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A GIS Based University's Campus Evacuation Plan in Case of Emergencies

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Abstract

Emergencies are bound to happen anywhere and at any time and as such pre-planning are necessary. There is limited attention, in the literature, on optimisation of resources in campus emergency planning, especially in developing countries. This study was therefore, designed to examine how students on a university campus can be optimally evacuated safely, in case of an emergency. The Central Place theory provided the framework, while a survey research design was adopted for the study. Olabisi Onabanjo University, Nigeria was purposively selected being a large university with poor previous response to emergencies. A total of 150 students were randomly selected across six faculties of the University. Location-allocation (L-A) model and binary logistic regression analysis were used for data analysis. Male students of the University were 50.7% and 94% of the students were between 18 and 30 years. Average lecture-hall capacity was 1143 ± 889 students, while average travel distance to lecture-halls was 369.49 ± 144.02 metres. The five-bus and six-bus emergency plans gave a maximum travel distance of 676.1 metres and 441.83 metres respectively. There was a 77.13% reduction in average travel distance between five-bus and six-bus emergency plans. The binary logistic regression model showed that 'consciousness of emergencies' ($B = 2.82$; $p \geq 0.05$) was the only factor that will significantly influence students to assist in an emergency. The optimal campus emergency plan provided an efficient evacuation of students. Thus planning strategy that can optimise resources should be adopted in emergencies.

Keywords: Decision Support System, Emergency Preparedness, Evacuation Plan, Location-Allocation Models, University Campus

Introduction

Emergencies can happen anywhere, at any time, and include everything from a natural disaster to a medical incident, to a fire. Thus, a definite plan to deal with major emergencies should be an important element of any organization or community. The attitude of 'it can't happen here' should not be entertained by organisations and communities. Since emergencies will occur, pre-planning is necessary. However, current trends show that, although, people are aware of hazards, they are often not adequately prepared for emergencies. Failure to plan can be construed as negligence. A major benefit of a plan is to provide guidance during an emergency.

Emergency planning and management is in phases. The phases are; overlapping, interwoven and related (Alexander, 2002; Quarantelli, 2005). They cover measures put in place in advance of a disaster (mitigation) and operational plans to facilitate an effective and efficient response to emergencies should they occur (preparedness). Also, it includes all the activities undertaken immediately before, during, and after a disaster or emergency occurs (response), and the set of activities undertaken after a disaster or emergency event (recovery).

Emergencies being, unfortunately, part of our lives, it is crucial to efficiently plan and allocate emergency response facilities that deliver effective and timely relief to people most in need. Emergency service facility allocation problems deal with locating emergency facilities among potential sites, to provide efficient and effective services over a wide area, with spatially distributed demands. In the past few decades, emergency service locations have drawn a great deal of attention from researchers (Algharib, 2011).

In such service location planning response, time is a critical factor when making decisions on the system configurations that determine life or death. If the emergency response system cannot provide service promptly, people's lives are jeopardized. The central place theory proposed by Walter Christaller, in 1933, is a model of optimum spatial location of facilities, which is concerned with the principle which states that facilities will be located at the point of minimal travel. Location-allocation models were formulated to operationalize this principle. Generally, location-allocation (L-A) problem is concerned with the siting of one or more facilities (the location problem) and the allocation of consumers to these facilities, in a way that optimizes certain objectives (called the objective function)+ such as: minimizing transportation costs/ distance travelled or maximizing population covered.

There are many variants of L-A models. The most commonly used L-A models are those based on minimizing distance and those based on maximizing coverage (Ghosh and Rushton, 1986). These models are the p-median and the covering models. The basic difference between the p-median and covering models is that, while the former seeks to minimise the weighted total distance traveled to a facility, the latter seeks to provide coverage to demand points, by bringing service within a specified distance or time, to the consumers (Church and ReVelle, 1974; Marianov and Serra, 2004). Most previous studies on application of L-A models in developing countries are in the realm of public health planning to effectively allocate resources and improve operations (Rahman & Smith, 2000). Studies that have applied L-A models to emergency planning are not common, especially in developing countries. One of the few studies that have applied L-A model in the area of emergency planning in a developing nation is by Algharib (2011).

Recent occurrences of natural and man-made disasters, such as fire, landslides, terrorist attacks, etc., are all over the world and university campuses are not excluded. For example in Nigeria a particular terrorist group is threatening university campuses. Thus university authorities need to have emergency plans in place to protect lives and properties. One major concern and challenge is how to optimise available resources in executing such plans. This study proposed a location-allocation (L-A) model based decision support system (DSS) to optimise deployment of resources in operationalizing a campus evacuation plan. A DSS is a computerized information system used to support decision-making in an organization (Investopedia, 2018).

The DSS is implemented within a geographic information system (GIS) environment and support such decisions as: (1) determining the number buses required to evacuate all student, (2) determining the optimal number and locations of evacuation points, and (3) compare different emergency plans to determine the most efficient. The proposed DSS, in this study, will assist the university's authority to safely evacuate the students out of the campus with the available number of buses, within the shortest possible time (or distance). However, for a well-designed emergency plan to be successful there must be collaboration and cooperation from the stakeholders, i.e. university staff, students and emergency service providers. Cooperation from the students is essential, hence this study examined factors that will predict students' willingness to assist others, especially visitors in the event of an emergency.

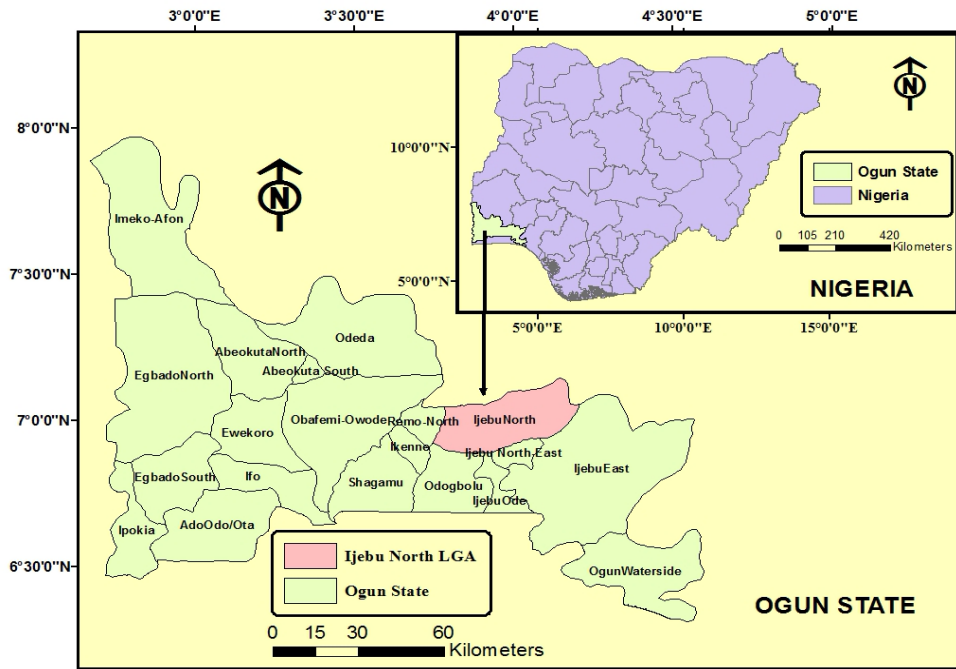
Materials and Methods

The proposed campus emergency preparedness plan covers evacuation plans for individual buildings and the whole campus. Emergency events like fire or a report of bomb threat within a building will require evacuating the occupants of the building concerned. The occupants are to move to a designated assembly area for the building. The detail of these procedures is not the focus of this study. However, emergencies like a gun attack by a gang, kidnapping of students, flooding of rivers, earthquake, forest wildfires, etc, will require the operationalization of a prepared plan for the whole campus. A proposal for such an evacuation plan is discussed in this study.

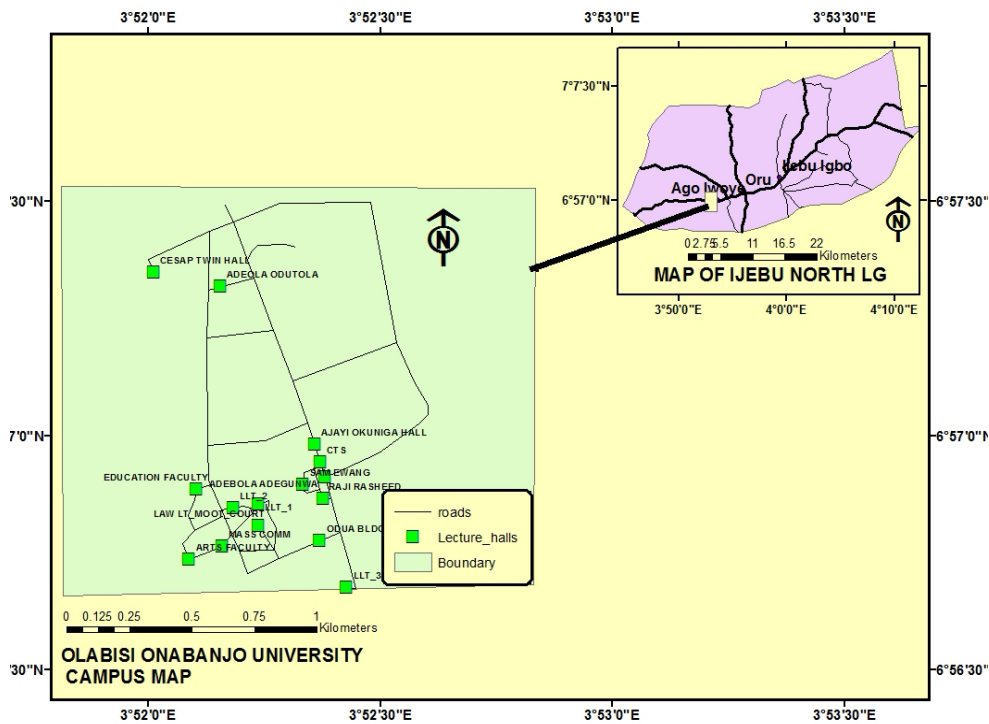
This study proposed a location-allocation (L-A) model-based decision support system (DSS) to implement the campus evacuation plan. A DSS is a computerized information system used to support decision-making in an organization. The DSS was implemented within ArcGIS v.10.3, a proprietary geographic information system (GIS). The DSS in this study provides an answer to “what-if-questions”. A given problem that can be posed for the DSS to solve is: “Find the locations of a number of evacuation points that will minimise the travel distance or time of all evacuees from known assembly areas”. The question can also be: “Find the minimum number of evacuation points required?” and “If the number of evacuation points increases by n , what will be the average distance or time of travel?”

The database for the DSS contains the coordinates of the centroids of the emergency assembly areas and their expected capacity. Also, the coordinates of the centroids of prospective evacuation points. The transport links in the area are also in the database. In this study, the motorable roads and footpaths are used, since in some cases, the campus occupants will get to the assembly area through the footpaths. The study area is Olabisi Onabanjo University, Nigeria. It is located at longitude 30 52” east of the Greenwich Meridian and at latitude 60 55” north of the Equator. See figure 1 for the location map.

This study obtained and ‘geo-referenced’ (i.e. aligned the map to actual ground coordinates) the Google map of Olabisi Onabanjo University. The coordinates of the centroids of the assembly areas and evacuation points, as well as the transport links, were obtained from the prepared map by digitizing them. These data were stored in the database of the GIS and used in the location-allocation (L-A) modelling to implement the DSS.



a



b

Figure 1: Study Area for this study. a) Nigeria and Ogun state showing Ijebu North Local Government Area, b) Ijebu North Local Government Area and Olabisi Onabanjo University Campus, Ago-Iwoye, the Study Area

Location-Allocation Model

Location-allocation methods are based on algorithms used to determine an optimal location for one or more facilities that will service demand from a given set of points. The particular location-allocation model used in this study is the p-median model. The objective of the p-median model is to minimise the total travel distance from a set of demand points (in our case – the assembly areas for lecture halls) to a set of facilities (in this study – the evacuation points). The specification of the p-median is:

$$\text{Minimize } Z = \sum_{i=1}^n \sum_{j=1}^p O_i \lambda_{ij} C_{ij} \quad (1)$$

Subject to the constraints:

$$\sum_{j=1}^p \lambda_{ij} = 1 \quad (2)$$

And

$$\lambda_{ij} = (1, 0) \quad \forall i, j \quad (3)$$

Where:

O_i = the quantity demanded at location i which has the coordinates (x_i, y_i)
 λ_{ij} = a binary variable equal to 1 if demand point i is allocated to centre j and equal to 0 if demand point is allocated elsewhere (consumers are allocated to their nearest centre).

Collaboration of students is essential for a successful campus emergency evacuation, as such, this study examined factors that will predict students’ behaviour in an emergency. Students of Olabisi Onabanjo University (OOU), Ago-Iwoye, Nigeria were surveyed in this study. The University is a state (owned and operated) university in Ago-Iwoye, Ogun State, Nigeria. The university has multiple campuses with the main campus (study location) in Ago-Iwoye. There are six faculties at the main campus with a students’ population of 17,914. One hundred and fifty students were selected randomly across the six faculties. The number of students selected in each faculty is proportional to the total in the faculty (see table 1).

The binary logistic regression model was used to predict the probability of a student of the University helping in the event of an emergency. Binary logistic regression is a statistical technique that can be used to predict the relationship between predictors (our independent variables) and a predicted variable (the dependent variable) where the dependent variable is dichotomous or binary in nature. There must be two or more predictors variables and they are tested, individually, to assess their predictive ability while controlling for the effects of other predictors in the model. The chi-square is used to statistically test whether including a variable in the predictive model increases goodness-of-fit measure. If chi-square is significant, the variable is considered to be a significant predictor in the equation.

The logistic regression or prediction equation for this study is given as;

$$y = \text{Log} \frac{p}{1-p} = \beta_0 + \beta_1 * X_1 + \beta_2 * X_2 - \beta_3 * X_3 + \beta_4 * X_4 \quad (4)$$

Where:

y is a dichotomous variable coded 1, if the student is willing to help in the event of an emergency and 0, if he/ she is not willing, and p is the probability of y .

β_0 is the intercept and $\beta_1 - \beta_4$ are the regression coefficients of $X_1 - X_4$; where $X_1 - X_4$ are the set of predictor variables.

The predictor variables used in this study are:

X_1 = gender of the respondents

X_2 = previous experience of an emergency situation

X_3 = previous involvement in a pre-emergency drill

X_4 = level of consciousness of an emergency

The variables are either dichotomous or categorical.

Table 1: Total number of students in each faculty under study

Faculty	No. of Students	No. of Sampled students
Administration and Managements Sciences	4155	35
Arts	2146	18
Education	2922	24
Law	1044	9
Science	4421	37
Social Sciences	3226	27
Overall Total No. Of Students	17914	150

Source: Olabisi Onabanjo University, Nigeria, Academics Affairs Unit, 2018

Table 2: Assembly points

Sn.	Assembly point location	Status
1	Students' hostel	Required
2	CESAP twin hall	Optional
3	Ajayi Okunuga and CTS	Optional
4	OGD and ICT centre	Required
5	Adebola Adegunwa and Sam Ewang	Optional
6	Large lecture theatre 1&2(LLT-1 & LLT-2)	Optional
7	Large lecture theatre 3(LLT-3), Moot court and Motion ground	Required
8	Law lecture theatre	Optional
9	Odua building	Optional
10	Mass com. lecture theatre	Optional
11	Arts Faculty	Optional
12	Education Faculty	Optional
13	Garage	Required

Results and discussion

In case of an emergency like a fire outbreak, within or close to a building, occupants are expected to move out of the building to a designated assembly area. Without the pre-planned assembly areas, chaos, panic, and more threats can ensue in the process of evacuation. Proposed assembly areas for Olabisi Onabanjo University main campus (see table 2 and figure 3) are at locations that are easily reachable from surrounding buildings. They are open lawn spaces. The recommended distance of an assembly area from a building is twice the height of the building (Viking, 2010). As none of the buildings on Olabisi Onabanjo University main campus is taller than 40 metres, the assembly areas are planned at about 80 metres from individual buildings. This is for extra safety in case the fire or earth quake, etc. were to cause the building to collapse. Head count, first aid, etc are to be applied at the assembly areas.

There are emergencies that might warrant the need for the whole university campus to be evacuated. In Nigeria, events like attacks from terrorists, armed robbers, bomb scares and kidnappers have occurred on some campuses. To evacuate the whole University campus, it is proposed that all the occupants are to leave the buildings to the designated assembly area for their building. The key problem is how to move all the occupants from the assembly areas out of the university campus, given the limited time and buses available.

This problem is what this study will attempt to solve. In this study, there are thirteen proposed assembly points. There are four big university buses and small commercially operated buses that are always available at the motor park, to be used to evacuate the students. The proposed evacuation plan is to allocate the thirteen assembly areas to five evacuation points from where the buses can move the students out of the campus in the shortest time. See Figure 2 for the configuration.

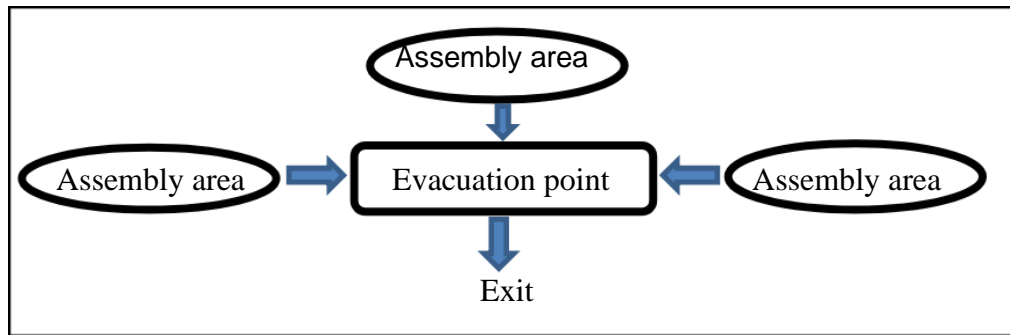


Figure 2: Outline of the University's emergency evacuation plan

The p-median location-allocation model is used to find the allocation plan that will minimise the travel distance from the thirteen assembly areas to chosen five evacuation points. The specific p-median model for this study is:

$$\text{Minimize } Z = \sum_{i=1}^n \sum_{j=1}^p O_i \lambda_{ij} C_{ij} \sum_{i=1}^n \sum_{j=1}^p O_i \lambda_{ij} C_{ij} \quad (5)$$

Location-allocation modelling normally requires that we know the demand (population) to be allocated to service centres. The population of students in the hostels, at the shopping centres and the ICT centre, at specific times of the day, might be difficult to estimate. Hence, these three places are designated as 'required' evacuation points, where buses must always be deployed in case of an emergency. The fourth 'required' evacuation point is the motor park. This is because it is part of the proposed evacuation plan that the small commercial buses at the motor park are to be used to complement the school buses in the event of an emergency. See the locations of the four required evacuation points in Figure 3.

The p-median solution to the location-allocation problem was done in a Geographic Information System environment (ArcGIS v10.15). Thirteen assembly areas were allocated to their nearest evacuation point via the shortest route, to achieve efficiency. Efficient allocation of resources is crucial in an emergency. The results of the allocation generated by the decision support system (DSS) is presented in table 3 and shown in Figures 3a and 3b. Figure 3a shows a five-bus emergency plan, where the five buses owned by the University and the commercially operated small buses will be used to evacuate students from five evacuation points. Each bus will be making trips from the assigned evacuation point to a designated safe location outside the campus. The p-median model of the DSS is to select 'freely', five optimal locations (locations that ensure minimum travel distance) out of thirteen potential sites for evacuation. However, the

proposed evacuation plan in this study, must always include four of the assembly areas as evacuation points. Thus, only one evacuation point can be freely chosen from nine assembly areas, to give the optimal solution. The five-bus solution (see Figure 3a) shows Large lecture theatre 1 (LLT-1) and Large lecture theatre 2 (LLT-2) assembly area chosen, in addition to the four required evacuation points. The decision support system in this study can provide a 'what-if-answer'. The emergency plan for six buses generated by the DSS is shown in Figure 3b. The four required evacuation points are still maintained, while LLT-1 and LLT-2 assembly areas (previously selected) and CESAP Hall assembly area were added. Table 3 also shows that the total capacity of the entire lecture halls is 11,431. This is an indication that at any given time, the University authority should be planning to evacuate about 11,400 students from the lecture halls. The last column in the table shows the travel distance from the assembly areas to the evacuation points for the five-bus plan. The summary statistics for the travel distance for the five-bus and six-bus emergency plans is presented in Table 4. The average distance from the lecture halls to the allocated evacuation centre is 328.43 metres for the five-bus plan, and this is reduced to 253.31 metres for the six-bus plan. The maximum distance that the farthest student will travel from an assembly area to an evacuation centre is 676.1 metres in the five-bus plan and this is reduced to 441.83 metres for the six-bus plan.

Emergency experience of students and their willingness to help in the event of an emergency

The success of an emergency plan will depend on the state of preparedness of all the stake holders. On a university campus, the students are in the majority and they must be prepared and willing to participate and help in an emergency situation. This section discusses results from a survey of the students of Olabisi Onabanjo University, Nigeria on their previous experience and readiness for emergencies. The demographic characteristics of the students are presented in Table 5. It is shown that 50.7 percent of the students involved in the survey are male. The age distribution of students involved in the survey shows that 1.3 percent are below 18 years, majority of the students are between 18 and 30 years, while 4 percent did not indicate their age. The survey also showed that 33.3 percent of the students have previously experienced an emergency situation. Involvement of students of the University in a pre-emergency drill was examined. A pre-emergency drill involves the simulation of an emergency with the aim of preparing the university community on the necessary actions to take when faced with a real emergency situation. About 74 percent of the students reported that they have not been previously involved in a pre-emergency drill. This indicates that the majority of the students have no idea of what necessary action to take in the event of an emergency. A study by Kapucu & Khosa (2013), across colleges in the United States, however, show that conducting regular pre-emergency drills and developing strong community partnerships, are the most important elements for creating a disaster-resilient university. However, Healy (2015) found in a campus safety survey, in the United States, that, 86 percent of United States institutions of higher education have an emergency operations plan (EOP), but about 26.5 percent have never conducted a comprehensive hazard and vulnerability assessment. This observation prompted the study author to question the effectiveness and accuracy of American colleges' current EOPs.

This study examined the willingness of the students to participate in a pre-emergency drill. The survey showed that 75.3 percent of the students are ready to participate if a pre-emergency drill is organised by the University. This study showed that 79.3 percent of the students are always conscious of the possibility of an emergency and as such are prepared. Tkachuck, et. al. (2018), however observed in their study that students' disaster consciousness was more related to perceived preparedness over actual preparedness and that their disaster experience significantly predicted both actual and perceived preparedness. Majority of the students in this study (91.3 percent), indicate that they are willing to render help to people in need during an emergency situation on campus. Factors that determine if a student will be willing to assist or not in the event of an emergency are examined in the following section.

Table 3: Allocation of assembly areas to evacuation points for the five-bus emergency plan

Sn	Assembly area to serve named lecture halls	Allocated evacuation point	Hall capacity	Travel distance
1	Ajayi Okunuga and CTS Halls	LLT-1 and LLT-2	646	441.83
2	Adebola Adenuga, Raji-Rasheed and Sam Ewang Halls	LLT-1 and LLT-2	1440	330.48
3	Large lecture theatre 1&2 (LLT-1& LLT-2)	LLT-1 and LLT-2	3084	0
4	Law lecture theatre	LLT-1 and LLT-2	610	262.99
5	Mass Com. lecture theatre	LLT-1 and LLT-2	426	280.47
6	Faculty of Arts lecture theatre	LLT-1 and LLT-2	834	388.61
7	Faculty of Education lecture theatre	LLT-1 and LLT-2	1089	212.13
8	CESAP Hall	OGD hall and ICT	810	676.10
9	Odua Building	LLT-3, Moot Court and Motion Ground (market)	249	363.27
10	Large lecture theatre 3 (LLT-3), Moot Court and Motion Ground (market)	LLT-3, Moot Court and Motion Ground ^a	2243	0
11	Students' hostel	Students' hostel ^a	Varies	0
12	Motor park	Motor park ^a	"	0
13	OGD hall and ICT	OGD hall and ICT ^a	"	0

^a Required evacuation point

Source: Computed from the p-median location allocation module of ArcGIS v10.15, 2018

Table 4: Summary of travel distance from assembly areas to evacuation points

Statistics	Distance in metres	
	Five-bus emergency plan	Six-bus emergency plan
Minimum	0 ^a	0 ^a
Maximum	676.1	441.83
Total travel	2,966.86	2,279.77
Mean travel	328.43	253.31
Standard deviation	172.09	150.09

^a Assembly area same as evacuation point.

Source: Computed from the p-median location allocation module of ArcGIS v10.15, 2018

Table 5: Demographic Characteristics of the students

Gender of students		
	Frequency	Percentage
No response	4	2.7
Male	76	50.7
Female	70	46.7
Age of students		
	Frequency	Percentage
No response	6	4.0
Below 18 years	2	1.3
18-30 years	141	94.0
31-50 years	1	0.7

Source: Authors' field survey, 2018

Examination of the decision of members of the university community to assist in the event of an emergency

Students and staff of the University should be fully informed and knowledgeable about evacuation procedures and should be ready to assist people, particularly the visitors, in an emergency. It is in line with this observation that this study used a binary logistic regression model to predict the willingness of the students to assist in the event of an emergency. The predicting factors in the logistic regression model are: gender, previous experience of emergency, previous involvement in a pre-emergency drill and level of consciousness of emergency.

The results from the modelling consist of an overall test of the model and test of significance of the coefficients. Table 6a shows omnibus tests of model coefficients. The p-value in the table is compared to a critical value (0.05) to determine if the overall model is statistically significant. The p value is the probability of obtaining the chi-square statistic (19.50) if there is in fact, no effect of the independent variables, taken together, on the dependent variable. In this study, the model is statistically significant because the p-value is 0.001. The indication is that the independent variables have a significant effect on the dependent variable. The regression coefficients (B) are shown in table 6b. The coefficients are the values for the logistic regression equation for predicting the dependent variable from the predictor (independent) variables.

The prediction equation expressed in terms of the variables used in this study is:

$$\log(p/1-p) = 0.584 + 0.498*\text{gender} + 0.912*\text{prev_exp} - 0.658*\text{involve_drill} + 2.817*\text{conscious} \quad (6)$$

Where p is the probability of willingness to assist in the event of an emergency.

The regression coefficients tell us about the relationship between the independent variables and the dependent variable. The regression coefficients in Table 6b, in the column labelled B, are in log-odds units, which are difficult to interpret, so they are often converted by exponentiation of the coefficients into odds ratios, and are in the column labeled "Exp(B)" in table 6b. The odds ratios present the extent to which raising the corresponding independent variable by one unit influences the odds ratio of the dependent variable. Wald and Sig. columns in Table 6b provide the Wald chi-square value and 2-tailed p-value used in testing the null hypothesis that the coefficient (parameter) is 0.

Coefficients having p-values less than alpha (0.05) are statistically significant. (i.e., you can reject the null hypothesis and say that the coefficient is significantly different from 0). In this study of all the independent variables, the variable 'conscious', with the p-value of 0.0, is the only variable that contributed significantly to the prediction of the dependent variable. Hence, for students who are conscious of an emergency occurrence, we expect to see 16.733 increase (B= 2.817) in the odds of the willingness of the students to give a helping hand to those in need, in an emergency, on campus. In conclusion, it is the level of consciousness of students, of emergencies, that determines their decision to assist in the event of an emergency.

Table 6a: Omnibus Tests of Model Coefficients

Chi-square value	Degrees of freedom	Significance
19.503	4	0.001

Source: Computed by authors with SPSS, 15, 2018

Table 6b. Variables in the equation

Variables	B	S.E	Wald	Df	Sig.	Exp(B)
Gender	0.498	0.786	0.402	1	0.526	1.646
Prev_exp	0.912	0.866	1.108	1	0.293	2.488
Involve_drill	-0.658	0.829	0.631	1	0.427	0.518
Conscious	2.817	0.774	13.257	1	0.000	16.733
Constant	0.584	0.522	1.253	1	0.263	1.794

Source: Computed by authors with SPSS, 15, 2018

Recommendations

Following the results of a study by Kapucu and Khosa (2013) across colleges in the US, it is recommended that universities should develop an all-hazards comprehensive plan, conduct emergency regular training and exercises, and develop strong community partnerships. These are important elements for creating a disaster-resilient university. The results from this study showed that as part of a university's hazard plan, there should be assembly points, in unobscured areas, that are clearly signposted. The assembly points can also appear on the campus emergency map on the university's website. It was emphasised that the university management should adopt emergency planning approaches which optimises available resources and that, emergency plans should be periodically adapted to changing circumstances.

This study discovered that, being conscious of emergencies is paramount to students' willingness to assist in the event of an emergency. It is suggested that the university management should conduct regular emergency trainings and exercises, which will likely strengthen students' consciousness of emergencies. The University's emergency plan should be in collaboration with the host community for additional/ complementary resources, such as fire, police and ambulance services. The emergency evacuation plan in this study showed how commercially operated buses owned by individuals in the host community were part of the plan.

Conclusion

Emergencies are bound to happen at times and places that are often not predictable. The key to handling emergencies successfully is 'preparedness' through careful planning. In emergency situations, the available resources are usually overwhelmed. Therefore, there will be a need to make the best use of resources. A method of planning and optimising the use of resources in an emergency was demonstrated in this study.

Abbreviations

CESAP: Centre for Sandwich Programmes; DSS: decision support system; EOP: emergency operation plan; GIS: geographic information system; ICT: Information-Communication Centre; L-A: location-allocation model; LLT: large lecture theatre; LT: lecture theatre; OGD: Otunba Gbenga Daniel hall; OOU: Olabisi Onabanjo University

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