the GAP classical assignment problem that Pentico [18] defined in the literature review. GAP was first developed by Ross and Soland [19]. GAP has fields of application in miscellaneous real-life problems such as evacuation, vehicle routing, grouping of flexible manufacturing systems, assignment of ships to docks, assignment of jobs to computers, assignment of facilities to locations, logistic distribution, resource allocation, etc. [20]. The model established based on the distances and number of persons in the evacuation problem to be implemented in the GAP model is given below [17]:

Notations:

x_{ij} = if agent i assigned to task j, 0 if not
a_{ij} = amount of agent i's capacity used if that agent is assigned to task j
b_i = available capacity of agent i
c_{ij} = the cost of assigning agent i to task j

Objective function:

$$Minimum \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} \quad (1)$$

Subject to:

$$\sum_{i=1}^{m} x_{ij} = 1, \quad j = 1, \dots, n \quad (2)$$

$$\sum_{j=1}^{n} a_{ij}x_{ij} \le b_i, \quad i = 1, \dots, m \quad (3)$$

$$x_{ij} = 0 \ or \ 1 \quad (4)$$

The first constraint (2) ensures that every task is assigned to only one agent. The second constraint (3) indicates that the set of tasks assigned to an agent do not exceed its capacity. It is a version of the classic assignment problem allowing for one machine to be assigned more than one job. Each job is assigned to one machine but more than one job may be assigned to one machine. Therefore, GAP may serve as an example for many assignment problems under a capacity limit. The aim is to assign the facilities to locations in such a way to minimize the total cost. At the end of assignment, one facility will be established at each location and no location or facility will remain uncovered. Elshafei [21], Burkard [22], Tsui and Chang [23], and Çela [24] used assignment model. Kang et al. [3] used the activity-exit assignment problem on hand as evacuation from multiple exits and evacuation from a single exit for a mall in Korea. Bretschneider and Kimms [25] developed a mixed integer mathematical model with the aim of ensuring the safe and fast evacuation in case of a disaster which may occur in the city. Vermuyten et al. [26] completed a literature review of optimization models made based on evacuation of pedestrians. Swamy [27] used an assignment model for evacuating people who entirely rely on public transportation in case of a hurricane. No study on evacuation problem of historical grand bazaar was found among the studies conducted. The historical grand bazaar was investigated based on the suggested mathematical model and the most convenient evacuation roads were determined.

4.2. Theory /Calculation

Evacuation Problem of Historical Grand Bazaar Istanbul

At the end of studies, it was decided to use the GAP method with the aim of determining the most convenient route to ensure the evacuation of visitors and employees from the bazaar in the shortest time in case of an emergency which may occur in historical Istanbul Grand Bazaar. A 0-1 mixed integer linear programming model was adapted to solve our problem according to the model described in the previous section. The indices, decision variables, parameters, constraints, and objective function of the suggested model are given below.

Notations:

$i =$ location numbers, $1 = 1,2,\dots,m$
$j =$ door numbers, $j = 1,2,\dots,n$
$d_{ij} =$ distance from location i to door j
$a_{ij} =$ the area of between location i and door j
$f_{ij} =$ the number of people between location i to door j
$\rho_{ij} =$ the density of people between location i to door j
$s_{ij} =$ the number of store between location i to door j
$k =$ average number of people in stores
$b_j =$ the capacity of door i

$$x_{ij} = \begin{cases} 1, \text{if location } i \text{ is assigned to door } j \\ 0, \text{otherwise} \end{cases}$$

Objective function:

$$Minimum \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij} f_{ij} x_{ij} \quad (5)$$

Eq. (2)-(4) are used the same as in the GAP model.

The objective function (5) is to minimize the loading for multiplication of locations and distance between doors with total number of persons. The multiplication of locations and distance between doors with number of persons which is used as the objective function is calculated based on the following equation (6):

$$f_{ij} = {}^{a_{ij}}/_{\rho_{ij}} + s_{ij}.k \quad (6)$$

Although there are currently 21 gates/exit doors which can be used to enter or exit the Grand Bazaar, 12 gates were selected which are suitable for exits in case of an emergency event. In addition to these 12 selected gates and the nodal points (junction), 50 locations in total were determined for the assignment for evacuation (Figure 4).

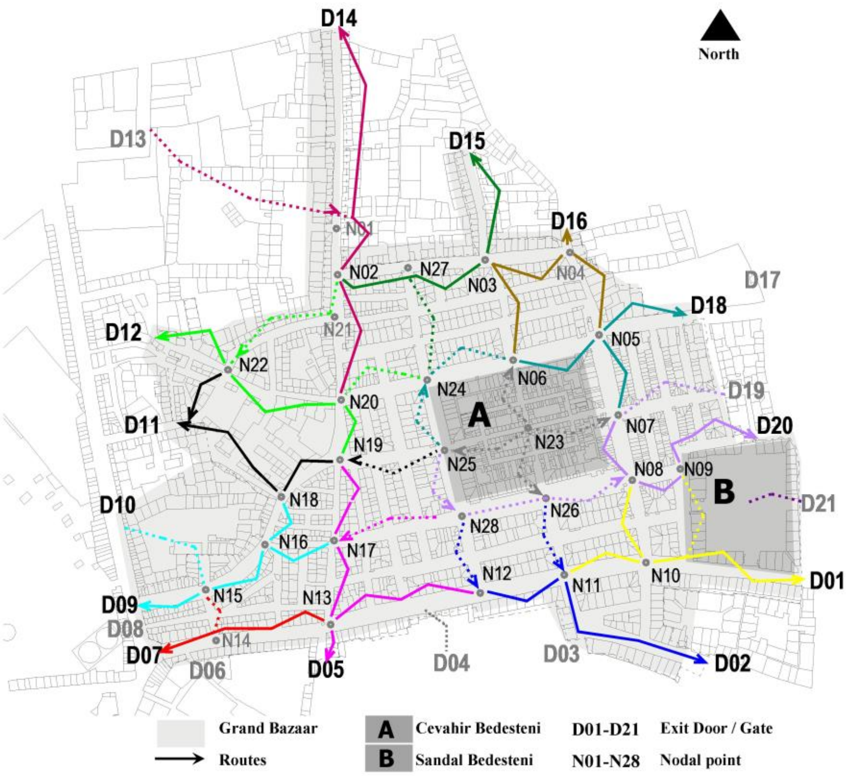

Fig. 4. Istanbul Grand Bazaar plan with gates/exits door and available routes

The capacity allowed to exit from gates was determined based on physical aspects and location of gates. The fixed number of persons per day during the open time of bazaar was determined based on the number of shops in the grand bazaar and on the assumption that on average two people work in these shops. There are approximately 3000 shops in the grand bazaar including the inn buildings which are directly connected with the bazaar. The analysed pedestrian Level of Service (LOS) is based on the measurement of pedestrian flow rate and sidewalk space in the Highway Capacity Manual HCM [28]. The pedestrian flow rate combining pedestrian speed, density, and volume is equivalent to vehicular flow. The analysis of the sidewalk level of service for the midblock uses the calculation of pedestrians per minute per metre (ped/min/m) as the basis for LOS classification A to F level as seen in Table 1 [28]. HCM's LOS criteria are taken into consideration in the study

Table 1. Average Flow LOS Criteria for Walkways and Sidewalks (pedestrian level of service, LOS) [31]

LOS Level	Space (m^2/person)	Flow rate (person/min/m)
At LOS A pedestrians move in desired paths without altering their movements in response to other pedestrians. Walking speeds are freely selected, and conflicts among pedestrians are unlikely.	>5.6	≤16
At LOS B there is sufficient area for pedestrians to select walking speeds freely to bypass other pedestrians, and to avoid crossing conflicts. At this level, pedestrians begin to be aware of other pedestrians, and to response to their presence when electing a walking path.	>3.7-5.6	>16-23
At LOS C space is sufficient for normal walking speeds, and for bypassing other pedestrians in primarily unidirectional streams. Reverse-direction or crossing movements can cause minor conflicts, and speeds and flow rate are somewhat lower.	>2.2-3.7	>23-33
At LOS D freedom to select individual walking speed and to bypass other pedestrians is restricted. Crossing or reverse-flow movements face a high probability of conflict, requiring frequent changes in speed and position. The LOS provides reasonably fluid flow, but friction and interaction between pedestrians is likely.	>1.4-2.2	>33-49
At LOS E, virtually all pedestrians restrict their normal walking speed, frequently adjusting their gait. At the lower range, forward movement is possible only by shuffling. Space is not sufficient for slowly walking pedestrians to pass. Cross- or reverse-flow movements are possible only with extreme difficulties. Design volumes approach the limit of walkway capacity, with stoppages and interruptions to flow.	>0.75-1.4	>49-75
At LOS F, all walking speeds are severely restricted, and forward progress is made only by shuffling. There is frequent unavoidable contact with other pedestrians. Cross-and reverse-flow movements are virtually impossible. Flow is sporadic and unstable. Space is more characteristic of queued pedestrians than of moving pedestrian streams.	≤0.75	variable

The area was calculated as (m^2)/2 on the assumption that there were 2 m^2/person on average by considering the level C based on the density of persons who walk around the bazaar and the wideness of roads. Ando et al. [28] defined the crowd density as 0.54 – 3.76 persons/m2.

In this study, the nodes are indicated as N01, N02, …, N28 and shown in Fig. 4. The gates are expressed as D01-N10, D02-N11, etc. The gates and nodes as well as the distance between gates d_{ij} are given in Appendix 1. The total number of people (f_{ij}) is calculated as the sum of the average number of people that visit the Grand Bazaar and the fixed number of people employed the shopping area and is shown in Appendix 2. The loading value ($d_{ij} * f_{ij}$) was calculated by multiplying distance and total number of people in the Grand Bazaar. More than one assignment must be made to some gates in order to be able to assign 50 nodes to 12 gates. Therefore, the exit capacities of some gates were adjusted to be more than 1 based on the wideness of the gates and status of streets on which they open. The capacities of gates b_j are given in Table 2. All data are designed as matrix format in the Excel spreadsheet. All matrices are defined as a reference name and then the 0-1 mixed integer linear programming model in Analytic Solver Platform was used to solve the GAP problem. This setting is shown in Fig. 5.

The Solver settings would be:

Objective function:

Minimize $AC$53 (Total Loading)

Variables:

Assignments ($P$3:$AA$52)

Constraints:

Assignments_per_door ($AB$3:$AB$52) = 1;

Total_per_door ≤ Required_per_door (P$53:$AA$53 ≤ P$54:$AA$54)

Binary:

Assignments= binary

The GAP model is solved as 0-1 mixed integer programming model by using Analytic Solver Platform. The model established by the data considered in the study is solved on a PC with the capacity of Intel(R) Core(TM) i3-4005U CPU @ 1.70GHz, 4.0 GB RAM in 10.78 seconds with 600 variables and 72 constraints. The below-mentioned solver model was established to obtain the solution assignments matrix given in Appendix 3.

Table 2. Capacity of gates/exit doors

Gates/Exit Doors	D01	D02	D05	D07	D09	D11	D12	D14	D15	D16	D18	D20	Total
Capacity	3	5	5	1	5	5	4	2	6	2	6	6	50

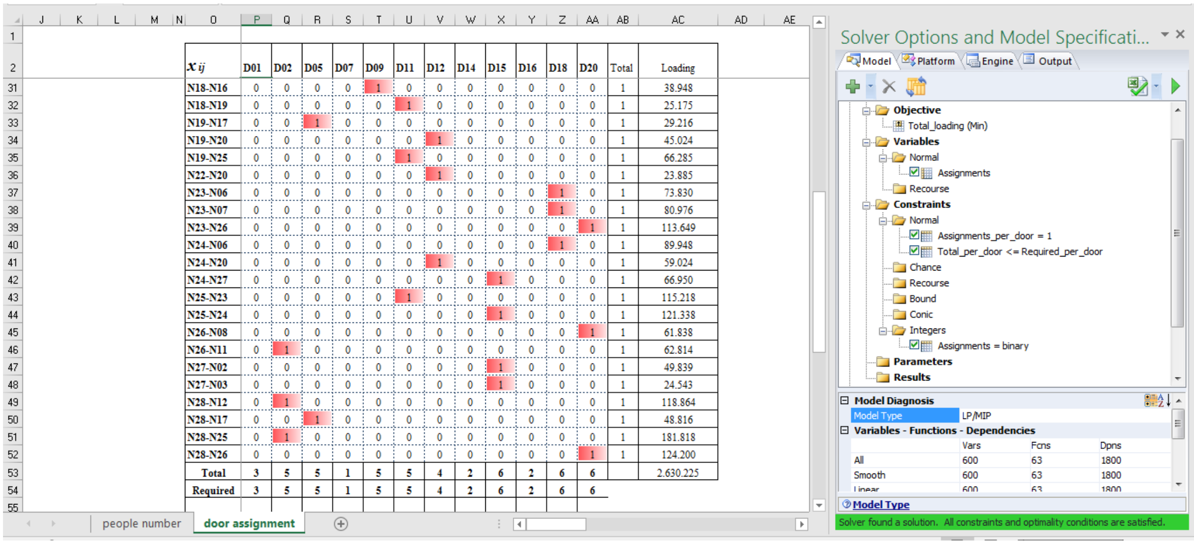

Fig. 5. The model interface view with the Analytic Solver Platform in Excel

Table 3. The result of assignment to gates/ exit doors

Gates/ Doors	Locations						Number of people
D01	D01-N10	N08-N10	N10-N11				1657
D02	D02-N11	N11-N12	N26-N11	N28-N12	N28-N25		3375
D05	D05-N13	N13-N12	N17-N13	N19-N17	N28-N17		1425
D07	D07-N13						412
D09	D09-N15	D10-N15	N15-N16	N16-N17	N18-N16		1903
D11	D11-N18	D11-N22	N18-N19	N19-N25	N25-N23		1912
D12	D12-N22	N19-N20	N22-N20	N24-N20			1270
D14	D14-N02	N02-N20					2177
D15	D15-N03	N03-N06	N24-N27	N25-N24	N27-N02	N27-N03	2524
D16	D16-N03	D16-N05					441
D18	D18-N05	N05-N07	N06-N05	N23-N06	N23-N07	N24-N06	3491
D20	D20-N09	N07-N08	N09-N08	N23-N26	N26-N08	N28-N26	3688

Table 3 shows the locations assigned to exit doors/gates and number of people predicted to exit from gates. Based on the results given in Table 3, for example; the evacuation of 1657 people who are located between N10, N08 and N11 nodes may be ensured from D1 gate. It is foreseen that the maximum number of people will be evacuated from D20 gate. The routes suggested for evacuation in case of emergency in the diagram of Grand Bazaar are given in Fig.6.

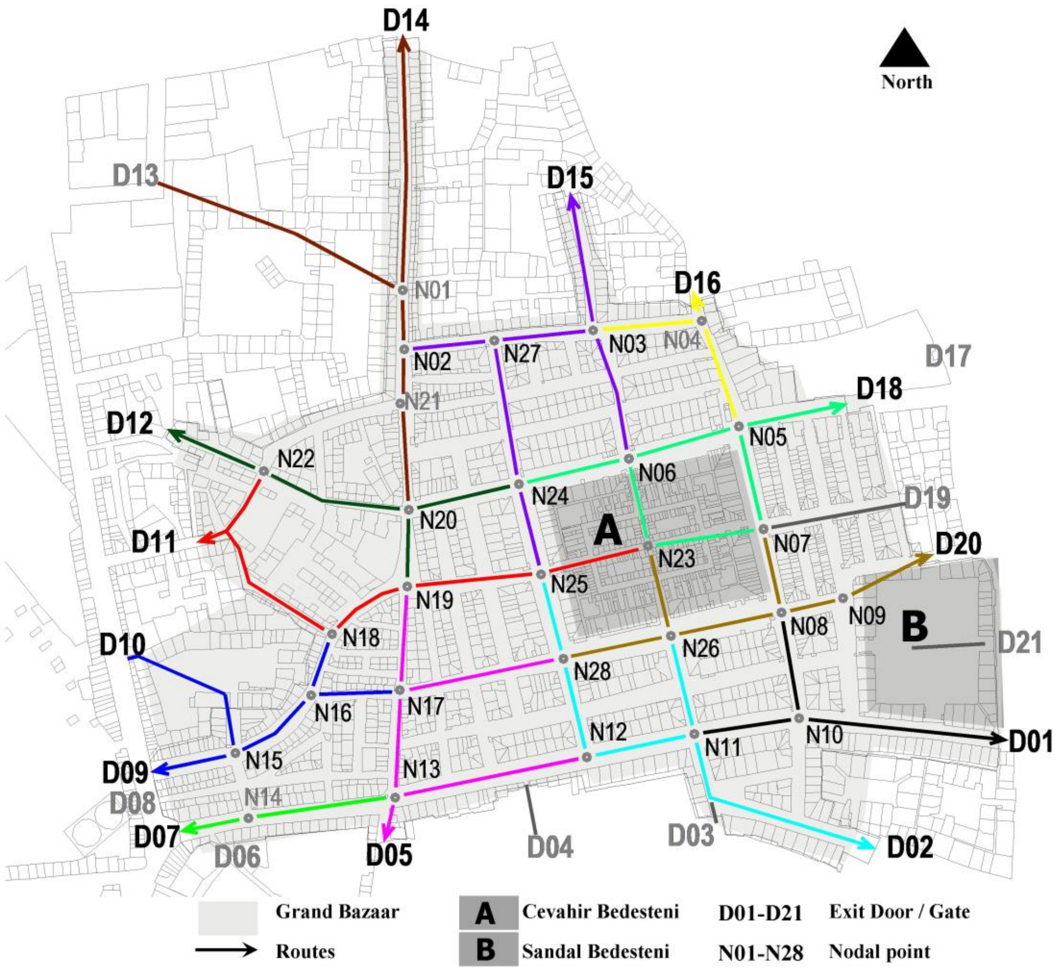

Fig. 6. The results of evacuation route planning for Istanbul Grand Bazaar

5. Results

Based on the results of the model (Fig. 6), the busiest gates in the Grand Bazaar are gates no: D20, D18, D14 and D02. The grid planned road order around the two bedestens indicates that there will be density flow from nodal points specifically around Cevahir bedesten (A in Fig.6) to gates/exit doors. Linear routes play a role in facilitating movement during evacuation. The main axes should be determined for evacuation by taking into consideration that the number of nodes requiring a change in direction for evacuation are high and the density in exit lines may vary based on the number of visitors and in this way, the improvement of escape complicating aspects present on these axes should be planned. The escape in the direction of gates no: D07, D09, D11 and D12 involves various levels of elevation. Having a slope has an adverse effect on evacuation. It may be said that the evacuation will be in the direction of elevation and gates no: D20 and D18 have adverse conditions in this regard. The exit route for gate no: D14 may pose a challenge in evacuation because of the road wideness, length and low possibility of alternative exit ways. In this regard, the road connections for inn buildings which open into the Grand Bazaar and are interconnected with the exterior roads should be improved and the burden should be placed on the main exit routes.

6. Conclusion

In this study, an analytic approach was suggested to provide for the safe evacuation of people who are in indoors in an emergency case, using the most convenient roads and doors without causing a commotion. In addition to this, all roads and doors in the historical Grand Bazaar were investigated and the wideness of roads and accessibility of access areas to exits were also taken into consideration. The evacuation plan was considered as a GAP and 0-1 mixed integer programming model was suggested for solution. In the model, the evacuation which ensured the least load for evacuation of the Grand Bazaar was created based on distances and number of persons. With mobile applications and indicators as the continuation of this study, the aim is to communicate the most convenient evacuation route to the people in the Grand Bazaar with the help of navigation features.

The implementation of a stochastic programming model may be undertaken in future studies by considering the variability of the number of people in the bazaar. The nodal points within the bazaar which were determined in the study have different properties. The interconnected nodal points have a homogenous character. Therefore, it will be significant in future studies to consider the efficiency of intermodal variability for evacuation.

Istanbul Grand Bazaar is a whole with its physical dimensions and the culture of commerce it contains. The precaution of protecting the integrity is prioritized. It may be also considered that the economic cost of sectoral discrimination in the bazaar is a disaster risk-increasing factor within the evaluation criteria.

The improvement of current exit doors should be prioritized to ensure safe evacuation conditions. The Grand Bazaar structural conditions should be dealt with together in the determination of evacuation routes. Prioritized planning should be completed for current risky sections. The necessity for ensuring safety in case of a disaster in terms of values that the bazaar incorporates reveals the significance of planning for the evacuation of valuable items-goods.

References

[1] R. L. Francis, "A 'Uniformity principle' for evacuation route allocation. Journal of Research of National Bureau of Standards", 86, pp. 509-513, 1981.

[2] S. C. Pursals and F. G. Garzon, "Optimal building evacuation time considering evacuation routes" European Journal of Operational Research, 192, pp. 692–699, 2009.

[3] J. Kang, I.-J. Jeong and J.-B. Kwun, "Optimal facility–final exit assignment algorithm for building complex evacuation" Computers & Industrial Engineering, 85, pp. 169–176, 2015.

[4] O. A. Cuesta, "Real-time evacuation route selection methodology for complex buildings", Fire Safety Journal, 91, 947–954, 2017.

[5] P.-H. Chen and F. Feng,"A fast flow control algorithm for real-time emergency evacuation in large indoor areas", Fire Safety Journal, 44, 732–740, 2009.

[6] C. Boonmee, M. Arimura and T. Asada, "Facility location optimization model for emergency humanitarian logistics" International Journal of Disaster Risk Reduction, 24, 485–498, 2017.

[7] S. Alighadr, A. Fallahi, J. Kiyono, F. N. Rizqi and M. Miyajima, "Emergency evacuation during a disaster, study case: Timche Muzaffariyye - Tabriz Bazaar". 15WCEE World Conference Earthquake Engineering, (p. Paper No. 3370). Lisbon, Portugal, 2012.

[8] L. Zhang, M. Liu, X. Wu, and S. M. AbouRizk, "Simulation-based route planning for pedestrian evacuation in metro stations: A case study", Automation in Construction, 71, pp. 430–442, 2016.

[9] H. Y. Şehsuvaroğlu, "Kapalıçarşı ve Tarihi. Türkiye Turing ve Otomobil Kurumu", pp. 6-7, 1954.

[10] Ç. Gülersoy, "Kapalı Çarşının Romanı", İstanbul : İstanbul Kitaplığı Ltd. Yayını, 1979.

[11] M. Cezar, "Tipik Yapılariyle Osmanlı Şehirciliğinde Çarşı ve Klasik Dönem İmar Sistemi" İstanbul: Mimar Sinan Üniversitesi Yayını, Milli Eğitim Basımevi, 1985.

[12] A. Batur and G. Tanyeli, "1894 Depremi ve İstanbul'un Tarihi Yapılarındaki Hasar Üzerine Bir Örnekleme Çalışması: Kapalıçarşı", 2.Ulusal Deprem Mühendisliği Konferansı, 244-252, İstanbul, 1993.

[13] W. Müller-Wiener, "İstanbul'un Tarihsel Topografyası", İstanbul: Yapı Kredi Yayınları, 2001.

[14] G. Yücel, "Deprem Tehlikesi ve Tarihi Çarşılar: İstanbul Kapalıçarşı", 3. Türkiye Deprem Mühendisliği ve Sismoloji Konferansı. İzmir: Dokuz Eylül Üniversitesi, 2015.

[15] G. Yücel and G. Arun, "Istanbul Grand Bazaar Evacuation System Vulnerability Assessment", Advanced Materials Research, 133-134, pp. 611-616, 2010.

[16] K. Mortan and Ö. Küçükerman, (2007). "Çarşı, Pazar, Ticaret ve Kapalıçarşı", Türkiye İş Bankası Kültür Yayınları, Ankara, 2007.

[17] D. W. Pentico, "Assignment problems: A golden anniversary survey", International Journal of Modern Physics B, 23(2), pp. 169-176, 2007.

[18] G. T. Ross and R. M. Soland, "A branch and bound algorithm for the generalized assignment problem" Mathematical programming, 8(1), pp. 91-103, 1975.

[19] Z. Drezner, "A new genetic algorithm for the quadratic assignment problem", INFORMS Journal on Computing, 15 (3), pp. 320–330, 2003.

[20] A. N. Elshafei, "Hospital layout as a quadratic assignment problem", Operational Research Quarterly, 28 (1), 167–179, 1977.

[21] R. Burkard, "Quadratic assignment problems", European Journal of Operational Research, 15 (3), pp. 283–289, 1984.

[22] L. Tsui and C.-H. Chang, "An optimal solution to a dock door assignment problem", Computers & Industrial Engineering, 23 (1–4), pp. 283–286, 1992.

[23] E. Çela, "The Quadratic Assignment Problem: Theory and Algorithms", Dordrecht, The Netherlands: Kluwer Academic Publishers, 1998.

[24] S. Bretschneider and A. Kimms, "A basic mathematical model for evacuation problems in urban areas", Transportation Research Part A, 45, pp. 523-539, 2011.

[25] H. Vermuyten, J. Belien, L. D. Boeck, G. Reniers and T. Wauters, "A review of optimisation models for pedestrian evacuation and design problems", Safety Science, 87, pp. 167-178, 2016.

[26] R. Swamy, J. Kang, R. Batta and Y. Chung, "Hurricane evacuation planning using public transportation", Socio-Economic Planning Sciences, 59, pp. 43-55, 2017.

[27] K. Ando, H. Ota and T. Oki, "Forecasting the flow of people", RRR, Railway Research Review, 45(8), pp. 8–14 (in Japanese), 1988.

[28] Transport Research Board. HCM Highway Capacity Manual. Highway Capacity Manual. National Research Council, National Academy of Science, 2000.

Appendix 1. Distances from gates to nodes, d_{ij} (m)

Gates/ Nodes	D01	D02	D05	D07	D09	D11	D12	D14	D15	D16	D18	D20
D01-N10	71	130	223	281	308	346	370	410	289	210	205	163
D02-N11	183	81	200	258	285	331	367	439	341	260	256	213
D05-N13	224	202	17	91	118	163	199	272	307	299	294	255
D07-N13	282	260	91	74	175	221	255	330	335	356	351	312
D09-N15	308	286	118	75	28	142	190	300	305	385	325	283
D10-N15	335	312	145	102	85	168	220	326	347	324	352	365
D11-N18	400	377	210	167	150	65	68	391	412	389	417	430
D11-N22	364	360	195	252	158	30	65	210	215	210	232	320
D12-N22	370	365	200	257	192	65	35	214	220	213	237	325
D14-N02	412	407	272	330	313	208	212	105	215	210	280	369
D15-N03	290	283	309	365	323	215	219	215	50	85	158	245
D16-N03	245	241	335	394	335	275	280	210	88	40	115	203
D16-N05	212	206	300	358	313	244	244	317	121	43	80	167
D18-N05	205	200	294	351	306	280	238	310	158	80	35	160
D20-N09	130	160	254	312	283	302	338	411	245	167	160	40
N02-N20	337	336	168	225	194	135	140	159	165	160	206	293
N03-N06	254	247	262	320	276	205	208	217	92	86	122	210
N05-N07	169	163	258	315	288	232	235	280	157	78	72	124
N06-N05	208	202	255	353	269	197	201	254	133	81	76	164
N07-N08	133	127	221	278	253	271	265	309	185	107	101	90
N08-N10	104	98	193	250	277	279	318	343	222	144	137	97
N09-N08	114	120	205	272	245	264	304	330	207	129	124	60
N10-N11	104	98	157	214	240	287	322	390	258	180	172	134
N11-N12	141	118	120	177	204	251	286	358	262	216	210	171
N13-N12	207	184	83	140	167	214	249	322	291	283	277	238
N15-N16	312	289	122	79	62	112	164	271	291	268	151	255
N16-N17	273	239	83	140	92	112	162	250	276	271	262	222
N17-N13	242	220	52	110	137	147	182	256	281	276	267	226
N18-N16	300	338	88	145	91	85	153	224	229	214	286	381
N18-N19	365	342	175	132	115	95	98	421	442	419	382	395
N19-N17	278	256	88	145	172	125	147	220	241	236	213	226
N19-N20	304	281	113	171	140	115	112	185	190	188	178	252
N19-N25	250	227	193	250	160	135	159	230	205	196	190	210
N22-N20	334	333	165	222	191	81	85	210	216	215	203	290
N23-N06	237	232	248	384	331	188	192	246	124	112	107	193
N23-N07	144	138	233	290	346	319	281	317	195	119	112	137
N23-N26	173	145	187	243	269	236	271	344	257	176	170	129
N24-N06	245	240	190	273	301	157	163	235	130	118	113	200
N24-N20	283	251	153	210	192	119	124	197	168	157	152	239
N24-N27	285	262	228	285	259	168	173	185	130	123	163	245
N25-N23	241	205	185	242	268	173	197	252	160	187	181	201
N25-N24	235	213	178	236	209	165	155	228	162	150	145	196
N26-N08	142	153	192	250	224	243	282	352	266	145	140	98
N26-N11	137	114	154	212	239	239	274	348	257	179	173	131
N27-N02	315	293	198	256	225	134	139	135	111	105	176	276
N27-N03	277	296	232	319	260	168	173	170	81	75	146	234
N28-N12	175	152	117	175	202	203	238	311	225	217	211	170
N28-N17	231	208	108	166	148	167	203	276	246	241	230	191
N28-N25	204	182	147	205	178	164	185	260	194	180	205	164
N28-N26	175	152	154	212	186	206	240	314	228	182	177	135

Appendix 2. The number of people between gates and nodes, f_{ij}

Gates/ Nodes	D01	D02	D05	D07	D09	D11	D12	D14	D15	D16	D18	D20
D01-N10	444	700	1076	1486	1730	1953	1729	2667	1594	1263	1232	669
D02-N11	1046	419	1018	1387	1558	1523	2007	2609	1902	1571	1540	1067
D05-N13	1227	1084	43	453	622	587	734	1672	1163	1180	1720	1247
D07-N13	1506	1298	361	412	641	770	946	1952	1718	1815	2000	1527
D09-N15	1767	1558	622	733	163	604	935	1942	1433	1450	1840	1633
D10-N15	1954	1745	709	660	513	791	998	2129	1620	1637	2115	1974
D11-N18	1661	1453	597	969	926	143	364	1605	1172	1194	1377	1683
D11-N22	2089	1904	944	1209	951	347	458	1671	1162	1179	1633	2169
D12-N22	1831	1689	700	1106	811	206	111	1435	926	943	1398	2017
D14-N02	2537	2460	1392	1764	1662	1139	1155	958	1128	1145	1649	2295
D15-N03	1744	1706	1438	1810	1433	1102	926	1408	157	331	835	1481
D16-N03	1437	1497	1925	2205	1765	1222	584	1425	331	174	678	1498
D16-N05	1413	1375	1535	1907	1531	1200	1089	1522	428	267	504	1150
D18-N05	1382	1344	1720	2092	1840	1452	1469	2151	868	504	236	1119
D20-N09	909	871	1247	1619	1633	1894	2044	2575	1481	1150	1119	175
N02-N20	1861	1650	714	1085	983	543	541	1219	710	727	1249	1895
N03-N06	1616	1578	1162	1534	1432	991	990	1445	351	368	707	1353
N05-N07	1146	1107	1484	1855	1862	1519	1459	1917	1463	565	534	882
N06-N05	1422	1383	1465	1836	1477	1089	1087	1973	627	543	512	1158
N07-N08	1022	983	1364	1735	1744	1670	1579	2577	1332	1001	970	758
N08-N10	586	548	924	1296	1466	1317	1464	2394	1300	969	938	485
N09-N08	734	696	1072	1444	1450	1503	1625	2400	1306	975	1118	323
N10-N11	627	537	802	1174	1342	1307	1484	2329	1483	1152	1121	648
N11-N12	833	624	599	971	1139	1070	1182	2084	1538	1361	1326	853
N13-N12	1186	977	394	765	934	899	1046	1984	1397	1414	1662	1206
N15-N16	1706	1497	561	468	341	441	648	1779	1270	1287	1765	1462
N16-N17	1444	1301	321	693	458	381	635	1586	1077	1175	1578	1290
N17-N13	1349	1140	204	575	638	546	693	1631	1122	1139	1591	1118
N18-N16	1381	1388	408	688	428	230	451	1575	1068	1166	1475	2073
N18-N19	1518	1309	454	825	783	265	509	1461	1028	1050	1233	1540
N19-N17	1396	1188	332	704	587	435	530	1468	959	976	1240	1297
N19-N20	1598	1390	453	825	723	353	402	1340	907	929	1112	1418
N19-N25	1480	1271	520	892	790	491	590	1528	957	974	1346	1858
N22-N20	1720	1577	623	994	892	264	281	1388	1005	1027	1160	1562
N23-N06	1600	1561	1367	1738	1379	939	937	1875	529	557	690	1336
N23-N07	1036	980	1380	1752	1546	1319	1266	2204	920	754	723	773
N23-N26	1010	801	982	1353	1348	1121	1268	2206	1132	1005	1182	881
N24-N06	1705	1667	1189	1560	1201	761	759	1697	635	827	796	1442
N24-N20	1639	1431	1130	1274	918	477	476	1414	812	892	991	1831
N24-N27	1928	1824	1116	1489	1166	689	688	1317	515	532	1014	1724
N25-N23	1450	1216	973	1345	1022	666	822	1760	952	980	1113	1439
N25-N24	1348	1140	975	1347	1101	650	710	1585	749	766	1030	1488
N26-N08	894	856	1040	1411	1394	1319	1466	2296	1612	1134	1104	631
N26-N11	760	551	732	1103	1159	1083	1702	2577	1265	1087	1236	763
N27-N02	1973	1865	860	1232	1130	817	728	1105	449	466	970	1775
N27-N03	1906	1802	1281	1653	1407	1179	852	1251	303	320	824	1470
N28-N12	990	782	551	923	864	789	981	1856	1223	1344	1415	1078
N28-N17	1271	1166	452	824	707	631	779	1717	1201	1218	1648	1887
N28-N25	1284	999	807	1178	962	787	872	1747	1097	1114	1362	1176
N28-N26	1125	841	981	1083	996	921	1113	1988	1338	1318	1393	920

Appendix 3. The assignment results of locations

Gates/Nodes	D1	D2	D5	D7	D9	D11	D12	D14	D15	D16	D18	D20	Total assignment	Total Loading
D01-N10	1	0	0	0	0	0	0	0	0	0	0	0	1	31.524
D02-N11	0	1	0	0	0	0	0	0	0	0	0	0	1	33.939
D05-N13	0	0	1	0	0	0	0	0	0	0	0	0	1	731
D07-N13	0	0	0	1	0	0	0	0	0	0	0	0	1	30.488
D09-N15	0	0	0	0	1	0	0	0	0	0	0	0	1	4.564
D10-N15	0	0	0	0	1	0	0	0	0	0	0	0	1	43.605
D11-N18	0	0	0	0	0	1	0	0	0	0	0	0	1	9.295
D11-N22	0	0	0	0	0	1	0	0	0	0	0	0	1	10.410
D12-N22	0	0	0	0	0	0	1	0	0	0	0	0	1	3.885
D14-N02	0	0	0	0	0	0	0	1	0	0	0	0	1	100.590
D15-N03	0	0	0	0	0	0	0	0	1	0	0	0	1	7.850
D16-N03	0	0	0	0	0	0	0	0	0	1	0	0	1	6.960
D16-N05	0	0	0	0	0	0	0	0	0	1	0	0	1	11.481
D18-N05	0	0	0	0	0	0	0	0	0	0	1	0	1	8.260
D20-N09	0	0	0	0	0	0	0	0	0	0	0	1	1	7.000
N02-N20	0	0	0	0	0	0	0	1	0	0	0	0	1	193.821
N03-N06	0	0	0	0	0	0	0	0	1	0	0	0	1	32.292
N05-N07	0	0	0	0	0	0	0	0	0	0	1	0	1	38.448
N06-N05	0	0	0	0	0	0	0	0	0	0	1	0	1	38.912
N07-N08	0	0	0	0	0	0	0	0	0	0	0	1	1	68.220
N08-N10	1	0	0	0	0	0	0	0	0	0	0	0	1	60.944
N09-N08	0	0	0	0	0	0	0	0	0	0	0	1	1	19.380
N11-N12	0	1	0	0	0	0	0	0	0	0	0	0	1	73.632
N10-N11	1	0	0	0	0	0	0	0	0	0	0	0	1	65.208
N13-N12	0	0	1	0	0	0	0	0	0	0	0	0	1	32.702
N15-N16	0	0	0	0	1	0	0	0	0	0	0	0	1	21.142
N16-N17	0	0	0	0	1	0	0	0	0	0	0	0	1	42.136
N17-N13	0	0	1	0	0	0	0	0	0	0	0	0	1	10.608
N18-N16	0	0	0	0	1	0	0	0	0	0	0	0	1	38.948
N18-N19	0	0	0	0	0	1	0	0	0	0	0	0	1	25.175
N19-N17	0	0	1	0	0	0	0	0	0	0	0	0	1	29.216
N19-N20	0	0	0	0	0	0	1	0	0	0	0	0	1	45.024
N19-N25	0	0	0	0	0	1	0	0	0	0	0	0	1	66.285
N22-N20	0	0	0	0	0	0	1	0	0	0	0	0	1	23.885
N23-N06	0	0	0	0	0	0	0	0	0	0	1	0	1	73.830
N23-N07	0	0	0	0	0	0	0	0	0	0	1	0	1	80.976
N23-N26	0	0	0	0	0	0	0	0	0	0	0	1	1	113.649
N24-N06	0	0	0	0	0	0	0	0	0	0	1	0	1	89.948
N24-N20	0	0	0	0	0	0	1	0	0	0	0	0	1	59.024
N24-N27	0	0	0	0	0	0	0	0	1	0	0	0	1	66.950
N25-N23	0	0	0	0	0	1	0	0	0	0	0	0	1	115.218
N25-N24	0	0	0	0	0	0	0	0	1	0	0	0	1	121.338
N26-N08	0	0	0	0	0	0	0	0	0	0	0	1	1	61.838
N26-N11	0	1	0	0	0	0	0	0	0	0	0	0	1	62.814
N27-N02	0	0	0	0	0	0	0	0	1	0	0	0	1	49.839
N27-N03	0	0	0	0	0	0	0	0	1	0	0	0	1	24.543
N28-N12	0	1	0	0	0	0	0	0	0	0	0	0	1	118.864
N28-N17	0	0	1	0	0	0	0	0	0	0	0	0	1	48.816
N28-N25	0	1	0	0	0	0	0	0	0	0	0	0	1	181.818
N28-N26	0	0	0	0	0	0	0	0	0	0	0	1	1	124.200
Total loading	3	5	5	1	5	5	4	2	6	2	6	6	50	2.630.225
Total Capacity	3	5	5	1	5	5	4	2	6	2	6	6	50	