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QUANTIFYING SOCIOECONOMIC DISRUPTIONS CAUSED BY CONSTRUCTION IN DENSELY POPULATED AREAS

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Abstract: Executing construction projects in densely populated areas can have significant impacts on the residents' quality of life during the construction phase. The social and economic impacts of dense-urban construction are reported for projects undertaken in planned areas as well as unplanned areas (such as slums and squatters). These impacts include residents' relocation, roads closure, loss of businesses' income, high noise levels, and temporary disruptions to essential services. On the other hand, socioeconomic disruptions resulting from poorly planned projects in densely populated areas generate resistance among residents to the executed projects, which in turn affects the success of the these projects. The objective of this paper is to present an assessment model capable of estimating and quantifying the level of socioeconomic disruptions expected to be experienced by residents of densely populated areas. This assessment model utilized GIS capabilities and can evaluate candidate construction plans in order to support decision makers in planning for such challenging projects. To this end, this model incorporates four newly developed socioeconomic metrics that are designed to assess (1) the travel delays due to roads closure and detours; (2) number of relocated residents during construction; (3) loss of income due to businesses closure or reduced accessibility; and (4) inconvenience due to high noise levels. In order to demonstrate the model capabilities, its assumptions, and underlying computations, a case study of an upgrading project in a densely populated area in Giza, Egypt is presented.

1 INTRODUCTION

There is a continuous increase in the population density in urban areas, which in turn imposes new construction management requirements for urban construction (Maas and Gassel 2005; Guglielmetti et al. 2008). Nowadays, a significant number of construction projects take place in congested urban sites (Gilchrist et al. 2002), which result in affecting the social and economic welfare of the local residents during the construction phase. For instance, highway construction and repair projects are reported to cause traffic congestions in the surrounding areas leading to travel delays (Tighe et al. 1999; Gilchrist and Allouche 2005). Furthermore, the population density around construction sites introduces a series of socioeconomic challenges that impact the project success, which include the disruptions due to cutting services, road closures, businesses loss of income, and residents' relocation (El-Anwar and Abdel Aziz 2014). Another challenge associated with construction operations and activities is the increasing levels of the ambient noise that have severe impacts on the nearby residents (Weixiong 2008).

Slums upgrading projects (as a major example for dense urban construction) is investigated in several previous studies (Abiko et al. 2007; The Cities Alliance 2008; and Viratkapan and Perera 2006). These studies reported a number of social, economic, construction and logistics challenges in and around slums upgrading projects, which makes them quite distinct and complex than development projects in formal-sector urban areas. Abdel Aziz and El-Anwar (2010) and El-Anwar and Abdel Aziz (2011) proposed the use of multi-objective optimization methodologies to achieve three main objectives for slums upgrading projects, including (1) maximizing the project benefits; (2) minimizing the total project costs and durations; and (3) minimizing the social and economic disruptions for resident families. The practical use of these optimization methodologies is dependent on developing social and economic assessment models to alternative construction plans.

Recent research studies focused on the advances of social impact assessment as a means to address these challenges. Burdge and Vanclay (1996), Becker (2001), Burdge (2003), and Becker and Vanclay (2003) discussed the emergence and development of social impact assessment. Other studies aimed at minimizing the social and economic disruptions experienced by resident families and local businesses during construction. In a notable study, Gilchrist and Allouche (2005) proposed a socioeconomic impact costing system based on measuring the disruption caused by construction on (1) traffic; (2) economic activities; (3) pollution; and (3) ecological, social and health conditions. This costing process utilizes mathematical equations to valuate a number of disruption indicators, which include travel delay, loss of income, productivity reduction, health cost, etc. The later research used some valuation methods as measuring loss of productivity, human capital, replacement cost, and user delay cost. However, these valuation methods require significant amounts of data, which might not be readily available in the project planning phase. In a relevant research field, El-Anwar and El-Rayes (2007), El-Anwar et al. (2010) and El-Anwar and Chen (2013) proposed metrics to support minimizing the socioeconomic disruptions for relocated families after natural disasters. These metrics focused on measuring the quality of the new housing locations in terms of employment and educational opportunities, housing quality, displacement distance, accessibility to important facilities and services, and housing delivery time. Similar efforts are needed to quantify the socioeconomic impacts of dense urban construction projects given their unique nature and challenges.

Although most contributions managed to identify the sources and indicators of socioeconomic disruption, there exist limited attempts to assess and quantify socioeconomic disruptions imposed by candidate construction plans. For example, Tsunokawa and Hoban (1997) addressed the difficulty of valuating the losses associated with temporary or permanent loss of houses and businesses. As a result, there exist a need for a practical and comprehensive methodology capable of assessing and quantifying the level of socioeconomic disruption experienced by residents in proximity of dense urban construction projects. This research is a first step to fill this gap using a novel socioeconomic assessment model. The following sections present the proposed model formulation and implementation, and demonstrate the model capabilities using an application example from a current project.

2 MODEL FORMULATION

In this research, the proposed model processes basic data about the urban area and the construction project to evaluate the socioeconomic condition of the area during construction. The model utilizes four main socioeconomic disruption indicators, addressing (1) travel distance delay; (2) resident relocation; (3) business loss; and (4) noise inconvenience. Each indicator is calculated by adding the values of disruption experienced by each resident or business vulnerable to such type of disruption, where the disruption value for each resident or business can range from 0 (indicating no disruption) to 1 (indicating maximum disruption). Furthermore, the effect of the disruption duration is incorporated using an exponential function reflecting the effect of prolonged duration of disruption.

2.1 Travel delay indicator (D_d)

This indicator measures the increase in distance travelled by a dweller from his/her home to a certain service. This increase of distance originates from road closure and detours as a result of construction operations. It is common to estimate the disruption caused by the increased distance using the ratio of the increased distance (ΔS) to the original distance travelled (S_0) to a certain type of service. However, using this calculation results in an infinite range of results (as the value of increased distance is not limited and might exceed the original distance multiple times). Thus, and for the sake of normalizing the ratio to the range from 0 to 1, the formula is modified to calculate the ratio between the increased travel distance (ΔS) to the final travelled distance (S) to a certain service. This modified ratio, however, will never reach a value of 1 (where this only occurs when ΔS approaches infinity, because ΔS is always smaller than the final distance S). As such, the model formulation enables decision makers to define a maximum distance (S_{max}) that if reached the resident is assumed to experience a maximum disruption value of 1. To this end, decision makers define a percentage (%s), which is multiplied by the final distance (S) to reduce the upper bound of the travel distance from S to S_{max}, as shown in Figure 1. Furthermore, the model formulation enables decision makers to define a minimum domain (ΔS_{min}), below which the increased travel distance has a negligible impact on residents (i.e. the ratio value is set to zero). For example, an increased distance of 100 metres may not produce any disruption. The proposed indicator can be calculated using Equations 1 and 2.

$$[1]\ D_{d,i} = \begin{cases} 0 & , \ 0 \le \Delta S < \Delta S_{min} \\ \left(\dfrac{\Delta S - \Delta S_{min}}{S_{max} - \Delta S_{min}}\right)^k & , \ \Delta S_{min} \le \Delta S < S_{max} \\ 1 & , \ \Delta S \ge S_{max} \end{cases}$$

$$[2]\ S_{max} = (\%s) \times S$$

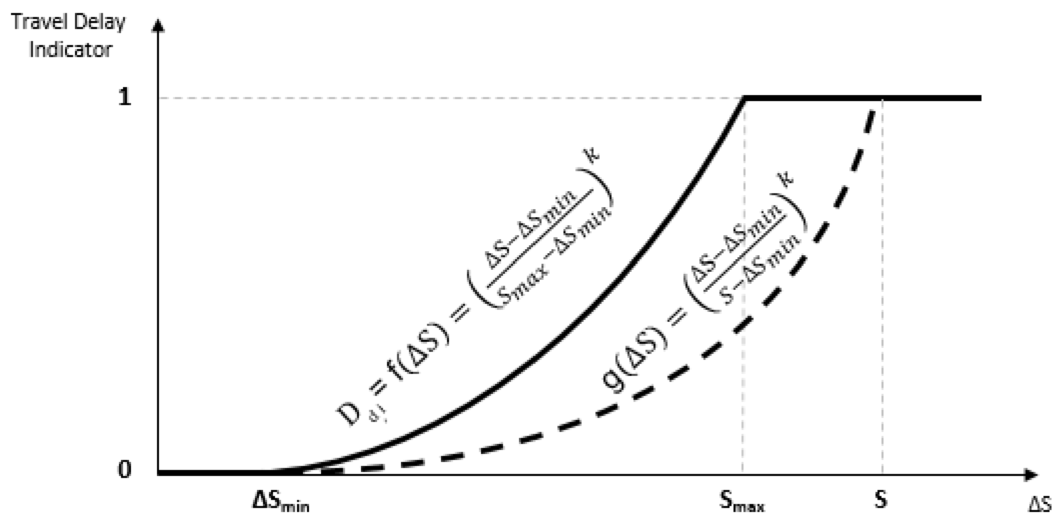


Figure 1: Impact of the user-defined percentage (%s) to reduce the domain upper bound from S to Smax

Where, $D_{d,i}$ is the value of disruption experienced by a dweller (i) due to travel delay to a certain type of service, ΔS is the increased travel distance measured for each resident dweller, S_{max} is the imposed upper bound to the travel distance, %s is the percentage of the final distance (S) travelled by a dweller after disruption which results in a maximum disruption value of 1, the final distance (S) is calculated by adding the increased distance (ΔS) to the original distance travelled before disruption (S_0), S_{min} is the defined increase in travel distance that results in negligible disruption, and k is a constant defining the incremental shape of the disruption function (i.e. k = 1 generates a linear function, k < 1 generates an exponential function, and k > 1 generates a logarithmic function).

Finally, the travel delay indicator (D_d) calculates the total value of travel delay disruption for all residents, as shown in Equation 3.

$$[3]\ D_d = \sum_{i=1}^{R} D_{d,i}$$

Where, R is the number of residents in the impacted site.

2.2 Resident relocation indicator (D_r)

Various factors might require relocating residents during construction, such as road closure, houses entrance blockage, and houses structural instability. The residents relocation indicator ($D_{r,i}$) computes the number of residents who will be affected by the temporary displacement and its associated socioeconomic disruptions, as shown in Equation 4.

[4] $D_r = \sum_{i=1}^{P} D_{r,i}$

Where, P is the original number of dwellers before construction, and $D_{r,i}$ is a binary variable that equals 1 if resident (i) is temporary relocated and equals 0 otherwise.

2.3 Business loss indicator (D_l)

Local businesses suffer two types of impact. The first type is function in the number of reduced customers (ΔC), which is incurred due to dwellers relocation away from the business location or as a result of road detours (where some dwellers might choose the second nearest business offering the same service), as shown in Equations 5 and 6.

[5] $$D_{l,i} = \begin{cases} 0 & , \ 0 \leq \Delta C < \Delta C_{min} \\ \left(\dfrac{\Delta C - \Delta C_{min}}{C_{max} - \Delta C_{min}}\right)^k & , \ \Delta C_{min} \leq \Delta C < C_{max} \\ 1 & , \ \Delta C \geq C_{max} \end{cases}$$

[6] $C_{max} = (\%c) \times C_0$

Where, $D_{l,i}$ is the value of economic disruption suffered by a certain business (i) as a result of customers reduction, ΔC is the number of reduced customers measured for each business, C_{max} is the upper bound of reduced customers resulting in a maximum disruption value of 1 and calculated as a percentage (%c) of the original number of customers (C_0) before disruption, ΔC_{min} is the reduction in the number of customers that results in negligible disruption, and k is a constant defining the shape of the disruption function.

The second type of loss is function in the number of closed businesses resulting from business inaccessibility due to road closure. In this case, a closed business (i) will have a maximum disruption value ($D_{l,i}$) of 1.

[7] $D_l = \sum_{i=1}^{B} D_{l,i}$,

Where, B is the original number of businesses before construction.

2.4 Noise inconvenience indicator (D_n)

Although there are many adverse health issues associated with construction activities, noise has always been a major source of complaints among urban construction projects (Hanson et al. 2006). The value of noise disruption is proportional to the number of residents living in the zones within harmful noise levels.

To measure the intensity of noise at a certain distance from the noise source, sound attenuation has to be considered. Sound attenuation depends on a number of factors, including the distance to the noise source, noise directivity, average air temperature, average atmospheric humidity, presence of obstructions and sound reflection (Harris 1966; Piercy et al. 1977).

Neglecting the minor effect of noise directivity, noise obstruction and reflection, which will be difficult to determine, the level of noise (N_i) affecting a certain dweller (i) as a result of a noise sources (j) can be calculated using Equation 8 (Lamancusa 2000). In the proposed model, dwellers subjected to the harmful noise levels will have a noise disruption value (H_i) equals to 1, while other unharmed dwellers take a disruption value of 0. Accordingly, the noise inconvenience indicator (D_n) is calculated using Equation 9.

[8] $N_i = 10 \times \log \left(\sum_{j=1}^{NS} 10^{\left(\frac{L_j - 20 \log r_{i,j} - 11 - A_{abs}}{10}\right)} \right)$

[9] $D_n = \sum_{i=1}^{R} H_i$

Where, L_j is the noise level in dB resulting from a source (j), NS is the total number of active noise sources, $r_{i,j}$ is the distance from noise source (j) to dweller (i) location in metres, A_{abs} is the atmospheric absorption in dB which is function in source frequency and average atmospheric temperature and humidity (Lamancusa 2000), H_i is the noise disruption value for each resident dweller (i) and R is the total number of residents in the impacted area.

2.5 Total socioeconomic disruption indicator (D_T)

The total value of socioeconomic disruption (D_T) is computed as the weighted average of the aforementioned normalized indicators multiplied by a factor accounting for the time duration of disruption. As such, the total value of socioeconomic disruption is given by Equation 10.

[10] $D_t = (W_d \times D_d + W_r \times D_r + W_l \times D_l + W_n \times D_n) \times T^z$

Where, W_d, W_r, W_l and W_n are the relative weights of the four socioeconomic disruption indicators, and the effect of disruption duration is incorporated using T^z, which is the exponent of the disruption duration, and z should be set to a value greater than 1 to indicate the exponential effect of prolonged socioeconomic disruption.

To enable the practical use of the proposed assessment methodology, an automated model is developed as described in the following section.

3 MODEL IMPLEMENTATION

The proposed model is implemented in three main steps, as shown in Figure 2.

3.1 Define Project Characteristics

The first step in the automated socioeconomic assessment model is to define the main characteristics of the project and its surrounding area. GIS is used to plot road networks, residential buildings locations, services locations and noise sources locations. A map layer is used to draft the area features, where each road in the network is defined as a vector having a start point and an end point. Buildings are defined as nodes each having a specific location. Services are also represented as nodes; but in addition to the location attributes, the type of service is also defined. Finally, noise sources are defined as nodes each having a location and noise source attributes.

A graphical user interface (GUI) is used to define additional variables, such as the total number of residents, average daily number of visits for each service type, average atmospheric temperature, and humidity. Moreover, the user defines construction-related data, including construction phasing, phases' durations, road closure plan, and noise levels associated with different construction resources and operations.

3.2 Input Socioeconomic Disruption Sources

The model studies the effect of two main socioeconomic disruption sources; (1) road closure, and (2) construction noise. Road closure has a direct effect on travel distances to services, the number of relocated residents, and businesses closure. Road closure has also an indirect effect on business loss through reduction in the number of customers due to their relocation away from the business location. Construction noise directly results in increasing the number of people exposed to harmful noise levels.

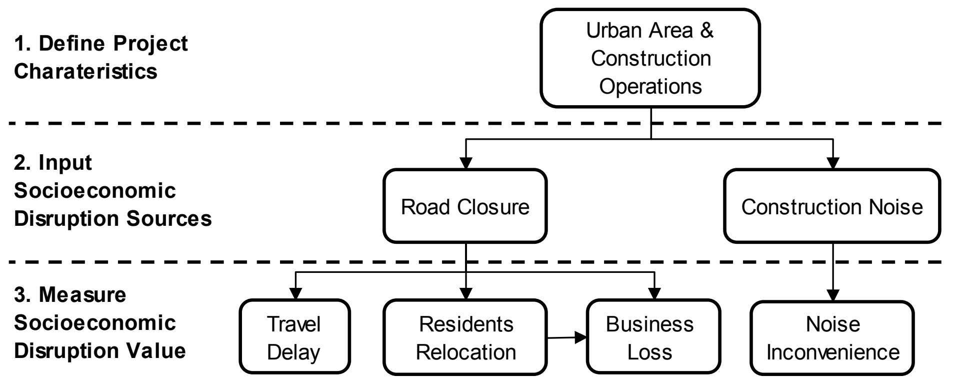


Figure 2: Model implementation phases

3.3 Measure Socioeconomic Disruption Value

Hoogendoorn (2003) shows that pedestrian's route choice has an infinite number of paths options, but a certain pedestrian will mainly choose a path with minimum travel time or minimum travel distance to his target location. To this end, the model manipulates the GIS data, where the road vectors are first converted into road segments linked together using intersection nodes, as shown in Figure 3. Dijkistra's Algorithm is used to calculate the shortest path travelled by a dweller to the nearest instance of each service type.

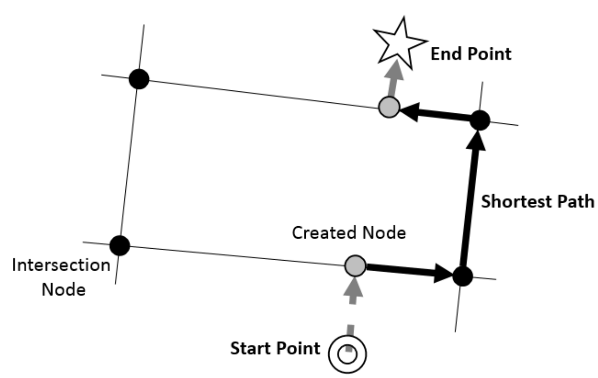


Figure 3: Dijkistra's shortest path

An initial (pre-construction) state is first generated to be compared to the different states corresponding to the candidate construction plans. In the initial state, each dweller node is associated with the ID of the nearest instance of each service type along with the travel distance. A backward calculation is then implemented using this data so that each service instance is associated with the initial number of customers (dwellers) visiting that service.

3.3.1 Measuring travel delay

To compute travel delay, the initial state is compared with the road closure scenario results. The significance of a certain travel pattern is inferred from the amount of its repetition due to the need to frequently visit a target service. The need to frequently visit services can be defined by the average number of monthly visits input for each type of service. For example, some services have higher rate of visits, such as groceries and bus stops, while others have limited number of visits.

3.3.2 Computing the number of relocated residents

A resident is assumed relocated if the road segment within which the resident's home is located is completely closed for construction reasons. The GIS model is used to identify the buildings whose roads are closed, and accordingly the number of relocated residents is calculated. Currently, the model assumes an average number of residents in each building, which can be modified in future developments to allow for specific buildings occupancy data.

3.3.3 Measuring businesses loss

The GUI allows the user to define each service type in the area either as a business or a public service. The expected number of customers measured after a road closure scenario is compared to the initial business state. For each construction plan, the number of closed businesses is first computed by identifying road closures. Secondly, the change in the number of customers is computed for the remaining businesses taking into account route changes and detours because of the construction operations.

3.3.4 Measuring noise inconvenience

Noise received at each dweller's location as a result of construction operations is calculated using the distances between the dweller's location and noise sources. This data is obtained from the GIS model. The noise inconvenience indicator is then measured by counting the number of dwellers subjected to harmful noise levels.

4 APPLICATION EXAMPLE

The proposed socioeconomic assessment model is applied to a dense urban construction project in Giza, Egypt. A main sewage pipe was broken at a depth of about 7.5 metres under Imam El-Ghazaly Street in the District of Imbaba, where the leakage of soil into the pipe led to critical settlements in the surrounding buildings. Auger piles were used as side supports for the required excavation depth in the narrow streets. Imbaba is a highly populated area in Greater Cairo. Moreover, Imam El-Ghazaly Street is considered a main street in the area with high concentration of residents and services.

The area under consideration is about 33,000 m^2 with a simple road network of narrow streets and high buildings density. There are about 188 buildings distributed over the residential zone. The construction operations required the closure of some road segments, as shown in Figure 4. The services in the area are mostly of a basic nature, including two bus stops, eight groceries, two pharmacies, three retail shops, two bakeries, four household appliances shops, four restaurants, and four workshops. All the previously mentioned services are considered for business disruption calculation except for the bus stops; thus the total number of disrupted businesses in the area is 27. The average temperature in the area is 30°C and average humidity is 75%, and the harmful noise level is set to 85 dB. Two main sources of noise are present; the first is a fixed generator producing 80 dB at 1100 Hz, while the second is a moving bored pile rig producing a noise of 75 dB at 950 Hz. The contractor has only one piling rig which makes the piling activity critical.

There are three studied construction scenarios. In the first scenario, construction will be executed in two phases, as shown in Figure 4. The two phases will be executed in series, where the road segment of phase 2 will be closed only after opening the road segments closed during phase 1. Noise resulting from the pile rig is assumed to occur at the midpoint of the closed road segment. The duration of executing each phase is about 6 months, where the site preparation and mobilization takes place in the first month of each construction phase. Accordingly, the total project duration is 12 months. The second scenario assumes that construction of the second phase will start one month before the end of phase one so that the mobilization and preparation period will overlap with the execution period of phase one. This will lead to a total project duration of 11 months. The third scenario assumes that construction will be executed in one phase by closing all the road segments for about 11 months. In this case, mobilization and site preparation will only occur once at the start of the project.

The variables of the travel distance delay function are assumed to have a minimum domain (ΔS_{min}) of 200 metres, a maximum domain of 95% of the final traveled distance (i.e. S_{max} = 95% X S) and a logarithmic curvature (k) value of 2. The function of business loss is assumed to have a minimum domain of 0 customers, a maximum domain of 80% of the initial number of business customers (i.e. C_{max} = 80% X C) and an exponential curvature (k) value of 0.8. The duration is very critical, so it is assumed to have an exponential value of (k) equals to 2. Moreover, the relative weights of the indicators are assumed to be 0.3 for dwellers relocation, 0.4 for business loss, 0.1 for travel distance delay and 0.2 for noise inconvenience indicators. The model enables the users to set the values of all these variables before running the socioeconomic analysis.

The model results show that the socioeconomic disruption indicators of the first and the second scenarios have near results which are much lower than those of the third scenario, as shown in Figure 5. The best scenario in this case is the second scenario which has the lowest total socioeconomic disruption indicator. The results also show that the highest impacts of this project are on noise inconvenience.

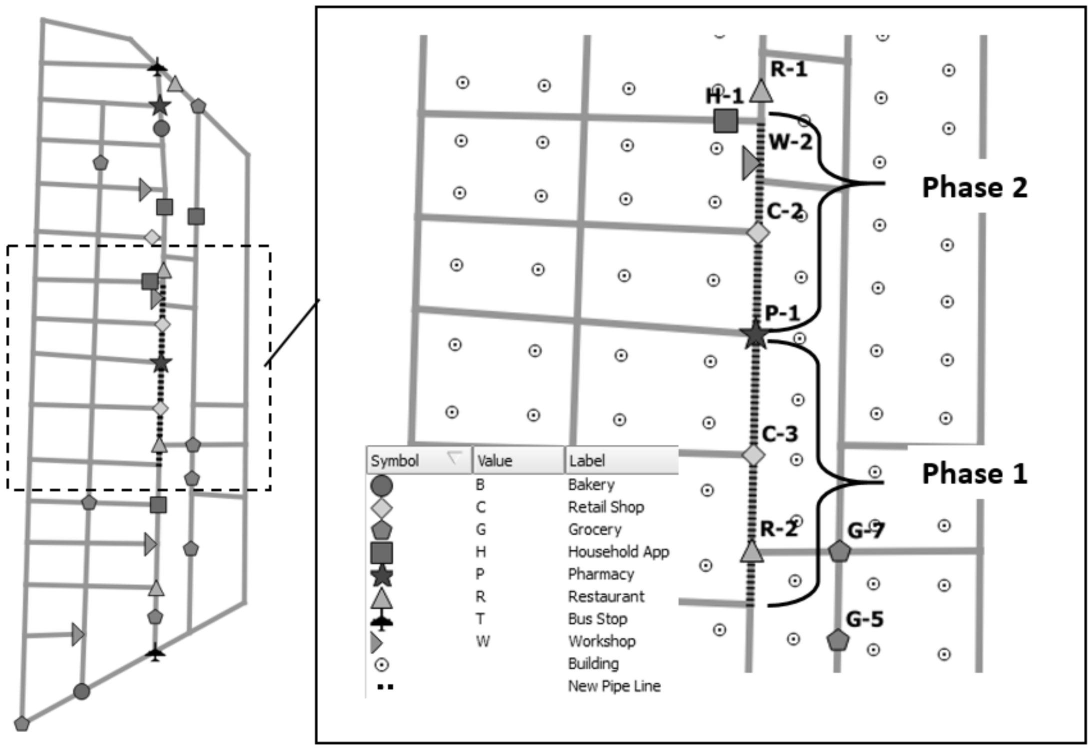
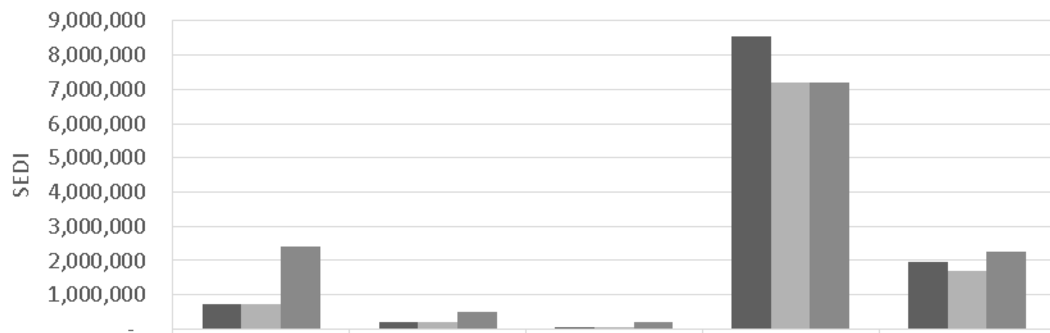


Figure 4: GIS Model of the project area showing the location of different types of services on the road network and the project phases

5 CONCLUSION

This paper presents a socioeconomic assessment model capable of quantifying the socioeconomic disruption experienced by residents in proximity to construction projects in dense urban settings. The model incorporates four important socioeconomic indicators; namely (1) Travel Distance Delay, (2) Residents Relocation, (3) Business Loss, and (4) Noise Inconvenience. The model enables decision makers to assign a relative weight to each of these four indicators and accounts for the impact of prolonged socioeconomic disruption when computing the total impact of any construction scenario.



	Dwellers Relocation SEDI	Business Closure SEDI	Distance Delay SEDI	Noise Inconvenience SEDI	Total SEDI
Scenario 1	712,800	202,176	64,800	8,553,600	1,971,475
Scenario 2	712,800	192,123	64,800	7,187,400	1,696,225
Scenario 3	2,395,800	504,207	217,800	7,187,400	2,278,841

Figure 5: Model results

In order to ensure the practicality of the proposed model and its ease of use, the model computations are automated using a GIS-based system integrated with a VBA user interface. The automated system allows decision makers to break down the construction project into phases and define different scenarios for possible construction plans. The model then assesses the socioeconomic impact of each plan in order to support reaching an informed decision that accounts for the welfare of nearby residents. The main challenge to using the developed system is the need for users to set the values of different variables (such as the minimum travel distance (S_{min}) that results in social disruption, etc.). Future research will address this limitation using sensitivity analysis to identify the significance of these variables.

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