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Development of an Analytical Framework to Rank Pedestrian and Cyclist Projects

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Development of an Analytical Framework to Rank Pedestrian and Cyclist Projects

Final Report

October 2015

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DEVELOPMENT OF AN ANALYTICAL FRAMEWORK TO RANK PEDESTRIAN AND CYCLIST PROJECTS

Final Report

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OCTOBER 30, 2015

Metric Conversion

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft.	feet	0.305	meters	m
yd.	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl. oz.	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz.	ounces	28.35	grams	g
lb.	pounds	0.454	kilograms	kg
T	Short tons (2000 lb.)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
ºF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	ºC

Technical Report Documentation

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Worsening traffic congestion and air pollution, rising road maintenance and construction costs, and escalating health risks from obesity to cardiovascular disease are among major motives triggering the attention of transportation authorities to walking and cycling. Increasing local demands to improve pedestrian/cyclist facilities place a burden on public authorities to balance limited resources with increasing demand. Fund scarcity is the major impediment to satisfy a high demand received from communities in all levels particularly from urban and suburban communities to improve cyclist and pedestrian facilities. To allocate funds to the most worthy and deserving projects, many standards, and procedures are followed by public agencies (nationally and globally) to prioritize projects for funding. Review of practices nationwide has shown that no acceptable standard follows by States and local governments and each state or even county has developed their own methodology to score and rank projects. To facilitate decision makers in prioritizing improvement projects, this study developed a ranking methodology and measurement technique to score each improvement project recommended to lessen the deficiencies of pedestrian/cyclist facility. The study delineates seven determinants to measure the effectiveness of each proposed project and rank them for funding.</td></tr>
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EXECUTIVE SUMMARY

Worsening traffic congestion and air pollution, rising road maintenance and construction costs, and escalating health risks from obesity to cardiovascular disease are among major motives triggering the attention of transportation authorities to walking and cycling. Increasing local demands to improve pedestrian/cyclist facilities place a burden on public authorities to balance limited resources with increasing demand. Fund scarcity is the major impediment to satisfy a high demand received from communities in all levels particularly from urban and suburban communities to improve cyclist and pedestrian facilities. To allocate funds to the most worthy and deserving projects, many standards, and procedures are followed by public agencies (nationally and globally) to prioritize projects for funding. Review of practices nationwide has shown that no acceptable standard follows by States and local governments and each state or even county has developed their own methodology to score and rank projects.

To facilitate decision makers in prioritizing improvement projects, the study developed a ranking methodology and measurement technique to score each improvement project recommended to lessen the deficiencies of pedestrian/cyclist facility. This measurement promotes the most efficient use of available capital. To achieve this objective, the metrics must be: 1) quantifiable – to be measured and numerated, 2) accessible and obtainable – to be estimated using data typically compiled by most transport agencies, 3) applicable – to be deployed in the field seamlessly, and 4) meritorious – to be identified as critical factors by most agencies.

The study delineates seven determinants to measure the effectiveness of each proposed project and rank them for funding: 1) Safety score utilizing crash rate, 2) Safety effectiveness score utilizing Crash Modification Factor (CMF), 3) Mobility score utilizing accessibility and connectivity scores, 4) Cost score utilizing implementation/capital cost, 5) Equity score utilizing socioeconomic feature (i.e. income), 6) Demand score utilizing the labor force population density, and 7) Qualitative score utilizing questionnaire documenting professional expert opinion. All determinants' values are categorized into six classes using different scaling systems to facilitate a homogenous comparison among all determinants.

The crash score is derived by the utilization of quartile scaling on the estimated crash rate (pedestrian/cyclist crashes occurred within the period of 2005-2011 per 100,000 population). Safety effectiveness score is yielded by utilizing the CMF of the proposed projects using CMF clearing house. The Jenks scaling system is utilized on the CMF data to derive the safety effectiveness score of the proposed project. To estimate connectivity scores for pedestrian and cyclist projects, a number of intersecting roadways (in different radiuses) are leveraged to yield the connectivity score. The accessibility score is estimated by the closeness of the proposed projects to major attraction places, i.e. downtown, CBD, shopping center, school. The final mobility score is calculated by averaging the connectivity and accessibility scores. The equity score of each city is computed using the inverse proportionate scaling on the median incomes. The demand score is yielded from the estimation of labor force population density and utilizing the proportional ranking. The capital costs of the proposed/planned improvements are leveraged to yield the cost score. The Jenks scaling technique is used to score cost determinant. The

qualitative score is yielded by developing four rational questions that may be impactful in a project selection. These questions are as follows:

1) Is there any political support?
2) Doesn't a project have some physical implementation constraint?
3) Is there any public comment/request?
4) Is there any project opportunity?

Review of studies and practices are substantiated that these determinants do not possess a same merit to rank projects; therefore, the study utilizes the weighting scheme to calculate the final score of a project. To detect meritorious projects for funding, projects are sorted in the descending order of their scores.

To demonstrate the feasibility of the deployment of the proposed approach, the study evaluated pedestrian/cyclist safety records (number of crashes and crash severity) in six major counties in the State of Illinois (Cook, DuPage, Kane, Lake, McHenry, and Will) within the period of 2005-2011. Cook County demonstrates the highest number of crashes among comparable counties. Within this county, ten cities/villages, i.e. Berwyn, Chicago, Chicago Heights, Cicero, Evanston, Harvey, Maywood, Niles, Oak Park, and Skokie, represent the highest need for pedestrian/cyclist improvement considering crash records (pedestrian/cyclist crashes per 100,000 population) analyzed during the period of 2005-2011. This preliminary evaluation is performed to examine the capability of the approach when improvement projects are proposed and submitted to the decision makers for funding among cities/villages with the highest demand and close competitions. Geospatial analysis was performed for each city documenting pedestrian/cyclist crashes and their severities, examine crash contributed circumstances, and delineate pedestrian/cyclist facilities' deficiencies. Utilizing this methodology, a final score was computed for each proposed project. To detect the most meritorious projects for funding, projects were sorted in descending order of their scores. Projects must be selected in a way to satisfy the budget constraint. A scenario was developed to illustrate the applicability of the developed methodology in practice. This scenario mimicked the condition when an agency had limited budget to allocate funds to pedestrian/cyclist projects. The developed ranking framework offers a practical approach for public authorities to prioritize pedestrian/cyclist projects and choose a site/sites among a pool of alternatives.

1. INTRODUCTION

From the 1960s until the mid-1990s, an exclusive attention to the seamless mobility of motorists caused improvements of non-motorized facilities to be disregarded and often eliminated making hostile environments for pedestrians and cyclists. To control or diminish the construction cost, few state agencies constructed sidewalks or bike routes along state highways and allocated this task to locals who did not have available resources or budgets. This impediment caused many travelers to abandon these modes of transportation. The National Household Travel Survey (NHTS) documented a decline in the walk share of trips from 6% in 1977 to 5.1% in 1995 (USDOT 2010). Worsening traffic congestion and air pollution, skyrocketing road maintenance and construction costs, and escalating health risks from obesity to cardiovascular disease are among major motives triggering the attention of transportation authorities to walking and cycling. Since the 1990's, research, practices, and regulations have been developed to prioritize walking and cycling. A small increase in the number of walking trips from 1995 till 2009 demonstrates this trend, increasing from 2.6% in 1995 to 2.8% in 2009 (USDOT 2010). Bicycling to work, which has been reported only since 1980, has increased from 0.4% in 1980 to 0.6% in 2009 (Pucher et al. 2011). The growing acceptance of cycling is observed in urban areas where more efforts are concerted to improve cycling infrastructure and safer environments for cyclers. For example, commuter cycling has doubled between 2007 and 2011 in New York City (NYCDOT accessed 2015).

It is apparent that improving cycling and walking facilities in areas where potential demands are evident such as urban areas provide an incentive for bikers, transit riders, and walkers to leave their cars at home and switch to these transportation modes. The communities that have been most successful at promoting walking and cycling provide facilities with specifications that exceed minimum national standards. Increasing local demands to improve pedestrian/cyclist facilities put a burden on public authorities to balance the demand with limited resources. To facilitate decision makers in prioritizing projects designed and proposed to improve walking/cycling, the study develops an analytical framework to prioritize projects based on defining and scoring a set of determinants. Six determinants are delineated to facilitate ranking projects: 1) Pedestrian/cyclist safety, 2) Project effectiveness including safety effectiveness (CMF) and mobility effectiveness (connectivity and accessibility), 3) Project life cycle cost, 4) Equity, 5) Demand, and 6) Qualitative metrics. All determinants are categorized/scored into six classes to provide a homogenous comparison among all determinants. Different scaling systems (i.e. quartile, Jenks/Natural breaks, proportional, and inverse proportional scaling) are manifested to score the determinants considering data characteristics and distributions. As studies/practices suggest, determinants may have different merits to quantify the final score; consequently the total score of each project is derived using the weighting system.

To investigate the feasibility of the deployment of the developed technique in practice, improvement projects are devised to lessen the deficiencies of pedestrian/cyclist facility in cities/villages located in Cook County in the State of Illinois where pedestrian/cyclist safety is in jeopardy. Pursuing the developed methodology, the final score of each proposed project is computed. The developed approach manifests a practical solution for public authorities to rank pedestrian/cyclist projects.

2. BACK GROUND AND LITERATURE REVIEW

Increasing traffic congestion, worsening climatic events threats due to the exhaustion of Greenhouse Gases (GHG) along socio-economic and cultural trends divert more attentions to build more walkable communities that less rely on car. A suitable walking environment promotes the public transportation utilization, since walking/cycling is a part of transit trips to access to public transit stations/stops at origin, destination, or both points. Many efforts have been performed in global, national, and local levels to promote walking and cycling.

The subsequent subsections demonstrate these efforts in the global and national level ranging from the geometric design of roadways and intersections to policy recodifications. The study will consider these efforts in defining improvement projects for understudied cities. However, the allocation of resources and funds to design, plan, and deploy these projects is a main challenge. This section also presents practices and researches to prioritize and rank these projects.

2.1. Global Efforts

2.1.1. European Pedestrian Priority Zone (PPZ)

Pedestrian Priority Zone (PPZ) has been established in certain European countries (e.g. France, United Kingdom, Switzerland, and Netherlands). While benefits of PPZ are not measured quantitatively and no statistic is presented to signify the improvement in pedestrian's safety and mobility, the surveys of locals demonstrate that locals feel safe in these zones. PPZ areas leverage distinctive designs to differentiate these zones from their environment setting such as visual elements, surface treatments, variations in levels, and street furniture. One of the most common treatments is reducing the speed limit to 20 mph or lower at PPZ. The main design principal of PPZ is to satisfy the needs of urban areas and the national ethos of road users. In Europe, PPZs are defined within three structures (Heydecker et al. 2009):

1. Pedestrianized zones
2. Shared areas/encounter zone/meeting zone where all road users share the space and pedestrians have priority
3. Low speed zones such as the 20 mph zone in UK and 30 km/h zones in continental Europe, where traffic speeds are substantially reduced.

These zones are often linked with a range of traffic calming techniques to reinforce behaviors. PPZs are appear to be introduced primarily to improve the street environment and local living conditions. Safety is often mentioned as a secondary benefit. Figure 1 depicts PPZs in some European countries; France, UK, Belgium, Switzerland, and Netherlands.

Pedestrian Priority Zone – France

Entrance to Home Zone – UK

Shared area – Belgium

Encounter Zone – Switzerland

Woonerf – different texture paving for biking and walking – Netherlands

Figure 1 PPZ in European countries (extracted from Heydecker et al. 2009)

2.1.2. Cycling in Copenhagen – Denmark

Copenhagen-Denmark is exceptional among European countries with the transport mode splits of 27% for car, 33% transit, 36% cycling, and 5% walking based on 2004 census data. Along a quiet residential street in Copenhagen, one finds more parked bicycles than cars. While the quantity of automobile traffic has increased 16% from 1995 to 2006, bicycle traffic is increasing faster. Consequently, the mass of cyclists traveling throughout the city has caused that more motorists are aware of cyclists and look out for them. Cycling becomes a standard and acceptable mode of transportation and must follow the same rules as vehicles (Nelson et al. 2006). Copenhagen transportation planners are promoting cycling through both soft and hard policies. Soft policies, such as campaigns and education, are an important component of cycle planning since they can encourage new bicyclists and influence changes in transportation behavior. Hard policies, such as creating new bicycling infrastructure, have the greatest impact when combined with campaigns and education.

Malmo's central train station

At intersection, bicycle light and 1.5 meter lane is provided for both straight and right- turning cyclists

Figure 2 Copenhagen - Denmark – Cycling (Nelson et al. 2006)

2.1.3. New Zealand (NZ)

Defined by New Zealand transport agency (NZ transport agency 2009), 'Walkability' describes the extent to which the built environment is walking-friendly based on the following characteristics:

1. Connectivity- connected to the origin and destination places
2. Legibility – easy to find your way through signposting and local maps
3. Comfortable- comfortable to walk considering width, gradient, fume, and shelter
4. Convenient - continuous, efficient, unimpeded by obstacles, and no delay routes
5. Pleasant – have enjoyable, interesting, quiet, clean with quality social interaction
6. Safe – safe from traffic danger in road crossing places
7. Secure - secure from criminal and antisocial activities
8. Universal – suitable for all pedestrians mobility including disable and vision-impaired pedestrians
9. Accessible – easy walking distance to popular destinations

To measure and quantify walkability for a community or an area, New Zealand transport agency develops connectivity indexes for routes identified between each pair of origin and destination (NZ transport agency 2009).

Figure 3 Lyttelton heritage pole – New Zealand (extracted from NZ transport agency 2009)

Review of New Zealand transport agency document, pedestrian planning and design guide 2009, demonstrates the existence of two practices that are not common in US; these are 1) pedestrian platform, and 2) scramble pedestrian phase. Pedestrian platforms are raised with commonly textured areas of roadway that act as a focus for crossings. Yet, they are part of the roadway and pedestrians must yield to vehicles.

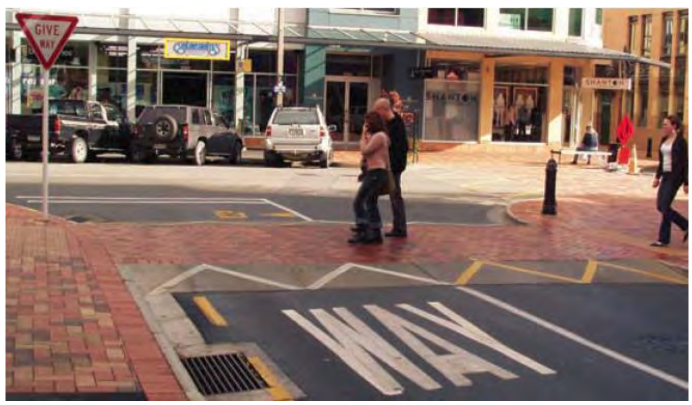


Figure 4 Pedestrian platform (extracted from NZ transport agency 2009)

At busy junctions with multiple approach lanes, signals are preferred approach over roundabouts. In these intersections, exclusive phases are introduced to permit diagonal crossing where pedestrian crossing is predominant in all directions such as Central Business District (CBD), or where turning conflicts cannot be sufficiently satisfied by other means.

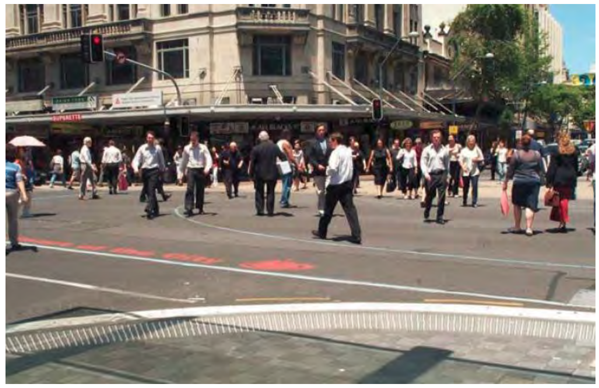


Figure 5 Exclusive pedestrian signal phase - scramble phase (extracted from NZ transport agency 2009)

2.1.4. United Kingdom (UK)

UK deploys comparable rule for facilities utilized by cyclists and pedestrians without any prioritization one over another. As shown in Figure 6, Toucan crossing ('Two can cross") is introduced for cyclists and pedestrians' crossing. The key benefit of this combined crossing is high visibility for fast-moving traffic traveling on the major road. This system can sense the numbers of crossing pedestrians and cyclists and provide shorter waiting cycles for pedestrians and cyclists. (European commission 2009)

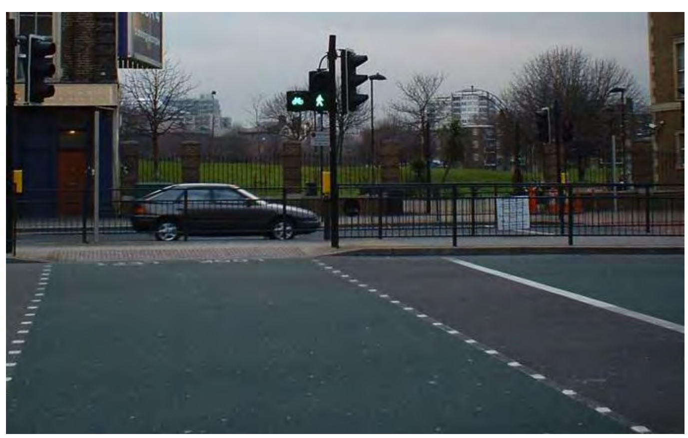


Figure 6 Toucan crossing (European commission 2009)

2.2. National Efforts

In 2007, a survey conducted by the National Association of Realtors and Smart Growth America (Smart Growth America accessed 2015), three-quarters of Americans believed that investments in the development of and improvements to public transportation are more rational long-term solutions than building new roads for reducing traffic congestion. Half of those surveyed think improving public transit would be the best way to reduce congestion, and 26 percent believe developing communities that reduce the need to drive would be the better alternative. Only one in five said building new roads was the answer. In this section, the study reviews briefly the national efforts to advocate these green modes of transportation with emphasis on local, i.e. Chicago and its metropolitan, efforts.

- **National Complete Street Coalition** advocates for communities to build new roads based on "Complete Street" guidelines. States, cities and towns are asking their planners and engineers to build road networks that are safer, more livable, and welcoming to everyone including pedestrians and cyclists (Smart Growth America accessed 2014). Figure 7 depicts an example of a Complete Street. Establishing a complete streets policy warrants that transportation planners and engineers plan, design, and operate the roadway system with all users in mind including public transportation vehicles and riders, cyclists, and pedestrians of all ages and abilities.

- **FHWA - Pedestrian and Bicycle Crash Analysis Tool (PBCAT)** is a crash software application tool intended to assist states and local coordinators, planners, and engineers to assess walking and cycling safety using pedestrians and cyclists crash data (Pedestrian and bicyclist information center, accessed 2014).

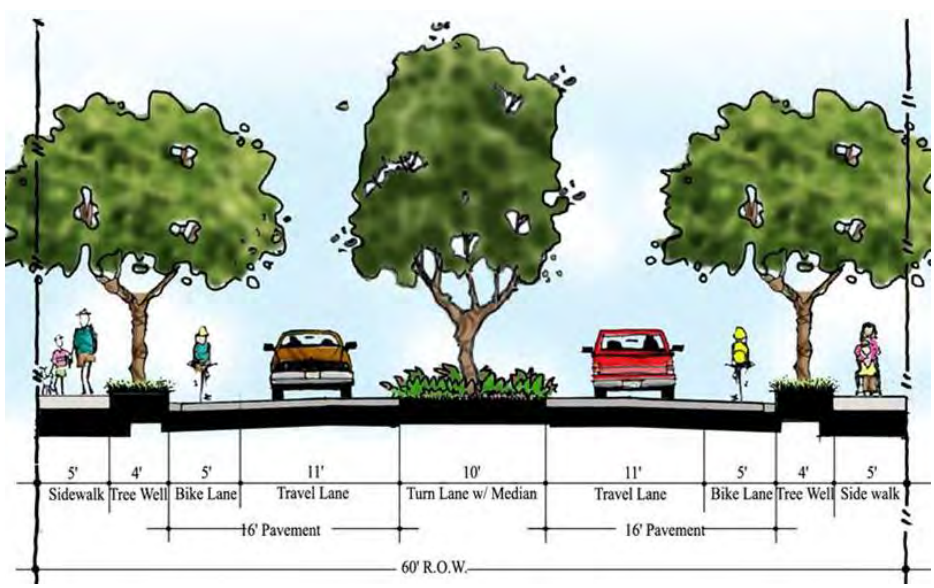


Figure 7 An example of a complete street

- **Local -** Many activities and efforts have been accomplished to advocate cycling and walking in Illinois. These efforts include organizations' establishment, policy making decisions, and practices. In following, the study pinpoints some of these efforts:
    - ***Active Transportation Alliance*** (accessed 2014) is the organization that was established with the mission of making cycling, walking, and public transit safe, convenient, and fun to ultimately achieve a significant shift from environmentally harmful, sedentary travel to clean, active travel. It advocates for transportation that encourages and promotes safety, physical activity, health, recreation, social interaction, equity, environmental stewardship and resource conservation.
    - ***CMAP-CMAQ*** (accessed 2014) was established to address the persistent problem of slow project development and to ensure prompt implementation of projects that provide continued air quality and congestion relief benefits. One of focus group of this program is "*Bicycle and Pedestrian Task Force*" which is responsible for reviewing and evaluating pedestrian and pedestrian project applications and recommend them for funding.
    - ***Municipal Conferences* –** These organizations facilitate collaborations amongst suburban municipalities in Cook County and the Collar Counties including Northwest (Northwest Municipalities Conferences, accessed 2014), west central (West central Municipality conference, accessed 2014), and south-west (Southwest conference of mayors, accessed 2014). They are delegated responsibility for certain transportation funding and a role in evaluating transportation projects.

It is envision that the outcomes of this study can assist decision makers in CMAQ and other local agencies to evaluate and rank projects for funding.

2.3. Projects Ranking Methodology

Constrained by revenue scarcity, public agencies must efficiently distribute funds to the most effective transportation projects. Several standards and methodologies have been developed to assist in the evaluation and prioritization tasks.

2.3.1. Worldwide - Qualitative Ranking

New Zealand transport agency (NZ transport agency 2009) prioritizes pedestrians' projects based on the following factors:

- Increase pedestrians' demands
- Increase trip linkage between origin and destination
- Decrease barrier/gap
- Proximity or geographic closeness to major origin and destination points
- Land use and closeness to area with the high number of vulnerable pedestrians such as school and hospital
- High perceived need or demand by pedestrian
- Decrease number of crashes

- Easy to implement
- Increase road hierarchy
- Combined approach taking into account pedestrians' actual and perceived needs

Road and traffic authority of New South Wales (NSW) of Australia (Road and traffic authority 2002) developed a methodology for pedestrian mobility and accessibility, i.e. Pedestrian and Access Mobility Plan (PAMP), to coordinate investments on safe, convenient, and coherent pedestrian infrastructure for its local Governments. This methodology defines the subsequent objectives and assigns a score to each objective from low (0-5) to medium (6-8) and high (9-10). Projects, then, are compared against these objectives to be scored according to the level of objectives' fulfillment. Conclusively, the projects get their final PAMP scores from poor (0-60) to acceptable (60-90), ending with good (90-100). The considered objectives include:

- To facilitate improvements in level of pedestrian access and priority particularly in high demand areas
- To reduce pedestrian access severance and enhance safe and convenient crossing opportunities on major roads
- To identify safety problems and resolve pedestrian safety
- To facilitate improvements in the level of personal mobility and safety for all pedestrians including older pedestrians, and pedestrians with disabilities
- To provide links with other transport services
- To ensure pedestrian facilities are employed in a consistent and appropriate manner
- To link existing vulnerable road users plans in a coordinated manner (e.g. bike plans, safer routes to school, maintenance programs, accessible public transport, etc.)
- To ensure that pedestrian facilities remain appropriate and relevant to the surrounding land use and pedestrian user groups
- To accommodate special event needs of pedestrians
- To meet obligations under the commonwealth Disability Discrimination Act

Victoria Transport Policy Institute in British Columbia (BC)-Canada (Todd Litman et al. 2009) considered four factors to evaluate gaps/barriers in pedestrian/cycling facilities, and to rank projects' improvements:

1. Level of demands or facility utilization
2. Degree of barriers (from minor to major) for all people including ones with different physical disabilities
3. Potential benefit features (e.g. to encourage modal shift, or to encourage recreational activities)
4. Cost and ease of improvement (including maintenance and incremental costs)

2.3.2. Nationwide – Qualitative Ranking

Review of practices nationwide demonstrates that there are no commonly accepted standards followed by all, or even most, states and local governments. The individual public agencies use a variety of evaluating, scoring and prioritizing strategies. The National Highway Traffic Safety

Administration has attempted to fill this gap with its own ranking system. The NHTSA process (Highway Safety Research Center 2009) defines metrics (criteria) according to the merit to the community, available funding, political climate and other factors. Based on these values, the weighting metric or index system is constructed with the following description and score.

- Crash severity (number of crashes occurred or likely to be occurred) – Score of 15
- Existing deficiency and Effectiveness of solution - Score of 15
- Probable use (travel demand) - Score of 15
- Likelihood of funding - Score of 10
- Feasibility (constructability, ROW, etc.) – Score of 15
- Public support – Score of 15
- Cost – Score of 15
- Bonus: achieves other goals (motorists/bicyclist safety, aesthetics) – Score of 10

Based on this guideline, projects should be reassessed and reprioritized annually, and funding should be assigned in a way that all regions receive some level of pedestrian facility enhancements without any concentration in a particular region.

Lee County in the State of Florida (Baier et al. 2013) develops the following prioritization criteria to rank projects:

- Intermodal connectivity (Max score 9)
  - Intermodal connectivity (Max score 2)
  - Connections to similar facility/closing the gaps (Max score 2)
  - Alternatives to driving alone (Max score 3)
  - Making regional connections (Max score 2)
- Public, personal and traffic safety (Max score 10)
  - Safety/crash history (Max score 3)
  - Traffic volume (Max score 3)
  - Posted traffic speed (Max score 3)
  - Emergency response times (Max score 1)
- Environmental, social and economic sustainability (Max score 14)
  - Residential access (Max score 3)
  - Employment access (Max score 2)
  - School access (Max score 2)
  - Parks and green space access (Max score 2)
  - Transit access (Max score 2)
  - Household units without vehicles (Max score 3)
- Fiscal responsibility (Max score 6)
  - Ease of implementation (Max score 3)
  - Land development potential (Max score 1)
  - Improve existing facility (Max score 1)
  - Long-term maintenance costs (Max score 1)

San Antonio in Bexar County (Texas) (MPO accessed 2014) defines the following criteria or priority areas to rank pedestrians/cyclists projects:

- Priority 1: Schools
- Priority 2: Transit
- Priority 3: Crashes/safety
- Priority 4: High density neighborhoods
- Priority 5: Downtown
- Priority 6: Underserved areas
- Priority 7: Employment centers

Virginia Transportation Research Council (Natarajan et al. 2008) develops a framework for cities and counties located in that state to rank or prioritize pedestrian/bike safety project. According to this framework, cities/counties identify hazardous locations and causal factors. Then, they must develop potential safety countermeasures and establish measures of effectiveness for each defined location. Afterward, each city/county submits proposals for such pedestrian/bicycle safety projects to the State. The state utilizes the following factors to prioritize projects:

- Project cost
- Ease of implementation and maintenance
- Total number of pedestrian/bike crashes
- Proximity to high-activity zones
- Latent demand for pedestrian/bike activity
- Support from local community
- Level of pedestrian/bike activity
- Opportunity to construct concurrently with an adjacent roadway projects
- Connectivity
- Demand for usage
- Potential to attract new pedestrians/bicyclists
- Presence of existing alternatives
- Type of road network
- Proximity to disadvantaged neighborhoods
- Adjacent population density planned/projected land use, etc.

In a comprehensive pedestrian plan for Town of Farmville in North Carolina (Town of Farmville 2013), the following goals and objectives were defined to establish friendly environment for pedestrian/cyclist: 1) improved safety, 2) education, 3) connectivity and accessibility, 4) enforcement, and 5) health promotion.

Some researchers and professionals (Walkability research accessed 2014) have considered Walk Score to measure the walkability of cities or addresses. Walk score analyzes walking routes to nearby attraction places or amenities. Points are awarded based on the distance to these amenities. Amenities within a 5-minute walk (0.25 miles) are given maximum points. A decay function is used to give points to more distant amenities, with no points given after a 30-

minute walk. This score is commonly utilized by researchers in the field of urban planning, real estate, and public health. With the same concept, transit score measures access to public transit and bike score measures the suitability of communities for biking.

In the recent study performed by National Cooperative Highway Research Program-NCHRP (Lagerwey et al. 2015), Federal attempts to develop a robust framework to rank pedestrian/cyclist project through identifying factors. This project has also developed an Excel-based application tool for decision makers interested to leverage this approach. The study accomplishes its objective through the execution of two phases: 1) Scoping including defining factors, variables, weights, and assessing available data, 2) prioritization including a measurement of data, scaling variables, and ranking. More elaborations on identified factors, scaling, and weighting scheme are presented throughout the study.

The reviews of studies and practices demonstrate that most have adopted the same concept, i.e. qualitative scoring and weighting system, to rank pedestrians/cyclists projects. Most of these studies adopted the linear scaling or a conventional addition of scores to yield the final scores and rank projects based on these final scores. All these studies suffer from the following gaps:

- *Subjectivity* – the outcomes are sensitive to the scores assigned by decision makers, engineers, and planners without any rational mapping between real data and their scores. This subjectivity generates controversy in the selection of the most apt project.
- *Accuracy* – As no analytical or quantitative methodology is presented for scoring, the accuracy of selection is rather diminished and an effectiveness of solutions cannot been measured to guide for future evaluations.

The NCHRP report 803 (Lagerwey et al. 2015) was the only study concluded recently that provides a quantitative approach to score projects based on qualitative and quantitative factors. However, this study attempts to present more practical approach and elucidate some nebulous points detected in this study.

3. DELINEATION OF DETERMINANANTS

As reviewed, current practices for prioritizing cyclist/pedestrian projects rely on the professional judgement of transportation professionals. Few of these systems incorporate quantitative analysis based on objective measures. This study seeks to develop an analytical methodology to quantify these metrics.

With this consideration, the study must develop a measurement technique to 1) fairly allocate funding, and 2) promote the most efficient use of available capitals. To achieve this goal, the metrics must be: 1) quantifiable – to be measured and numerated, 2) accessible and obtainable – to be estimated using data typically compiled by most transport agencies, 3) applicable – to be applied and measured at the field, and 4) meritorious – to be leveraged by most agencies as critical factors . Upon the identification of these factors and the delineation of suitable scoring techniques, the study will be able to calculate the final scores and rank projects. In following, the study delineates determinants leveraged to rank projects and provides rationales for this selection.

3.1. Pedestrian/Cyclist Safety (*$S[C_r]$*)

Studies and practices (Lagerwey et al. 2015, Natarajan et al. 2008, Highway Safety Research Center 2009, and Metropolitan Planning Organization accessed 2014) identify the following parameters to measure safety in understudied locations:

1. Pedestrian/Cyclist crash frequency
2. Pedestrian/Cyclist fatal and sever injury frequency
3. Pedestrian/Cyclist crash/fatality/severity rate

The conventional safety assessment method is based on the frequency of crashes or frequency of severity of crashes. While the crash (or severity) frequency does not consider the crash exposure seized by pedestrian/cyclist count data, this technique is commonly utilized in practice. Mainly, because the pedestrian/cyclist count data is not widely available. To tackle this shortcoming, studies were performed and concluded that there is a correlation between pedestrian volume/count and commercial/business/public building areas. Shin et al. (2007) concluded that there was a close relationship between the pedestrian volume and the spatial network in business and commercial areas. Schneider et al. (2010) developed a model for modeling pedestrian volume around intersections in Alameda County, California. They found that population, number of jobs, number of commercial retail properties, and proximity of transit stations are determining factors on pedestrian intersection crashes. With this consideration, researchers and practitioners have normalized pedestrian/bicyclist crash frequency with the population (City of Mesa 2009, NYC 2010, and UNC 2010) to reflect the crash exposure factor. The pedestrian/cyclist crash rate per 100,000 population is calculated using Equation 1 (NHTSA-FARS accessed 2014).

$$Cri = (ai / Pi) * 100{,}000 \qquad \textbf{Equation 1}$$

Where,

C_{ri} = Pedestrian/cyclist crash rate per 100,000 population for the year "i"

a_i = Number of pedestrian/cyclist crashes for the year "i"

P_i = Population for the year "i"

It is essential to compile data for the minimum of three consecutive, or five non-consecutive, years to overcome the regression to mean bias (AAHSTO 2010). As variations are usually due to the normal randomness of crash occurrences, sites experiencing extreme cases in one period, they are likely to experience lower crash frequencies in another period. In spite of this variation, the crash occurrences are clustered around an average (mean) which can be modeled with Normal/Gaussian distribution. To yield the safety determinant of each project, the study compiles and calculates crash rate per 100,000 population for 7 years period (see the case study).

To find the best approach to score determinants, NCHRP Report 803 (Lagerwey et al. 2015) recommended three major scaling methods to classify parameters with outliers: 1) quantile scaling, 2) rank order, 3) Jenks natural breaks. To produce, thematic maps, Stern et al. (2006) defined four major methods of data classification with outliers: 1) mean-standard deviation, 2) Quantiles, 3) Maximum breaks, 4) natural/Jenks breaks (often used in GIS applications). As crash rate follows normal distribution and an existence of outlier is probable, the study leverages quartile scaling to score the safety determinant (*S[C_r]*). Using the box plot which is a descriptive statistical method to group numerical data through their quartile, data is classified into 4 groups where the data value between 25% (first quartile = q1) and 75% (third quartile = q3) are in the box, as shown in Figure 8. Whiskers, i.e. lines extending vertically from the box, which reflects the lower and upper bound are calculated using Equation 2:

*Lower bound = q1 – [1.5 * (q3 – q1)]* **Equation 2**

*Upper bound = q3 + [1.5 * (q3 – q1)]*

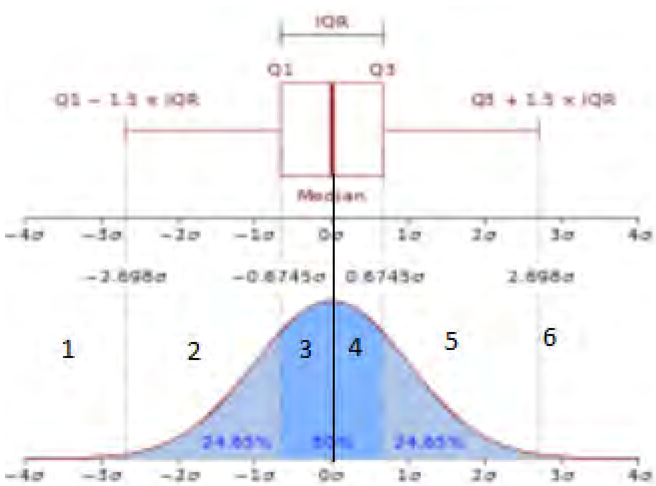


Figure 8 The boxplot and scoring region

The 1.5 multiplier corresponds to ±2.695σ (where σ is the standard deviation) and covers 99.3% of the data for the Normal distribution. Any data point located out of the lower/upper whiskers considers as an outlier and scores according to the code presented in Figure 9. The final safety score of a project (*S[C_r]*) is estimated by averaging each year score. The highest score (=6) is assigned to a site/sites with the highest crash rate.

If C_r > (quartile 3 + whisker) then S [C_r] = 6
If C_r <= (quartile 3 + whisker) AND C_r > quartile 3 then S [C_r] = 5
If C_r <= quartile 3 AND C_r > quartile 2 then S [C_r] = 4
If C_r <= quartile 2 AND C_r > quartile 1 then S [C_r] = 3
If C_r <= quartile 1 AND C_r > (quartile 1 – Whisker) then S [C_r] = 2
If C_r <= (quartile 1 – Whisker) then S [C_r] = 1

Figure 9 Scoring methodology for crash rate scores

3.2. Project Effectiveness

The effectiveness of proposed projects designed to improve deficiencies of pedestrian/cyclist facilities can be examined from two folds: safety and mobility. From the safety standpoint, the study defines the Crash Modification Factor (CMF) or Crash Reduction Factor (CRF) as the parameter to measure the safety effectiveness of projects. From the mobility standpoint, many factors can be delineated to measure and assess an improvement of pedestrian/cyclist mobility. Nevertheless, two key factors are recognized to measure and evaluate the project mobility effectiveness: connectivity and accessibility. In following, each factor is elaborated thoroughly.

3.2.1. Crash Modification Factor (Safety effectiveness – S[E])

This factor captures the effectiveness of a safety countermeasure proposed to improve safety. A CMF is a multiplier utilized to estimate the expected number of crashes after the implementation of a given safety countermeasure at a specific site. As shown in Equation 3, Crash Reduction Factor (CRF), which is the percentage of crash reduction expected after the implementation of a given safety countermeasure, and CMF are interchangeable.

$$CMF = 1 - (CRF/100) \qquad \textbf{Equation 3}$$

A CMF is a positive number. If a CMF yields a number between zero and less than one, the safety countermeasure is considered effective and expected to decrease the number of crashes. A CMF greater than one (negative CRF) means that the countermeasure is expected to increase the number of crashes. Commonly, this phenomenon happens when a countermeasure decreases a specific type of crashes (e.g. head-on collision), while increases other crash types (e.g. rear-end crashes). Federal Highway Administration (FHWA) with the assistance of University of North Carolina (UNC- Accessed 2014) designed, developed, and hosted the CMF clearinghouse website cataloging CMFs developed by transportation professionals and scholars. The website has inventoried more than 3,500 CMFs and is updated in a regular basis. About 244 of these CMFs were developed for pedestrian/cyclists crashes. An evaluation of the CMF variation is performed on the pedestrian/cyclist CMFs. Figure 10 depicts the histogram of CMF for these types of crashes (pedestrian and cyclist). After a distribution fitting assessment, Logistic distribution is identified as a best fitted distribution.

As shown in Figure 10, 132 of CMFs yield values less than one, which are expected to decrease the number of crashes for pedestrians/cyclists. Yet, some outliers can be observed. Considering the shape of histogram and existence of outliers, Jenks-natural breaks is the best fit to perform scaling. To be consistent with the rest of scaling classifications, six data clusters are used to categorize CMF.

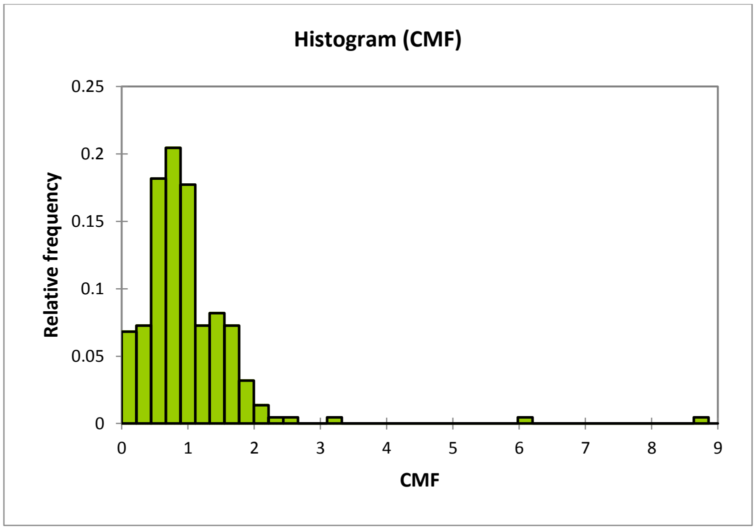


Figure 10 Pedestrian and cyclist CMF histogram

As CMFs less than one are impactful, the Jenks/Natural break procedure is applied on all CMF developed for pedestrian/cyclist considering this crucial element. Jenks is an iterative procedure to find the most suitable and logical classification to group dataset. Jenks classifies data based on the principle of minimizing value differences among data within the same class and maximizing the distance between the groups/classes. The procedure is coded under VB (Visual Basic) in Excel macro-enabled environment. Appendix 1 Table A-1 demonstrates the procedure of finding an appropriate classification under Jenks/natural breaks process. With the GVF (Goodness of Variance Fit) equal to 0.936, the following scoring thresholds are concluded and demonstrated in Figure 11:

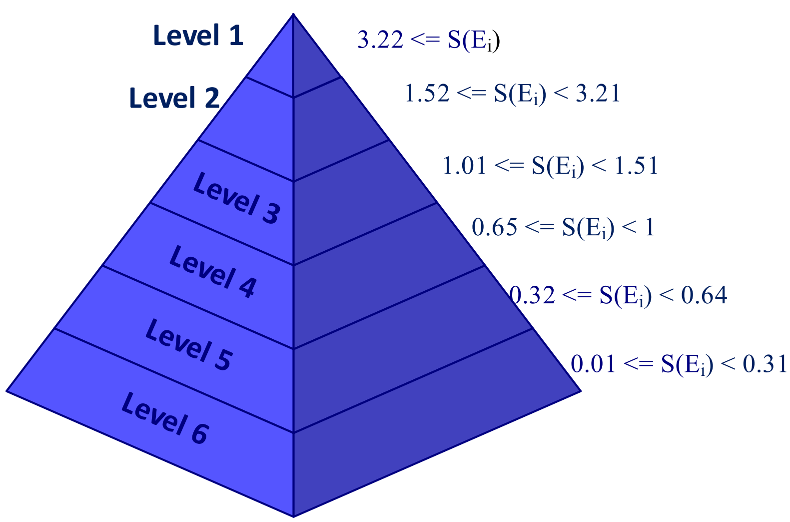


Figure 11 Safety Effectiveness S(E) Scoring System using Jenks/natural break approach

It is worth mentioning that GVF ranges between 0 and 1; “1” indicates the perfect fit, while “0” shows extreme inapt. If CMF for any proposed countermeasure is not available, city’s engineers should perform professional assessments on the effectiveness of the proposed countermeasure considering factors pertinent to the estimation of CMF. The algorithm and techniques utilized by transportation professionals and scholars to compute CMF can be found in the CMF clearinghouse (UNC 2014).

3.2.2. Connectivity/Accessibility (Mobility effectiveness - S[M])

Studies and practices have delineated the following elements to capture connectivity and accessibility:

- Number of intersecting roadway segments per square mile (Lagerwey et al. 2015, Walkability research accessed 2014)
- Miles of roadway per square mile (Lagerwey et al. 2015)
- Existence and continuity of sidewalk, width of sidewalk/shoulder ((Lagerwey et al. 2015, Baier et al. 2013, Town of Farmville et al. 2013, Walkability research accessed 2014)
- Closeness to attraction places/ activity center/school (Baier et al. 2013, Walkability research accessed 2014, Natarajan et al. 2008, Town of Farmville et al. 2013)
- Existences/number/type of bike lanes (Lagerwey et al. 2015, Walkability research accessed 2014, Natarajan et al. 2008, Baier et al. 2013)
- Compliance with standards and accessibility for disables (Lagerwey et al. 2015, Town of Farmville et al. 2013). This includes curb ramps, sidewalk/bike lane widths

Walk Score is a measure of community walkability. It computes walkability based on the existence of walkway, closeness to attraction amenities (e.g. public building, residential development, shop, school, park, hospital, transit, and high density area/CBD/downtown), population density, block length, and intersection density. However, the algorithm behind this measurement is proprietary (*Based on the response given to the author by the developers of this score*) and has not been published. With this consideration, the author has considered two key determinants to yield pedestrian connectivity/accessibility; 1) roadway connectivity by capturing a number of intersecting roadways per square mile, and 2) accessibility to major attraction places by improving pedestrian mobility in the vicinity of these locations. The pedestrian connectivity ($s_p[c]$) methodology is as follows:

- Determine the number of intersection per square mile of the most connected network such as CBD or City’s downtown which serves as the highest connected network. The score of 6 is assigned to this reference site, i.e. $s_r[c] = n_r$.
- Extract a number of intersections per square mile of area where the proposed project is planned to establish, i.e. $s_p[c] = n$. The area is defined by drawing a circle around the understudied location (center of circle) with the radius of 0.56.
- Compute the score of connectivity for the understudied location using the interpolation, i.e. $s_p[c] = (n*6)/n_r$.

The pedestrian accessibility ($s_p[a]$) is calculated using the following scheme:

- Find the amenities close to the proposed project locations, i.e. downtown, school, shopping center, park.
- Assign the score based on the distance between the proposed project location and amenities. Points are awarded based on the distance to amenities (*d*) and the rationale behind walkable distance expressed in studies (e.g. *27 and 29*) using the following logic:
  - If $d <= 0.2$ then $s_p[a] = 6$
  - If $0.2 < d <= 0.4$ then $s_p[a] = 5$
  - If $0.4 < d <= 0.6$ then $s_p[a] = 4$
  - If $0.6 < d <= 0.8$ then $s_p[a] = 3$
  - If $0.8 < d <= 1$ then $s_p[a] = 2$
  - If $1 < d <= 1.2$ then $s_p[a] = 1$
  - No points given after 1.2 mile or 25-minute walk.

The final pedestrian connectivity/accessibility *(SM])* is yielded by the average or weighted average of two determinants ($s_p[c]$ and $s_p[a]$). Bike connectivity is estimated using the pedestrian connectivity scheme. However the bike accessibility ($s_b[a]$) is estimated with revising the distance between the location of the proposed project and amenities. Using the subsequent procedure, the study assumes the desirable biking distance is about 2-mile with no points will be given to the segment more than 5-mile (USDOT 1992, and FHWA 2006):

- Find the amenities close to the understudied location, i.e. downtown, school, shopping center, park.
- Assign the score based on the distance between the understudied location and amenities. Points are awarded based on the distance to amenities (*d*) using the following logic:
  - If $d <= 1$ then $s_b[a] = 6$
  - If $1 < d <= 2$ then $s_b[a] = 5$
  - If $2 < d <= 3$ then $s_b[a] = 4$
  - If $3 < d <= 4$ then $s_b[a] = 3$
  - If $4 < d <= 5$ then $s_b[a] = 2$
  - No points given after 5 mile.

Similar to the pedestrian connectivity/accessibility score, bike connectivity/accessibility score is estimated using the average or weighted average of bike connectivity and accessibility scores, i.e. $s_b[c]$ and $s_b[a]$.

3.3. Project Cost *(S[I])*

Considering the scarcity of capital to fund projects, cost is a key determination factor to fund the improvement projects. However, cost should not been assessed in a vacuum. From an economic perspective, Life Cycle Cost Analysis (LCCA) is an approach to determine the most cost-effective alternative among a pool of options to build, operate, maintain, and finally dispose. Therefore, the study considers the following factors to be contained in the "cost" score.

- Capital cost
- Maintenance cost under its life span
- Operation cost (if applicable)
- Salvage cost at the end of useful life (if applicable)

With this consideration, the present cost value of any proposed plan should be computed using LCCA technique formulated in Equation 4.

I_i = PV (capital cost) + PV (maintenance cost) + PV (operation cost) – PV (salvage cost)

$$I_i = Pv\ (C_i) + M_i * \frac{(1+r)^t - 1}{d * (1+r)^t} + O_i * \frac{(1+r)^t - 1}{d * (1+r)^t} - S_i * \frac{1}{(1+r)^t} \quad \textbf{\textit{Equation 4}}$$

Where,

I_i = Present value (PV) of costs for alternative i
S_i = One time negative cost - salvage value of alternative i
r = Interest/discount rate
t= Useful life of alternative i
M_i = Annual recurring fixed maintenance costs for the life of alternative i
O_i = Annual recurring fixed operation costs for the life of alternative i

Funded by FHWA, UNC (2013) furnished a rich dataset on pedestrian/cyclist infrastructure improvement costs compiled from states all over US based on reported bids and actual implementation costs. Though, the implementation costs and bids vary from state to state, it provides a valuable resources for transportation professionals. For more than 1,700 recorded countermeasures, the capital costs (i.e. low and high costs with/out inflation) are provided with the measurement unit (e.g. per foot, per approach, per mile, per crossing) and partially completed annual costs and life expectancies. In cases that no estimated monetary values can be found in that dataset, the cost of comparable projects can be chosen for estimation.

To scale the cost value and determine the cost score, two classification techniques are suitable: Quartile and Jenks. Since costs vary and do not follow normal distribution, the proportional scaling, rank order scaling, and mean standard deviation scaling are not apt techniques to scale costs and assign cost scores. If the quartile scaling is an appropriate approach, the pseudocode presented in Figure 12 can be utilized to yield projects' cost scores:

```
If Ii < (quartile 1 – Whisker) then S [Ii] = 6
Else If Ii < quartile 1 AND Ii >= (quartile 1 – Whisker) then S [Ii] = 5
Else If Ii < quartile 2 AND Ii >= quartile 1 then S [Ii] = 4
Else If Ii < quartile 3 AND Ii >= quartile 2 then S [Ii] = 3
Else If Ii < (quartile 3 + whisker) AND Ii >= quartile 3 then S [Ii] = 2
Else If Ii >= (quartile 3 + whisker) then S [Ii] = 1
End
```

Figure 12 Scoring methodology for the project cost

Quartiles and whiskers are computed by the compilation of costs of all projects applied for funding. To utilized Jenks approach, the algorithm developed in the prior application is utilized to score costs in 6 classes. The project with the lowest cost score attains the highest priority with the score of 6. The study leverages both techniques to find the most suitable one to score costs in the case study. Appendix 2 demonstrates this effort.

3.4. Equity (*S[Q]*)

The equity factor that is delineated to attract more resources to less privileged areas where the car ownership is low and the need for pedestrian/cyclist friendly environment is sensed. This factor is captured by the city's median income. This determinant is also recommended by other studies (Baier 2013, MPO-San Antonio accessed 2014, Natarajan et al. 2008, and Lagerwey et al. 2015) to encompass equity. The statistics for the abovementioned determinant can be derived from the census city-data. While car ownership is also stated by some studies as a measurement element for equity, this study has investigated and concluded (using the case study data) that there is heterogeneity between low income areas and car ownership. Based on census data, some low income areas had reported higher car ownership rates than some areas with larger incomes. This may be due to the poor roadway design (unfriendliness of roadway for pedestrians/cyclists), crime rate (safety concerns), low concentration of businesses and employment centers (low economic prosperity), or lack of availability to public transit systems in these areas. These circumstances may encourage residents to own a car.

As the median incomes of cities do not have an extreme low or high and do not present a wide gap among alternatives, the likelihood of outliers is low. Hence, the study leverages the inverse proportionate scaling. The inverse proportionate scaling is chosen, as the project with the lowest median income attains the highest priority with the score of 6. The inverse proportional scaling is calculated using Equation 5.

$$S[Q] = [\frac{(\bar{I} - \bar{I}min) * \hat{s}}{(\bar{I}max - \bar{I}min)} - \hat{s}] * (-1) \qquad \textbf{Equation 5}$$

Where,

$\bar{I}$ = Median income of the understudied city

$\bar{I}_{min}$ = Minimum of median income among all alternatives

$\bar{I}_{max}$ = Maximum of median income among all alternatives

$\hat{s}$ = Number of classes (=6) to score equity

3.5. Demand (*S[D]*)

The intensity of demand for a facility improvement is contingent to the utilization of the facility. Thus, the demand score should be measured by the number of pedestrians/cyclists using the facilities. However, count data is not available in the predominant cases. Conversely, the study utilizes the labor force population density to yield the demand intensity. The labor force population density is estimated by dividing a number of employees by a measure of area. The demand score is then yielded by the proportional ranking of the labor force density. This ranking tactic is chosen since the existence of outlier (extreme low/high numbers) is minimal. While the linearity of data is not warranted, the proportional ranking does not distort or bias the results (see the case study). The proportional ranking is formulated in Equation 6.

$$S[D] = \frac{(đ - đmin) * ŝ}{(đmax - đmin)} \qquad \textbf{\textit{Equation 6}}$$

Where,

đ = Population density of the understudied city
đmin = Minimum of labor force population density among all alternatives
đmax = Maximum of labor force population density among all alternatives
$\hat{s}$ = Number of classes (=6) to score demand

3.6. Qualitative Features (*S[L]*)

Qualitative score represents key elements recommended to be considered in improvement projects which are qualitative in nature and cannot be quantified such as stakeholder's inputs, public comments/requests, project constrains, political supports, etc. These factors may vary from case to case; though, the inclusion of these factors is essential. The score is estimated based on the number of "yes" (=1) or "no" (=0) responses to certain predefined questions. Then, the score is estimated using Equation 7 with the highest score ended to "6" when all criteria are considered or the lowest score of "0" when no factor is met. One (=1) is assigned to a question that the inclusion of that element has a positive effect on the implementation of the proposed project.

$$S[L] = \frac{\sum_{i=1}^{n} l_i}{N} * \hat{s} \qquad \textbf{\textit{Equation 7}}$$

Where,

N = Number of questions
L = Number of questions with the value of "1"
$\hat{s}$ = Number of classes (=6) to score qualitative elements

4. SCORE DETERMINATION

The previously described determinants do not factor equally into the significance of projects. Thus, the study utilizes a weighting scheme to embrace the merit of each indicator in the final score for a project. To rank alternatives (projects) for funding, the total score of each alternative is formulated using Equation 8 and depicted in Figure 13:

$$S_k[T] = \frac{Wc*Sk[C_r] + We*Sk[E] + Wm*Sk[M] + Wi*Sk[I] + Wq*Sk[Q] + Wd*Sk[D] + Wl*Sk[L]}{W_c + W_e + W_i + W_q + W_d + W_a + W_l} \qquad \textbf{\textit{Equation 8}}$$

Where,

$S_k[T]$ = Total score of alternative k
$S_k[C_r]$ = Safety (crash rate) score for alternative k
$S_k[E]$ = Safety effectiveness (CMF) score for alternative k
$S_k[M]$ = Mobility (accessibility/connectivity) score for alternative k
$S_k[I]$ = Cost score for alternative k

$S_k[Q]$= Equity score for alternative k
$S_k[D]$ = Demand score for alternative k
$S_k[L]$ = Qualitative score for alternative k
W_c = Weight of safety
W_e = Weight of CMF
W_m = Weight of accessibility/connectivity
W_i = Weight of implementation cost
W_q = Weight of equity
W_d = Weight of demand
W_l = Weight of qualitative factors

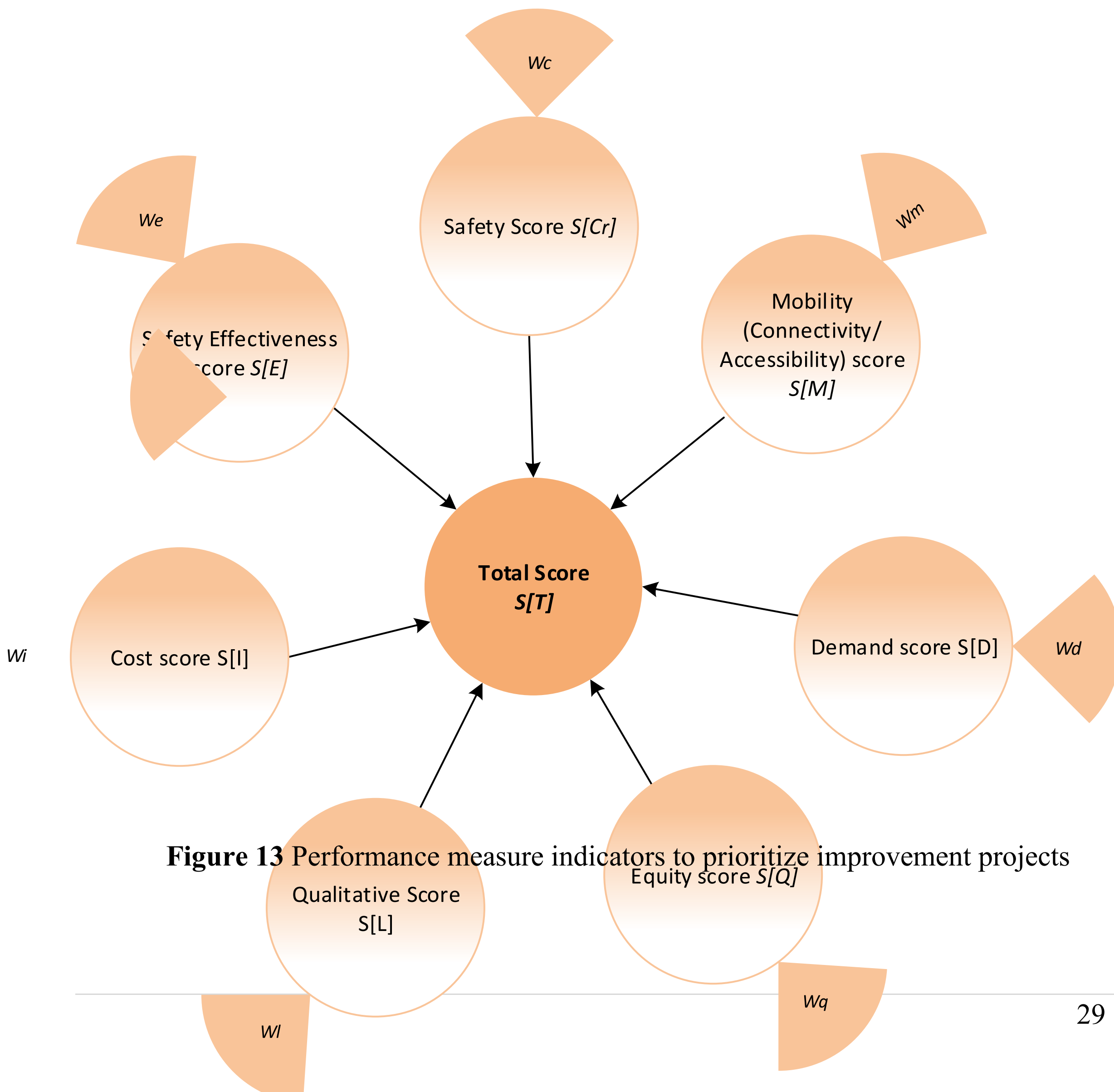


Figure 13 Performance measure indicators to prioritize improvement projects

5. CASE STUDY

To validate the feasibility of the deployment of the proposed approach, the study evaluated pedestrian/cyclist safety records (number of crashes and crash severity) of five major counties in the State of Illinois (Cook, DuPage, Kane, Lake, McHenry, and Will) within the period of 2005-2011. Cook County demonstrates the highest number of crashes among comparable counties. Within this county, ten cities/villages(Berwyn, Chicago, Chicago Heights, Cicero, Evanston, Harvey, Maywood, Niles, Oak Park, and Skokie) represent the highest need for pedestrian/cyclist improvement considering crash records (pedestrian/cyclist crashes per 100,000 population) analyzed during the period of 2005-2011.

This preliminary evaluation is performed to examine the capability of the approach when improvement projects are proposed and submitted to the decision makers for funding among cities/villages with the highest demand and close competitions. Geospatial analysis has been performed within each aforementioned city to locate pedestrian/cyclist crashes and their severities, examine crash contributed circumstances, and delineate pedestrian/cyclist facility deficiencies. The examination of facility deficiencies is performed benefitting from the review of studies/practices (FHWA 2006, NHTSA-FHWA 2012, FHWA 2008, AASHTO 2011, Pedsafe accessed 2014, and Martin 2006) and experience. For instance, Martin (2006) developed a hierarchical list of improvements to reduce pedestrian causalities in London. An enhancement in pedestrian crossing and an improvement in signalized intersection were on the top of his list. According to NHTSA-FHWA statistic (2012), a median island at uncontrolled locations can help reduce pedestrian crashes by up to 40 percent on two-way streets. Using the Google earth street view archive, pedestrian/cyclist crash locations are thoroughly evaluated for any potential deficiencies.

Pursuing the developed methodology, the scores for each developed improvement in each community is populated and presented in the subsequent subsections. The crash score (*S[Cr]*) is derived by the utilization of quartile scaling on the estimated crash rate (pedestrian/cyclist crashes occurred within the period of 2005-2011 per 100,000 population) in each city. Safety effectiveness score (S[E]) is yielded by utilizing the CMF of the proposed projects using CMF clearing house (FHWA - accessed 2014). As elaborated in Section 3.2.1, the Jenks scaling system is utilized on the CMF data to derive the safety effectiveness score (*S[E]*) of the proposed project. To estimate connectivity and accessibility scores for pedestrian and cyclist projects, a number of projects (see below) are proposed in locations with high number of pedestrian and cyclist crashes occurred during the period of 2007-2009. These projects are proposed based on engineering judgment and analyses of facilities using Google map archive. The connectivity (*s[c]*) and accessibility (*s[a]*) scores are assessed for each proposed improvement using the methodology developed earlier and the final mobility score (*S[M]*) is calculated by averaging the connectivity and accessibility scores. The equity score (*S[Q]*) of each city is computed using the inverse proportionate scaling (Equation 5) on the median incomes. The demand score (*S[D]*) is yielded from the estimation of population density of each city and utilizing the proportional ranking (Equation 6). The capital costs of the proposed/planned improvements are derived from the UNC database (2014). Since the cost data comprises a high gap between the lowest and highest project costs, it seems Jenks scaling technique is more apt approach to score cost determinant. However, Quartile scaling has also been adopted to derive the project cost score (*S[I]*). Appendix 2 demonstrates the procedure of scaling using both techniques, Quartile scaling, and Jenks scaling, and the rationale behind the selection of the most apt scaling system. The qualitative score (*S[L]*) is yielded by developing four rational questions that may be impactful in a project selection. These questions are as follows:

1) Is there any political support?
2) Doesn't a project have some physical implementation constraint?
3) Is there any public comment/request?
4) Is there any project opportunity?

The procedure of qualitative scoring follows the methodology discussed earlier and leveraging Equation 7.

To determine the weight of each determinant in the final score, the following weighting scheme is pursued: 1) W_c (weight of safety) = 3, W_e (weight of CMF) = 3, W_m (weight of accessibility/connectivity) = 2, W_i (weight of implementation cost) = 2, W_q (weight of equity) = 2, W_d (weight of demand) = 2, and W_l = (weight of qualitative factors) = 1. Conclusively, the final score is computed using Equation 8.

In the following subsections, the study presents the procedure of estimation of each determinate for each community.

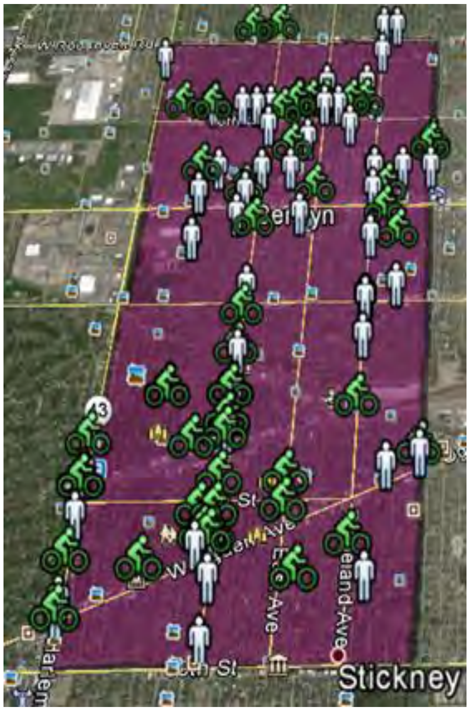
5.1. Berwyn – Determinants Estimation

According to 2010 census data (US Census accessed 2015), the population of Berwyn is 56,657 and has 18,910 households. The total land area of Berwyn is about 3.9 sq. mi. The racial profile of Berwyn is as follows: 1) White 60.48%, 3) 6.40% African American, 3) 0.59% Native American, 4) 2.52% Asian, and 5) 26.61% some other race. Hispanics and Latinos of any race made up 59.44% of the population. Based on this census, 28,702 people in the labor force are commuting to work via: a) car drove alone [24,883], b) car-pool [2,929], c) public transit [2,745], and d) walking [1,157]. Berwyn has the highest density in the State of Illinois with 14,527/sq. mi and labor force density of 7,359 employees per square mile.

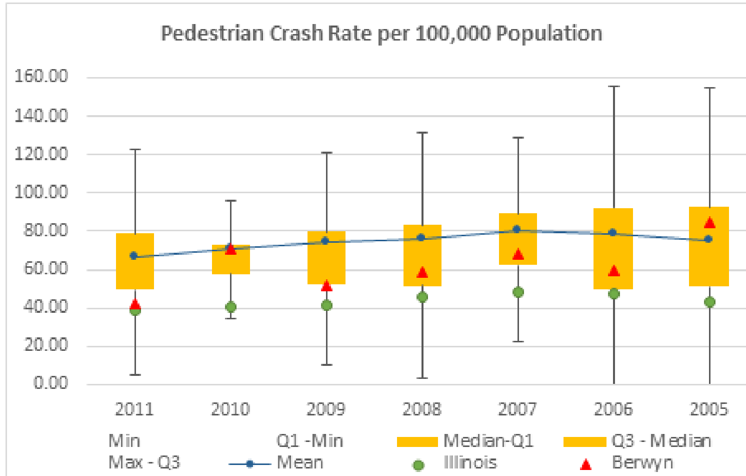
Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 34.47 which corresponds to the pedestrian crash score of (S [Cr] =) "3" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 22.33 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "3.43" using the same method (Quartile scaling). Figure 14a demonstrates the pedestrian/pedal-cyclist crash location in the city of Berwyn during the period of 2007-2009. Figures 14b and 14c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the pedestrian/pedal-cyclist crash rates were higher than the average crash rate of cities in all years. The mean line (blue line) represents the average crash rates for all under study cities.

As the median income in the city of Berwyn is $51,192, the equity score (S [Q] =) is 3.5 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 6. The connectivity score is estimated by defining Berwyn's downtown as a reference. Berwyn's downtown is delineated as a square mile area limited to Roosevelt Rd. from north, Cermak Rd. from south, Home Ave. from west, and Lombard Ave. from east.

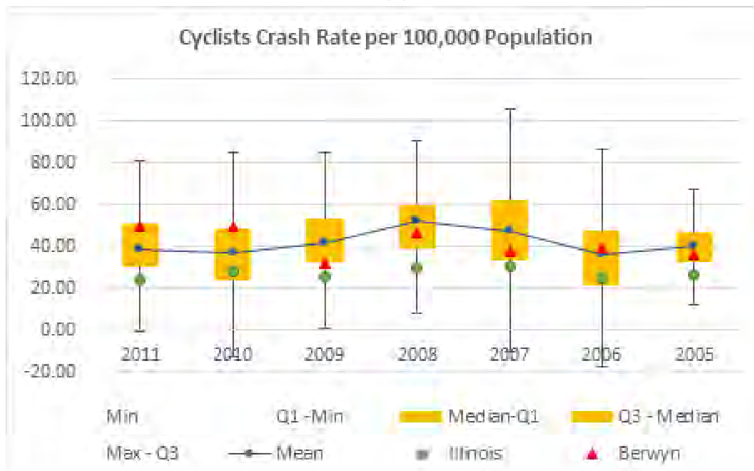
The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S[M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.



(a)



(b)



(c)

Figure 14 Berwyn crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the following pedestrian countermeasures are delineated in two locations:

- Grove Ave./ Cermak Rd. : The proposed countermeasures are 1) the installment of pedestrian traffic signals: this countermeasure has CMF = 0.45-0.5 corresponds to the safety effectiveness score (S [E]) of 5; and 2) the establishment of crosswalk: this countermeasure has the CMF = 0.65 corresponding to the safety effectiveness score (S [E]) of 4. Therefore, the average safety effectiveness score (S[E] =) yields the score of 4.5. The connectivity score (S[c]=) is 2.53 and the accessibility score (S[a]=) is 6, as it is close to school and shopping center within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 4.27. The cost of the installment of pedestrian traffic signal head is about $1,159/each. The cost of the implementation of crosswalk is about $350/each. Therefore, the total budget for the installment of pedestrian traffic signal for two approaches and the cost of installment of crosswalk marking for 4 approaches are about

$3,718. Using the Jenks scaling system, the total cost of $3,718 corresponds to S [I] = 6. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, no=0 to the third question, and yes=1 to the last question.

- 29th Pl./ Oak Park Rd. The proposed countermeasure is the installment of HAWK Beacon (High-Intensity Activated cross-WalK beacon). This countermeasure has CMF = 0.71 corresponding to the safety effectiveness score (S [E] =) of 4. The connectivity score (S[c]=) is 3.14 and the accessibility score (S[a]=) is 6, as it is close to YMCA and park within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 4.57. The cost of the installment of HAWK Beacon is about $95,732/each. Therefore, the total budget for the installment of HAWK for two approaches is about $191,445. Using the Jenks scaling system, the total cost of $191,445 corresponds to S [I] = 1. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

The following pedal-cyclist countermeasures are delineated for two locations:

- Construct 1-mile dedicated bike lane along 16th street: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 4.06 and the accessibility score (S[a] =) is 6, as it is close to two schools and park within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.03. The cost of construction of bike lane is about $6,000/mile. Using the Jenks scaling system, the total cost of $6,000 corresponds to S [I] = 5. The qualitative score (S [L] =) for this proposed project yields the score of 1.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, no=0 to the third question, and yes=1 to the last question.

- Construct 2-mile dedicated bike lane at S. Oak Park Ave. from 34th St. to 16th St: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 3.52 and the accessibility score (S[a] =) is 6, as it is close to shopping center and park within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 4.76. The cost of construction of bike lane is about $6,000/mile. Using the Jenks scaling system, the total cost of $12,000 corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

5.2. Chicago - Determinants Estimation

According to 2010 census data (US Census accessed 2015), the population of Chicago is 2,695,598 and has 1,045,560 households. The total land area of Chicago is about 227 sq. mi. The racial profile of Chicago is as follows: 1) White 45%, 2) 32.9% African American, 3) 0.5% Native American, 4) 5.5% Asian, and 5) 13.4% from some other races. Hispanics and Latinos of any race made up 28.9% of the population. Based on this census, 1,410,294 people in the labor force are commuting to work via: a) car drove alone [610,610], b) car-pool [116,286], c) public transit [324,316], and d) walking [77,753]. Chicago has a labor force density of 6,027 employees per square mile.

Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 66.45 which corresponds to the pedestrian crash score of (S [Cr] =) "5.29" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 30.2 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "4.86" using the same method (Quartile scaling). Figure 15a demonstrates the pedestrian/pedal-cyclist crash location in the city of Chicago during the period of 2007-2009. Figures 15b and 15c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observes, the pedestrian/pedal-cyclist crash rates were higher than the average crash rate of other cities included in the study. The mean line (blue line) represents the average crash rates for all under study cities.

As the median income in the city of Chicago is $47,408, the equity score (S [Q] =) is 3.9 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 4.9. The connectivity score is estimated by defining the Chicago's downtown as a reference. Chicago's downtown is delineated within two parts with the total area of 1 square mile: 1) one is limited to east-west Wacker Dr. from north, Van Buren St. from south, Michigan Ave. from east, and north-south Wacker Dr. from west; and 2) another is limited to Oak St./Lake Shore Dr. from north, Hubbard St. from south, Columbus Dr. from east and Wells St. from west.

The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S [M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.

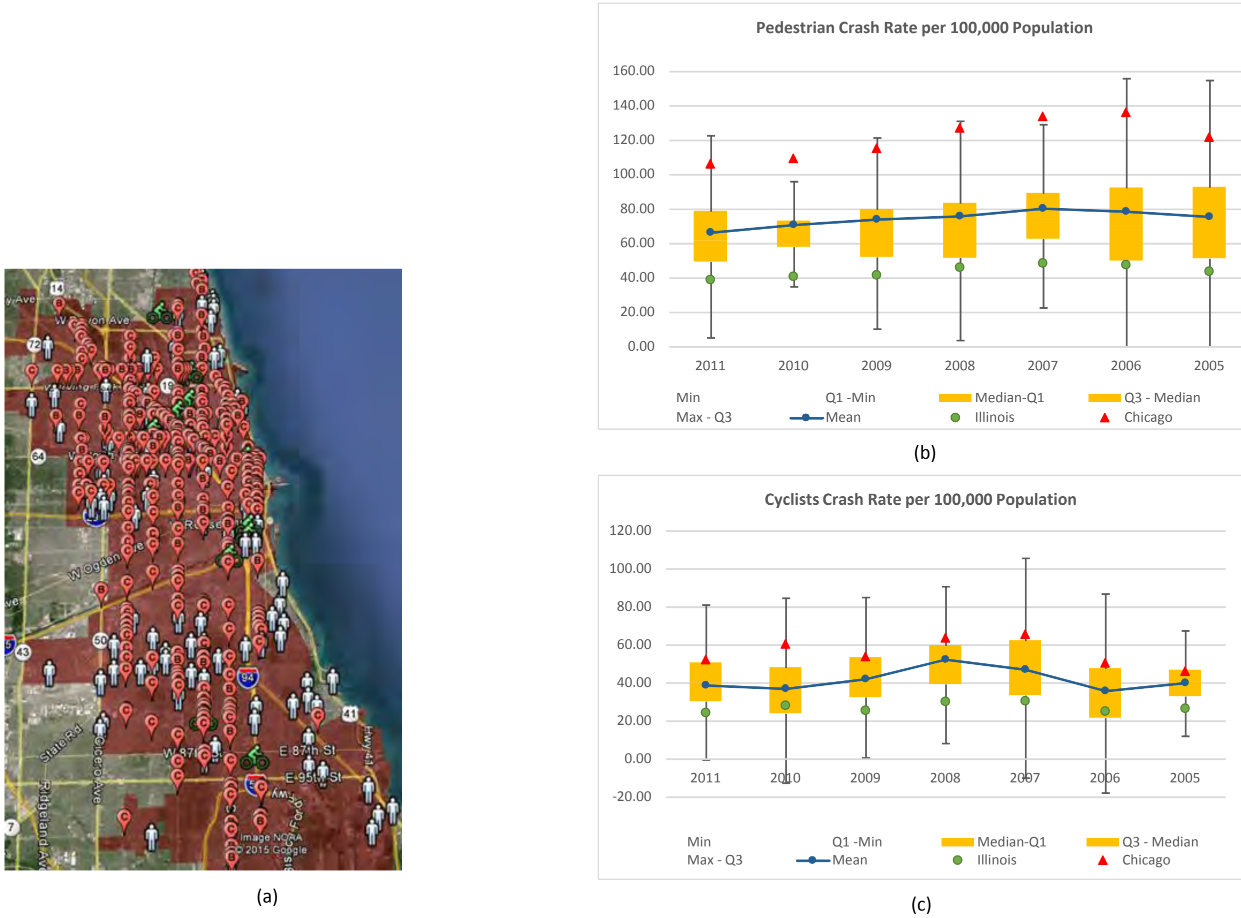


Figure 15 Chicago crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the pedestrian countermeasures are delineated in following locations:

- Harrison St./Financial Pl.: The proposed countermeasure is the installment of raised or high visibility crosswalk. This countermeasure has CMF = 0.63 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 2.87 and the accessibility score (S[a] =) is 5, as it is close to CBD, the university auditorium/public library within the radius >0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 3.94. The cost of the installment of raised or high visibility crosswalk is about $3200 for entire intersection. Using the Jenks scaling system, the cost score (S [I] =) equals to 6. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, no=0 to the third question, and yes=1 to the last question.

- Damen Ave./Armitage Ave.: The proposed countermeasure is the extension of curb. This countermeasure has CMF = 0.57 (CH2MHill 2013) corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 6 and the accessibility score (S[a] =) is 6, as it is close to shopping center and school within the radius <= 0.2 mile. Hence, the mobility score (S [M] =) is 6. The cost of the extension of curb is about $20k for each corner. Therefore, the total budget is about $80k for entire intersection with 4 approaches. Using the Jenks scaling system, the cost score (S [I] =) equals to 3. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, no=0 to the third question, and no=0 to the last question.

- Chicago Ave./Homan Ave.: The proposed countermeasure is the extension of curb. This countermeasure has CMF = 0.57 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 6 and the accessibility score (S[a] =) is 6, as it is close to shopping center and school within the radius <= 0.2 mile. Hence, the mobility score (S [M] =) is 6. The cost of the extension of curb is about $20k for each corner. Therefore, the total budget is about $80k for entire intersection with 4 approaches. Using the Jenks scaling system, the cost score (S [I] =) equals to 3. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Ashland Ave./78th St.: The proposed countermeasures are: 1) the extension of curb, and 2) the installment of raised median on Ashland Ave. The curb countermeasure has CMF = 0.57 corresponding to the safety effectiveness score (S [E] =) of 5. The raised median has CMF = 0.7 corresponding to S [E] = 4. Therefore, the average S [E] equals to 4.5. The connectivity score (S[c] =) is 3.15 and the accessibility score (S[a] =) is 5, as it is close to school within the radius of 0.2 > and <= 0.4 mile. Hence, the mobility score (S [M] =) is 4.08. The cost of the extension of curb is about $20k for each corner. Therefore, the total budget of curb extension for two approaches is about $40k for the intersection. Simultaneously, the cost of providing raised median is about $366 per foot. Using the reference (Designing complete street - accessed 2015), the cost of raised median of two approaches for median with the width of 6 ft. and 20 ft. long is about $87,840. Hence, the total budget for this intervention is about $127,840. Using the Jenks scaling system, the cost score (S [I] =) equals to 2. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Ashland Ave./76th St.: The proposed countermeasures are: 1) the extension of curb, and 2) the installment of raised median on Ashland Ave. The curb countermeasure has CMF = 0.57 corresponding to the safety effectiveness score (S [E] =) of 5. The raised median has CMF = 0.7 corresponding to S [E] = 4. Therefore, the average S [E] equals to 4.5. The connectivity score (S[c] =) is 2.69 and the accessibility score (S[a] =) is 6, as it is close to school within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 4.35. The cost of the extension of curb is about $20k for each corner. Therefore, the total budget of curb extension for two approaches is about $40k for the intersection. Simultaneously, the cost of providing raised median is about $366 per foot. Using the reference (Designing complete street – accessed 2015), the cost of raised median of two approaches for median with the width of 6 ft. and 20 ft. long is about $87,840. Hence, the total budget for this intervention is about $127,840. Using the Jenks scaling system, the cost score (S [I] =) equals to 2. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

The following pedal-cyclist countermeasures are delineated for following locations:

- Construct 6.2 miles of dedicated bike lane along Irving Park Rd.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 6 and the accessibility score (S[a] =) is 6, as it is close to two schools and park within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 6. The cost of the construction of bike lane is about $6,000/mile. Therefore the cost of deployment is about $37,200. Using the Jenks scaling system, the total cost of $37,200 corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Install and modify signal for pedal-cyclists for 7 intersections along Irving Park Rd: This countermeasure has the CMF of 0.63 which equals to S [E] of 5. The connectivity score (S[c] =) is 6 and the accessibility score (S[a] =) is 6, as it is close to two schools and park within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 6. The cost of the installment of one pedal-cyclist signal is about $12,803. Therefore the total cost of signal installment is about $89,620. Considering the total cost of constructing bike lane ($37,200) and pedal-cyclist signal deployment ($89,620), total budget for constructing and installing is about $126,819. Using the Jenks scaling system, this total cost corresponds to S [I] = 2. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

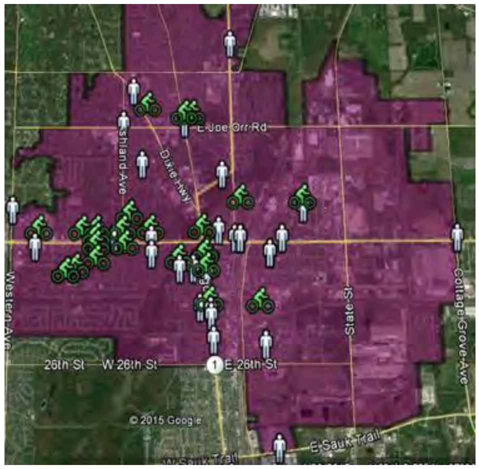
5.3. Chicago Heights - Determinants Estimation

According to 2010 census data (US Census accessed 2015), the population of Chicago Heights is 30,276 and has 9,587 households. The total land area of Chicago Heights is about 10.1 sq. mi. The racial profile of Chicago Heights is as follows: 1) White 38%, 2) 41.5% African American, 3) 0.6% Native American, 4) 0.4% Asian, and 5) 16.6% from some other races. Hispanics and Latinos of any race made up 33.9% of the population. Based on this census, 13,174 people in the labor force are commuting to work via: a) car drove alone [8,588], b) car-pool [1,339], c) public transit [651], and d) walking [194]. Chicago Heights has a labor force density of 1,306 employees per square mile.

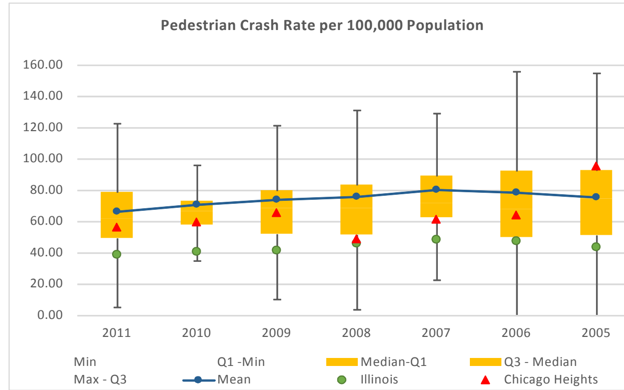
Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 36.07 which corresponds to the pedestrian crash score of (S [Cr] =) "3" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 16.65 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "2.57" using the same method (Quartile scaling). Figure 16a demonstrates the pedestrian/pedal-cyclist crash location in the city of Chicago Heights during the period of 2007-2009. Figures 16b and 16c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the box plots depict mixed results with the average of pedestrian/pedal-cyclist crash rates lower than the average crash rate of cities understudy in most years. The mean line (blue line) represents the average crash rates for all under study cities.

As the median income in the city of Chicago Heights is $42,959, the equity score (S [Q] =) is 4.4 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 1. The connectivity score is estimated by defining the Chicago Heights downtown as a reference. Chicago Heights downtown is delineated as a square mile area limited within a circle with a radius of 0.56 and Halsted St./Rt. 30 as a center of circle.

The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S [M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.



(a)



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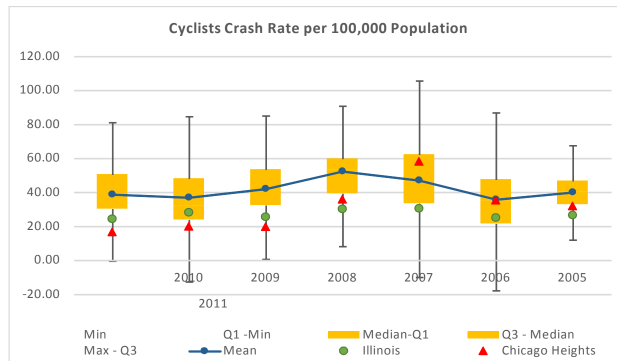


(c)

Figure 16 Chicago Heights crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the following pedestrian countermeasures are delineated in two locations:

- Main St./ Rt 1: The proposed countermeasures are 1) the installment of HAWK Beacon, and 2) providing high visibility crosswalk. The first countermeasure has CMF = 0.71 corresponding to the safety effectiveness score (S [E] =) of 4 and the second one has the CMF= 0.6 corresponding to the safety effectiveness score (S [E] =) of 5. Therefore the average S [E] equals to 4.5. The connectivity score (S[c] =) is 4 and the accessibility score (S[a] =) is 5, as it is close to school and park within the radius of > 0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 4.5. The cost of the installment of HAWK Beacon is about $95,732/each and the cost of high visibility crosswalk marking is $3200 per intersection. Therefore, the total budget for the installment of HAWK for two approaches ($191,445) and the installment of high visibility crosswalk are about $194,645. Using the Jenks scaling system, the total cost of $194,645 corresponds to S [I] = 1. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Main St./ East End Ave.: The proposed countermeasure is the installment of HAWK Beacon. This countermeasure has CMF = 0.71 corresponding to the safety effectiveness score (S [E] =) of 4. The connectivity score (S[c] =) is 4 and the accessibility score (S[a] =) is 5, as it is close to school and park within the radius of > 0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 4.5. The cost of the installment of HAWK beacon is about $95,732/each. Therefore, the total budget for the installment of HAWK for two approaches is about $191,445. Using the Jenks scaling system, the total cost corresponds to S [I] = 1. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

The following pedal-cyclist countermeasure is delineated for two locations:

- Construct 1.72 mile of dedicated bike lane along Lincoln Hwy.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 4.46 and the accessibility score (S[a] =) is 6, as it is close to school, hospital, and park within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.23. The cost of construction of bike lane is about $6,000/mile. Using the Jenks scaling system, the total cost of $10,320 corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Construct 2.13 mile of dedicated bike lane along Chicago St.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 4.13 and the accessibility score (S[a] =) is 6, as it is close to school, hospital, library, and park within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.07. The cost of construction of bike lane is about $6,000/mile. Using the Jenks scaling system, the total cost of $12,780 corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 6 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

5.4. Cicero - Determinants Estimation

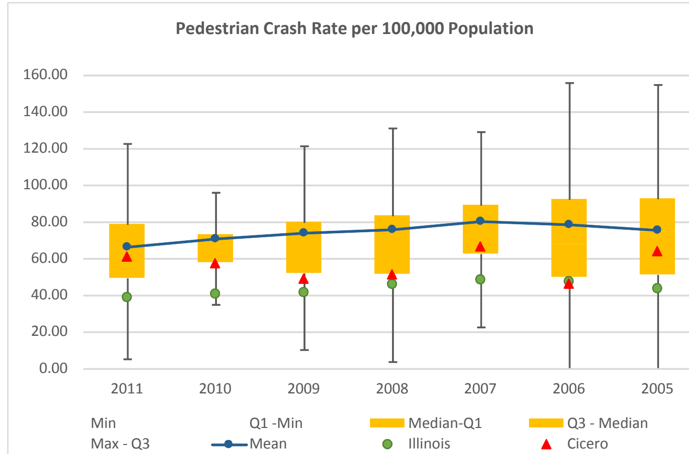
According to 2010 census data (US Census accessed 2015), the population of Cicero is 83,891 and has 22,101 households. The total land area of Cicero is about 5.9 sq. mi. The racial profile of Cicero is as follows: 1) White 51.9%, 2) 3.8% African American, 3) 0.8% Native American, 4) 0.6% Asian, and 5) 39.9% from some other races. Hispanics and Latinos of any race made up 86.6% of the population. Based on this census, 39,324 people in the labor force are commuting to work via: a) car drove alone [21,883], b) car-pool [6,300], c) public transit [3,548], and d) walking [1,171]. Cicero has a labor force density of 6,699 employees per square mile.

Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 31.48 which corresponds to the pedestrian crash score of (S [Cr] =) "2.43" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 13.33 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "2.14" using the same method (Quartile scaling). Figure 17a demonstrates the pedestrian/pedal-cyclist crash location in the city of Cicero during the period of 2007-2009. Figures 17b and 17c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the pedestrian/pedal-cyclist crash rates in this city are lower than the average crash rate of cities understudy. The mean line (blue line) represents the average crash rates for all under study cities

As the median income in the city of Cicero is $45,656, the equity score (S [Q] =) is 4.1 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 5.45. The connectivity score is estimated by defining the Cicero's downtown as a reference. Cicero's downtown is delineated as a square mile area limited to 21st St. from north, 26th St. from south, Lombard Ave. from west, and Cicero Ave. from east.

The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S[M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.

(a)



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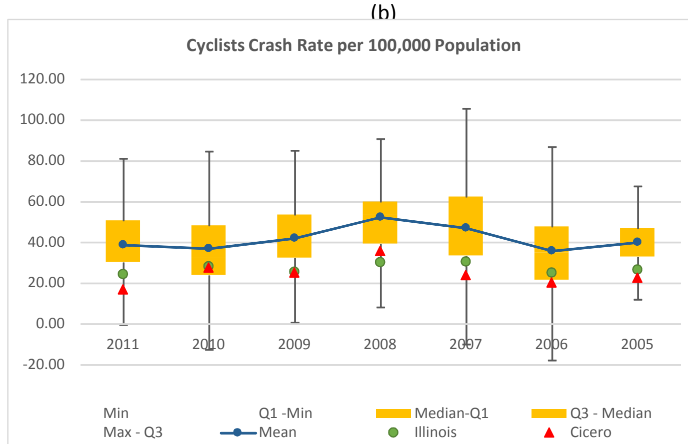


(c)

Figure 17 Cicero crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the pedestrian countermeasures are delineated in following locations:

- Cicero Ave./22nd St.: The proposed countermeasure is the construction of median as a refugee-island for pedestrian in four approaches. This countermeasure has CMF = 0.61 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 2.89 and the accessibility score (S[a] =) is 6, as it is close to school and shopping center within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 4.45. The cost of providing raised median is about $366 per foot. Using the reference (Designing complete street – accessed 2015), the cost of raised median for four approaches for median with the width of 6 ft. and 20 ft. long is about $175,680. Using the Jenks scaling system, the cost score (S [I] =) equals to 1. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Austin Ave./22nd St.: The proposed countermeasure is the construction of median as a refugee-island for pedestrian in four approaches. This countermeasure has CMF = 0.61 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 5.92 and the accessibility score (S[a] =) is 5, as it is close to school and downtown within the radius of > 0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 5.46. The cost of providing raised median is about $366 per foot. Using the reference (Designing complete street – accessed 2015), the cost of raised median for four approaches for median with the width of 6 ft. and 20 ft. long is about $175,680. Using the Jenks scaling system, the cost score (S [I] =) equals to 1. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

The following pedal-cyclist countermeasure is delineated for following location:

- Construct 2-mile dedicated bike lane at on Cicero Ave. from Roosevelt Rd. to 31st St.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 2.89 and the accessibility score (S[a] =) is 6, as it is close to a school and shopping center within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 4.45. The cost of construction of bike lane is about $6,000/mile. Using the Jenks scaling system, the total cost of $12,000 corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

5.5. Evanston - Determinants Estimation

According to 2010 census data (US Census accessed 2015), the population of Evanston is 74,486 and has 30,047 households. The total land area of Evanston is about 7.8 sq. mi. The racial profile of Evanston is as follows: 1) White 65.6%, 2) 18.1% African American, 3) 0.2% Native American, 4) 8.6% Asian, and 5) 3.8% from some other races. Hispanics and Latinos of any race made up 9% of the population. Based on this census, 39,427 people in the labor force are commuting to work via: a) car drove alone [17,471], b) car-pool [2,437], c) public transit [7,224], and d) walking [4,147]. Evanston has a labor force density of 5,055 employees per square mile.

Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 39.37 which corresponds to the pedestrian crash score of (S [Cr] =) "3.86" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 35.65 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "5.29" using the same method (Quartile scaling). Figure 18a demonstrates the pedestrian/pedal-cyclist crash location in the city of Evanston during the period of 2007-2009. Figures 18b and 18c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the pedestrian crash rates in this city lie on the blue line which represents the average crash rates for all under study cities in most years. However, the pedal-cyclist crash rates are above the average blue line in all years.

As the median income in the city of Evanston is $68,051, the equity score (S [Q] =) is 1.8 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 4.1. The connectivity score is estimated by defining the Evanston's downtown as a reference. Evanston's downtown is delineated as a square mile area limited within a circle with a radius of 0.56 and Ridge Ave. / Lake St. as a center of circle.

The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S[M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.

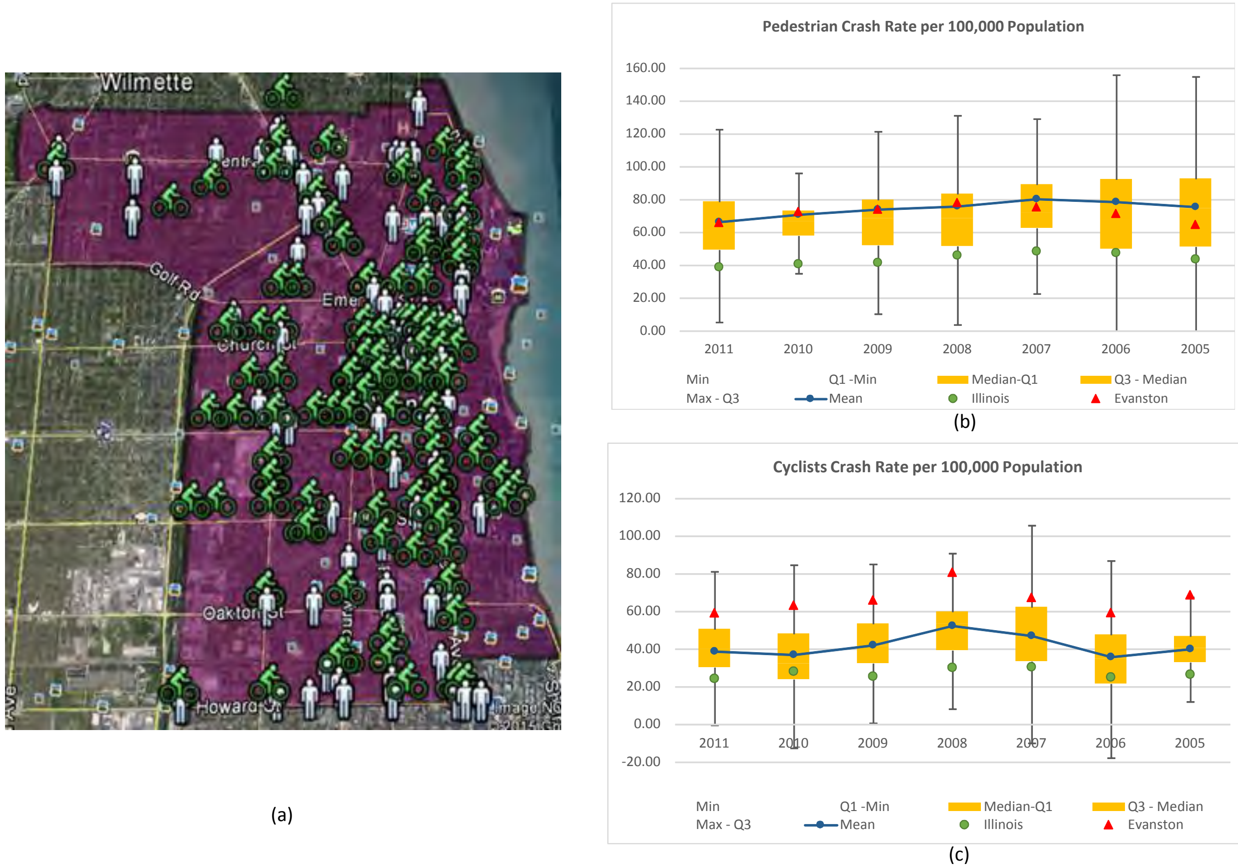


Figure 18 Evanston crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the pedestrian countermeasures are delineated in following locations:

- Ridge Ave./Davis St. : The proposed countermeasure is the installment of raised or high visibility crosswalk (Multi-direction) crossing and modify signal phasing. This countermeasure has CMF = 0.6-0.63 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 5.34 and the accessibility score (S[a] =) is 6, as it is close to school, park, and YMCA within the radius <= 0.2 mile. Hence, the mobility score (S [M] =) is 5.67. The cost of the installment of raised or high visibility crosswalk is about $3,200 for entire intersection and the cost of modifying signal phasing for pedestrian and cyclists is about $3,660. Therefore, the total budget for this development is about $6,860. Using the Jenks scaling system, the cost score (S [I] =) corresponds to 5. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, yes=1 to the third question, and no=0 to the last question.

- Church St./Sherman Ave.: The proposed countermeasure is the installment of raised or high visibility crosswalk (Multi-direction) crossing and modify signal phasing. This countermeasure has CMF = 0.6-0.63 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 5.09 and the accessibility score (S[a] =) is 6, as it is close to school, shopping center, and library within the radius <= 0.2 mile. Hence, the mobility score (S [M] =) is 5.55. The cost of the installment of raised or high visibility crosswalk is about $3,200 for entire intersection and the cost of modifying signal phasing for pedestrian and cyclists is about $3,660. Therefore, the total budget for this development is about $6,860. Using the Jenks scaling system, the cost score (S [I] =) corresponds to 5. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and no=0 to the last question.

- Davis St./ Benson Ave.: The proposed countermeasure is the installment of raised or high visibility crosswalk (Multi-direction) crossing and modify signal phasing. This countermeasure has CMF = 0.6-0.63 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 4.91 and the accessibility score (S[a] =) is 5, as it is close to university, library, and shopping within the radius of > 0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 4.96. The cost of the installment of raised or high visibility crosswalk is about $3,200 for entire intersection and the cost of modifying signal phasing for pedestrian and cyclists is about $3,660. Therefore, the total budget for this development is about $6,860. Using the Jenks scaling system, the cost score (S [I] =) corresponds to 5. The qualitative score (S [L] =) for this proposed project yields the score of 1.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and no=0 to the last question.

- Dempster St. /Chicago Ave.: The proposed countermeasure is to modify signal phasing. This countermeasure has CMF = 0.63 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 5.26 and the accessibility score (S[a] =) is 6, as it is close to a school and park within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 5.63. The cost of modifying signal phasing for pedestrian and cyclists is about $3,660. Using the Jenks scaling system, the cost score (S [I] =) corresponds to 6. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, yes=1 to the third question, and no=0 to the last question.

The following pedal-cyclist countermeasures are delineated for following locations:

- Construct 1.5 miles of dedicated bike lane along Dempster St.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 5.49 and the accessibility score (S[a] =) is 6, as it is close to three schools and park within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.75. The cost of the construction of bike lane is about $6,000/mile. Therefore the cost of deployment is about $9,000. Using the Jenks scaling system, the total cost of $9,000 corresponds to S [I] = 5. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Install and modify signal for pedal-cyclists for two intersections at Dempster St. with the highest number of cyclist crashes: This countermeasure has the CMF of 0.63 which equals to S [E] of 5. The connectivity score (S[c] =) is 5.49 and the accessibility score (S[a] =) is 6, as it is close to a school and park within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.75. The cost of the installment of one pedal-cyclists signal is about $12,803. Therefore the total cost of signal installment is about $25,606. Using the Jenks scaling system, this total cost corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

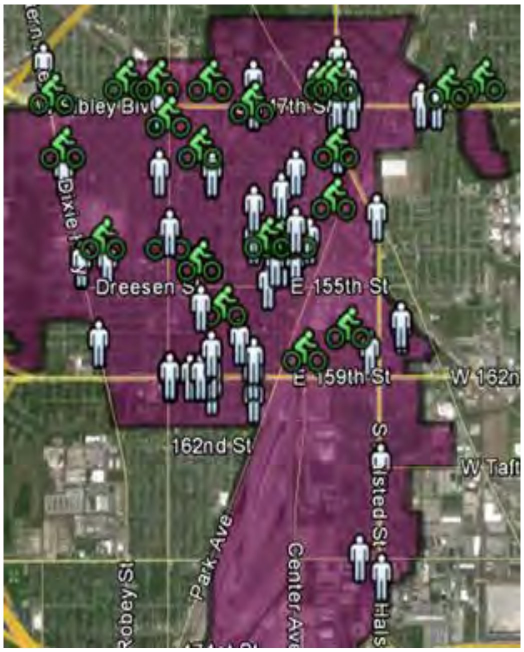
5.6. Harvey - Determinants Estimation

According to 2010 census data (US Census accessed 2015), the population of Harvey is 25,282 and has 7,947 households. The total land area of Harvey is about 6.3 sq. mi. The racial profile of Harvey is as follows: 1) White 10%, 2) 75.8% African American, 3) 0.3% Native American, 4) 0.9% Asian, and 5) 11.3% from some other races. Hispanics and Latinos of any race made up 19% of the population. Based on this census, 9,831 people in the labor force are commuting to work via: a) car drove alone [5,081], b) car-pool [759], c) public transit [832], and d) walking [259]. Harvey has a labor force density of 1,560 employees per square mile.

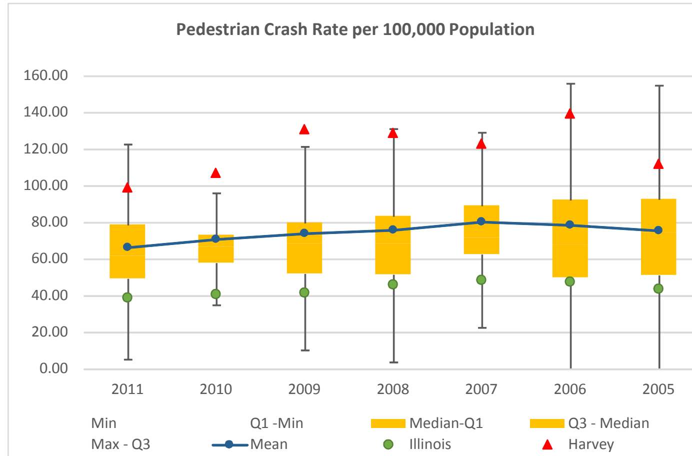
Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 65.33 which corresponds to the pedestrian crash score of (S [Cr] =) "5.29" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 20.92 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "3.29" using the same method (Quartile scaling). Figure 19a demonstrates the pedestrian/pedal-cyclist crash location in the city of Harvey during the period of 2007-2009. Figures 19b and 19c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the pedestrian crash rates in this city are above the average blue line (average of pedal-cyclists crash rates of cities under study) in all years. However, the pedal-cyclist crash rates are around the average blue line with some years higher and some years lower than the blue line.

As the median income in the city of Harvey is $28,123, the equity score (S [Q] =) is 6 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 1.21. The connectivity score is estimated by defining the Harvey's downtown as a reference. Harvey's downtown is delineated as a square mile area limited to 150th St. from north, 157th St. from south, Robey Ave. from west, and Center Ave. from east.

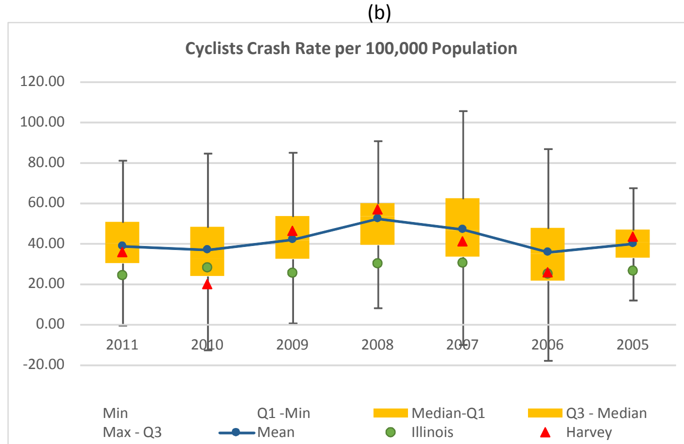
The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S[M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.



(a)



(b)



(c)

Figure 19 Harvey crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the pedestrian countermeasures are delineated in following locations:

- 159th St. /Wood Ave.: The proposed countermeasure is the construction of median as a refugee-island for pedestrian in two approaches. This countermeasure has CMF = 0.61 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 4.46 and the accessibility score (S[a] =) is 6, as it is close to two schools within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 5.23. The cost of providing raised median is about $366 per foot. Using the designing complete street reference (accessed 2015), the cost of raised median for two approaches for median with the width of 6ft and 20 ft. long is about $87,840. Using the Jenks scaling system, the cost score (S [I] =) equals to 3. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- 159th St./Marshfield Ave.: The proposed countermeasure is the installment of HAWK Beacon. This countermeasure has CMF = 0.71 corresponding to the safety effectiveness score (S [E] =) of 4. The connectivity score (S[c] =) is 4.2 and the accessibility score (S[a] =) is 6, as it is close to school and park within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 5.1. The cost of the installment of HAWK beacon is about $95,732/each. Therefore, the total budget for the installment of HAWK for two approaches is about $191,445. Using the Jenks scaling system, the total cost corresponds to S [I] = 1. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Center Ave. / E.154th St.: The proposed countermeasures are 1) the installment of pedestrian traffic signals: this countermeasure has CMF = 0.45-0.5 corresponds to the safety effectiveness score (S [E]) of 5; 2) the modification of signal phasing: this countermeasure has the CMF = 0.63 corresponding to the safety effectiveness score (S[E]) of 5. The connectivity score (S[c] =) is 5.53 and the accessibility score (S[a] =) is 5, as it is close to school within the radius of > 0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 5.27. The cost of the installment of pedestrian traffic signal head and push button is about $800/each or $3,200 per intersection. The cost of signal rephrasing is about $3,660. Therefore the total budget is about $6,860. Using the Jenks scaling system, the total cost of $6,860 corresponds to S [I] = 5. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

  The following pedal-cyclist countermeasure is delineated for one location:

- Construct 1.4 miles of dedicated bike lane at 154th St. between Park Ave. and Dixie Hwy.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 5.64 and the accessibility score (S[a] =) is 6, as it is close to a school and hospital within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.82. The cost of the construction of bike lane is about $6000/mile. Therefore the cost of deployment is about $8,400. Using the Jenks scaling system, the total cost of $8,400 corresponds to S [I] = 5. The qualitative score (S [L] =) for this proposed project yields the score of 1.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, no=0 to the third question, and yes=1 to the last question.

5.7. Maywood - Determinants Estimation

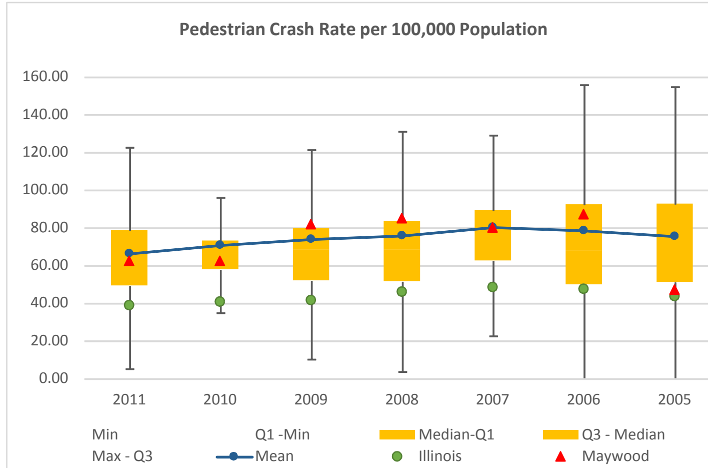
According to 2010 census data (US Census accessed 2015), the population of Maywood is 24,090 and has 7,407 households. The total land area of Maywood is about 2.7 sq. mi. The racial profile of Maywood is as follows: 1) White 12.6%, 2) 74.4% African American, 3) 0.3% Native American, 4) 0.5% Asian, and 5) 10.3% from some other races. Hispanics and Latinos of any race made up 20.8% of the population. Based on this census, 11,609 people in the labor force are commuting to work via: a) car drove alone [7,047], b) car-pool [934], c) public transit [655], and d) walking [165]. Maywood has a labor force density of 4,268 employees per square mile.

Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 39.12 which corresponds to the pedestrian crash score of (S [Cr] =) "3.86" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 19.23 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "3" using the same method (Quartile scaling). Figure 20a demonstrates the pedestrian/pedal-cyclist crash location in Maywood during the period of 2007-2009. Figures 20b and 20c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the pedestrian/pedal-cyclist crash rates depict mixed results with the pedestrian/pedal-cyclist crash rates of this city varying around the average crash rate of cities understudy. The mean line (blue line) represents the average crash rates for all under study cities.

As the median income in the city of Harvey is $43,869, the equity score (S [Q] =) is 4.3 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 3.45. The connectivity score is estimated by defining Maywood's downtown as a reference. Maywood's downtown is delineated as a square mile area limited to Rice St. from north, Fillmore St. from south, 9th Ave. from west, and 1st Ave. from east.

The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S[M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.

(a)



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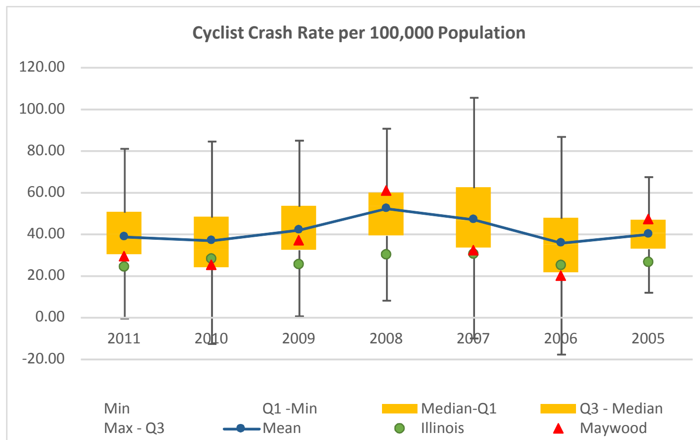


(c)

Figure 20 Maywood crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the pedestrian countermeasures are delineated in the following locations:

- 1st Ave./ School St.: The proposed countermeasure is the installment of HAWK Beacon and crosswalk in two approaches. This countermeasure has CMF = 0.71 corresponding to the safety effectiveness score (S [E] =) of 4. The connectivity score (S[c] =) is 3.06 and the accessibility score (S[a] =) is 6, as it is close to school within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 4.53. The cost of the installment of HAWK Beacon and crosswalk are about $95,732/each and $350 per approach correspondingly. Therefore the total budget of HAWK and high visibility crosswalk is about $192,145.Using the Jenks scaling system, the total cost corresponds to S [I] = 1. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

- 5th Ave./Lake St.: The proposed countermeasure is the extension of curb. This countermeasure has CMF = 0.57 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 3.58 and the accessibility score (S[a] =) is 6, as it is close to school and downtown within the radius <= 0.2 mile. Hence, the mobility score (S [M] =) is 4.79. The cost of the extension of curb is about $20k for each corner. Therefore, the total budget is about $80k for entire intersection with 4 approaches. Using the Jenks scaling system, the cost score (S [I] =) equals to 3. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, no=0 to the second question, no=0 to the third question, and yes=1 to the last question.

The following pedal-cyclist countermeasure is delineated for one location:

- Construct 1.3 miles of dedicated bike lane along Madison St.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 4.29 and the accessibility score (S[a] =) is 6, as it is close to a school within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.15. The cost of the construction of bike lane is about $6,000/mile. Therefore the cost of deployment is about $7,800. Using the Jenks scaling system, the total cost of $7,800 corresponds to S [I] = 5. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

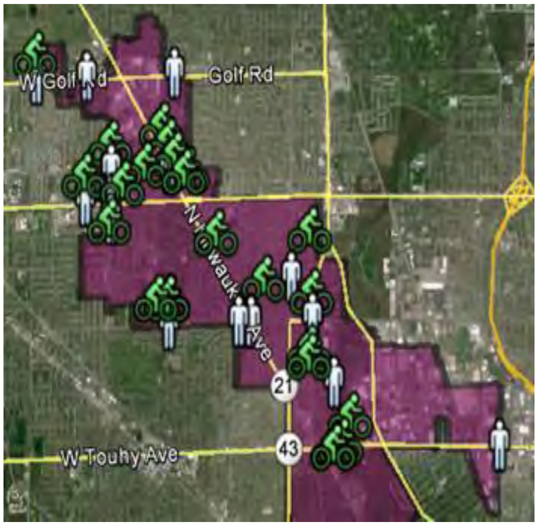
5.8. Niles - Determinants Estimation

According to 2010 census data (US Census accessed 2015), the population of Niles is 29,803 and has 11,906 households. The total land area of Niles is about 5.9 sq. mi. The racial profile of Niles is as follows: 1) 76.3% White, 2) 1.4% African American, 3) 0.1% Native American, 4) 16.7% Asian, and 5) 3.4% from some other races. Hispanics and Latinos of any race made up 8.7% of the population. Based on this census, 14,355 people in the labor force are commuting to work via: a) car drove alone [9,595], b) car-pool [940], c) public transit [1,079], and d) walking [194]. Niles has a labor force density of 2,454 employees per square mile.

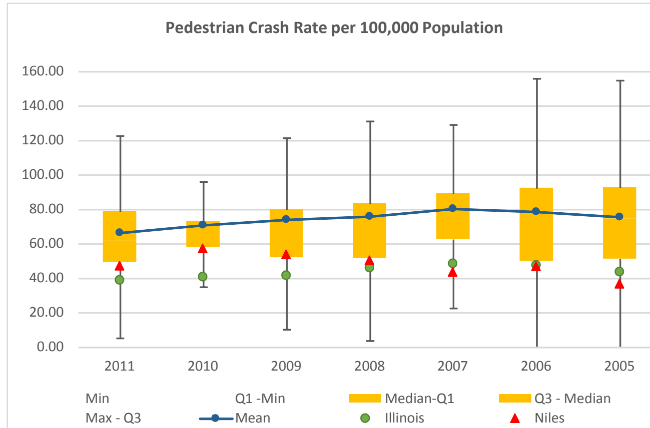
Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 26.74 which corresponds to the pedestrian crash score of (S [Cr] =) "2.14" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 15.18 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "2.29" using the same method (Quartile scaling). Figure 21a demonstrates the pedestrian/pedal-cyclist crash location in the city of Niles during the period of 2007-2009. Figures 21b and 21c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the pedestrian/pedal-cyclist crash rates in this city are lower than the average crash rate of cities understudy. The mean line (blue line) represents the average crash rates for all understudied cities.

As the median income in the city of Niles is $45,546, the equity score (S [Q] =) is 4.1 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 1.95. The connectivity score is estimated by defining Niles's downtown as a reference. Niles's downtown is delineated as a square mile area limited within a circle with a radius of 0.56 and Waukegan Rd./ Oakton St. as a center of circle.

The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S[M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.



(a)



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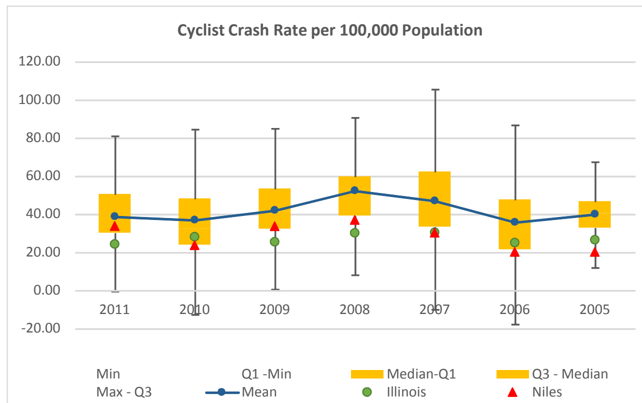


(c)

Figure 21 Niles crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the pedestrian countermeasures are delineated in the following locations:

- Milwaukee Ave./Oakton St.: The proposed countermeasure is the construction of median as a refugee-island for pedestrian in four approaches. This countermeasure has CMF = 0.61 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 6 and the accessibility score (S[a] =) is 6, as it is close to school and shopping center within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 6. The cost of providing raised median is about $366 per foot. Using the designing complete street reference (accessed 2015), the cost of raised median for four approaches for median with the width of 6 ft. and 20 ft. long is about $175,680. Using the Jenks scaling system, the cost score (S [I] =) equals to 1. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, no=0 to the third question, and yes=1 to the last question.

- Milwaukee Ave./Ballard St.: The proposed countermeasure is the construction of median as a refugee-island for pedestrian in two approaches. This countermeasure has CMF = 0.61 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 5.68 and the accessibility score (S[a] =) is 5, as it is close to school within the radius of > 0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 5.34. The cost of providing raised median is about $366 per foot. Using the designing complete street reference (accessed 2015), the cost of raised median for two approaches for median with the width of 6 ft. and 20 ft. long is about $87,840. Using the Jenks scaling system, the cost score (S [I] =) equals to 3. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, no=0 to the third question, and yes=1 to the last question.

- Greenwood Ave./ Ballard St.: The proposed countermeasure is the construction of median as a refugee-island for pedestrian in four approaches. This countermeasure has CMF = 0.61 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 6 and the accessibility score (S[a] =) is 6, as it is close to school and shopping center within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 6. The cost of providing raised median is about $366 per foot. Using the designing complete street reference (accessed 2015), the cost of raised median for four approaches for median with the width of 6 ft. and 20 ft. long is about $175,680. Using the Jenks scaling system, the cost score (S [I] =) equals to 1. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, no=0 to the third question, and yes=1 to the last question.

The following pedal-cyclist countermeasure is delineated for one location:

- Construct 3.8 miles of dedicated bike lane along Milwaukee Ave.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 6 and the accessibility score (S[a] =) is 6, as it is close to two schools within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 6. The cost of the construction of bike lane is about $6,000/mile. Therefore the total cost of deployment is about $22,800. Using the Jenks scaling system, the total cost of $22,800 corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, yes=1 to the third question, and no=0 to the last question.

5.9. Oak Park - Determinants Estimation

According to 2010 census data (US Census accessed 2015), the population of Oak Park is 51,878 people and has 22,670 households. The total land area of Oak Park is about 4.7 sq. mi. The racial profile of Oak Park is as follows: 1) 67.7% White, 2) 21.7% African American, 3) 0.2% Native American, 4) 4.8% Asian, and 5) 2% from some other races. Hispanics and Latinos of any race made up 6.8% of the population. Based on this census, 29,715 people in the labor force are commuting to work via: a) car drove alone [15,376], b) car-pool [1,796], c) public transit [6,021], and d) walking [983]. Oak Park has a labor force density of 6,322 employees per square mile.

Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 44.94 which corresponds to the pedestrian crash score of (S [Cr] =) "4.57" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 26.76 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "4.29" using the same method (Quartile scaling). Figure 22a demonstrates the pedestrian/pedal-cyclist crash location in the city of Oak Park during the period of 2007-2009. Figures 22b and 22c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the box plots depict mixed results with the pedestrian/pedal-cyclist crash rates of this city varying around the average crash rate of cities understudy. The mean line (blue line) represents the average crash rates for all understudied cities.

As the median income in the city of Oak Park is $75,118, the equity score (S [Q] =) is 1 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 5.14. The connectivity score is estimated by defining the Oak Park's downtown as a reference. Oak Park's downtown is delineated as a square mile area limited to Chicago Ave. from north, Madison St. from south, Harlem Ave. from west, and Ridgeland Ave. from east.

The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S[M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.

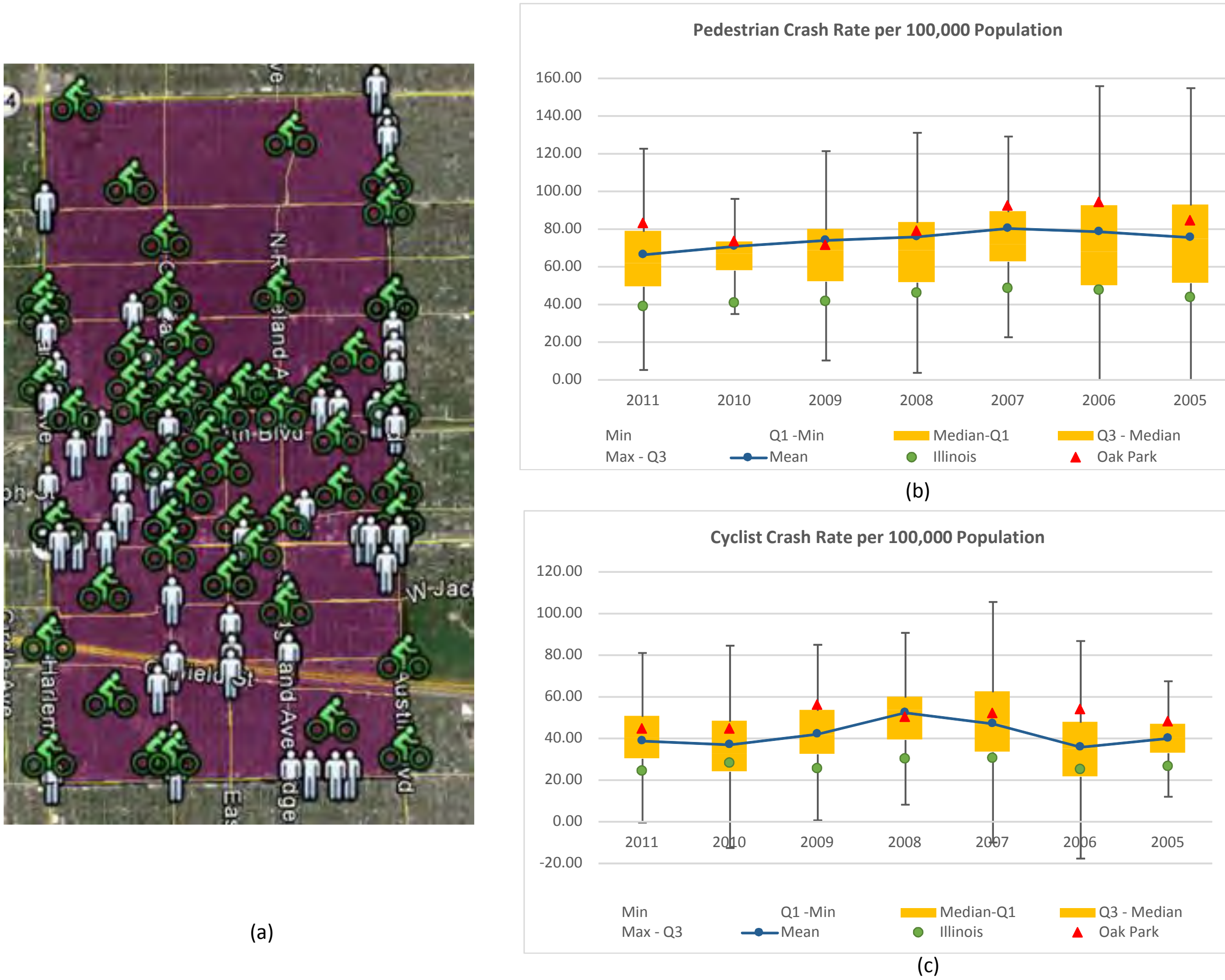


Figure 22 Oak Park crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the pedestrian countermeasures are delineated in the following locations:

- Austin Blvd./South Blvd.: The proposed countermeasure is the installment of raised or high visibility crosswalk (Multi-direction) crossing. This countermeasure has CMF = 0.6 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 5.15 and the accessibility score (S[a] =) is 5, as it is close to school, medical center, and park within the radius of >0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 5.08. The cost of the installment of raised or high visibility crosswalk is about $3,200 for entire intersection. Using the Jenks scaling system, the total cost of $3,200 corresponds to the cost score (S [I] =) of 5. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Austin Blvd./Lake St.: The proposed countermeasure is the extension of curb in four approaches. This countermeasure has CMF = 0.57 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 5.56 and the accessibility score (S[a] =) is 5, as it is close to a school within the radius of >0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 5.28. The cost of the extension of curb is about $20k for each corner. Therefore, the total budget is about $80k for entire intersection with 4 approaches. Using the Jenks scaling system, the cost score (S [I] =) equals to 3. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Marion St./North Blvd.: The proposed countermeasure is the installment of raised or high visibility crosswalk (Multi-direction) crossing. This countermeasure has CMF = 0.6 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 4.99 and the accessibility score (S[a] =) is 5, as it is close to school and park within the radius of >0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 5. The cost of the installment of raised or high visibility crosswalk is about $3,200 for entire intersection. Using the Jenks scaling system, the total cost of $3,200 corresponds to the cost score (S [I] =) of 5. The qualitative score (S [L] =) for this proposed project yields the score of 6 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

The following pedal-cyclist countermeasure is delineated for one location:

- Construct 1.34 miles of dedicated bike lane along Lake St. from Forest Ave. to Austin Blvd.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 4.87 and the accessibility score (S[a] =) is 6, as it is close to a school within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.44. The cost of the construction of bike lane is about $6,000/mile. Therefore the total cost of deployment is about $8,040. Using the Jenks scaling system, the total cost of $8,040 corresponds to S [I] = 5. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, no=0 to the second question, yes=1 to the third question, and yes=1 to the last question.

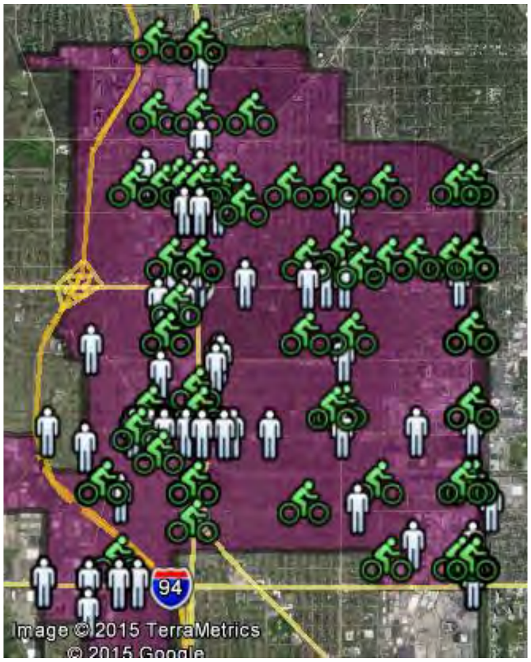
5.10. Skokie - Determinants Estimation

According to 2010 census data (US Census accessed 2015), the population of Skokie is 64,784 and has 23,531 households. The total land area of Skokie is about 10.1 sq. mi. The racial profile of Skokie is as follows: 1) 60.3% White, 2) 7.3% African American, 3) 0.2% Native American, 4) 25.5% Asian, and 5) 3.1% from some other races. Hispanics and Latinos of any race made up 8.8% of the population. Based on this census, 33,787 people in the labor force are commuting to work via: a) car drove alone [22,358], b) car-pool [3,065], c) public transit [2,806], and d) walking [472]. Skokie has a labor force density of 3,359 employees per square mile.

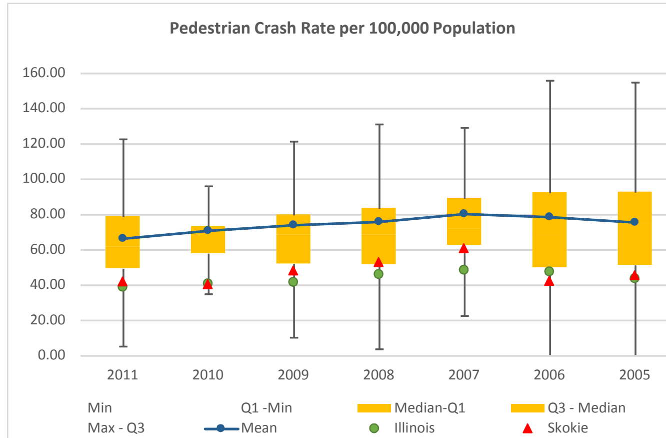
Based on 2005-2011 crash data, the average pedestrian crashes per 100,000 population is 26.86 which corresponds to the pedestrian crash score of (S [Cr] =) "2.14" using quartile scaling developed in Section 3.1. The average pedal-cyclist crashes per 100,000 population is 25.88 which corresponds to the pedal-cyclist crash score of (S [Cr] =) "4" using the same method (Quartile scaling). Figure 23a demonstrates the pedestrian/pedal-cyclist crash location in the city of Skokie during the period of 2007-2009. Figures 23b and 23c depict the box plot analysis (see Section 3.1 for more detail) of pedestrian/pedal-cyclist crashes during the period of 2005-2011. As one can observe, the pedestrian crash rates in this city much lower than the average crash rates for all under study cities in most years. However, the pedal-cyclist crash rates lie on or above the average blue line in all years. The mean line (blue line) represents the average crash rates for all understudied cities.

As the median income in the city of Skokie is $67,030, the equity score (S [Q] =) is 1.9 using Equation 5. Leveraging Equation 6, the demand score (S [D] =) is 2.7. The connectivity score is estimated by defining the Skokie's downtown as a reference. Skokie's downtown is delineated as a square mile area limited within a circle with a radius of 0.56 and Gross Point Rd./ Church St. as a center of circle.

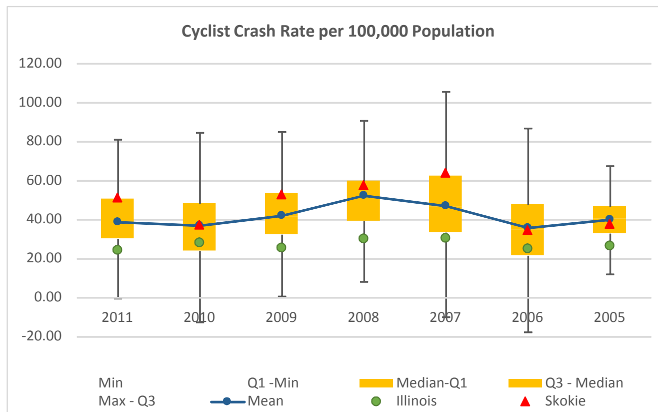
The number of intersections (n_R) are counted in that area (downtown) and assumed as the most connected network. Then, the number of intersections located in a radius of 0.56 of the following locations (n_P) are counted to yield for one square mile. The connectivity score is yielded from the comparison of the number of intersections counted in the square mile of the proposed projects (see following for the exact locations) and downtown area ($S[c] = n_R/n_P$). The accessibility score is derived from the approach outlined in Section 3.2.2. The final mobility score (S[M]) is calculated by averaging the connectivity and accessibility scores. The qualitative score for each proposed project is assessed using the proscribed questions.



(a)



(b)



(c)

Figure 23 Skokie crash analysis: a) geospatial analysis of pedestrian/pedal-cyclist crash location, b) Box plot analysis of pedestrian crash rate per 100,000 population, c) Box plot analysis of pedal-cyclist crash rate per 100,000 population

With this consideration, the pedestrian countermeasures are delineated in the following locations:

- Oakton St./Niles Ave.: The proposed countermeasure is the extension of curb in four approaches. This countermeasure has CMF = 0.57 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 4.89 and the accessibility score (S[a] =) is 6, as it is close to a school within the radius of <= 0.2 mile. Hence, the mobility score (S [M] =) is 5.45. The cost of the extension of curb is about $20k for each corner. Therefore, the total budget is about $80k for entire intersection with 4 approaches. Using the Jenks scaling system, the cost score (S [I] =) equals to 3. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, no=0 to the third question, and yes=1 to the last question.

- Skokie Blvd./ Church St.: The proposed countermeasure is the construction of median as a refugee-island for pedestrian in two approaches. This countermeasure has CMF = 0.61

corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 6 and the accessibility score (S[a] =) is 5, as it is close to shopping center and park within the radius of > 0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 5.5. The cost of providing raised median is about $366 per foot. Using the designing complete street reference (accessed 2015), the cost of raised median for two approaches for median with the width of 6 ft. and 20 ft. long is about $87,840. Using the Jenks scaling system, the cost score (S [I] =) equals to 3. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and no=0 to the last question.

Church St./Gross Point Rd.: The proposed countermeasure is the construction of median as a refugee-island for pedestrian in four approaches. This countermeasure has CMF = 0.61 corresponding to the safety effectiveness score (S [E] =) of 5. The connectivity score (S[c] =) is 5.72 and the accessibility score (S[a] =) is 5, as it is close to shopping center and park within the radius of > 0.2 and <= 0.4 mile. Hence, the mobility score (S [M] =) is 5.36. The cost of providing raised median is about $366 per foot. Using the designing complete street reference (accessed 2015), the cost of raised median for four approaches for median with the width of 6 ft. and 20 ft. long is about $175,680. Using the Jenks scaling system, the cost score (S [I] =) equals to 1. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, no=0 to the third question, and yes=1 to the last question.

The following pedal-cyclist countermeasures are delineated for following locations:

- Install and modify signal for pedal-cyclists at McCormick Blvd./Touhy Ave.: This countermeasure has the CMF of 0.63 which equals to S [E] of 5. The connectivity score (S[c] =) is 3.91 and the accessibility score (S[a] =) is 6, as it is close to a school within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 4.96. The cost of the installment of one pedal-cyclists signal is about $12,803. Using the Jenks scaling system, this total cost corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, no=0 to the third question, and yes=1 to the last question.

- Install and modify signal for pedal-cyclists at McCormick Blvd./Main St.: This countermeasure has the CMF of 0.63 which equals to S [E] of 5. The connectivity score (S[c] =) is 4.82 and the accessibility score (S[a] =) is 6, as it is close to a school within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.41. The cost of the installment of one pedal-cyclists signal is about $12,803. Using the Jenks scaling system, this total cost corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 6 using Equation 7 and answering to the qualitative questions with yes=1 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

- Install and modify signal for pedal-cyclists at McCormick Blvd./Dempster St.: This countermeasure has the CMF of 0.63 which equals to S [E] of 5. The connectivity score (S[c] =) is 5.29 and the accessibility score (S[a] =) is 6, as it is close to a school within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.65. The cost of the installment of one pedal-cyclists signal is about $12,803. Using the Jenks scaling system, this total cost corresponds to S [I] = 4. The qualitative score (S [L] =) for this proposed project yields the score of 3 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and no=0 to the last question.

- Construct 1 mile of dedicated bike lane along Church St.: This countermeasure has the CMF of 0.19 which equals to S [E] of 6. The connectivity score (S[c] =) is 4.89 and the accessibility score (S[a] =) is 6, as it is close to a school within the radius of <= 1 mile. Hence, the mobility score (S [M] =) is 5.45. The cost of the construction of bike lane is about $6,000/mile. Using the Jenks scaling system, the total cost of $6,000 corresponds to S [I] = 5. The qualitative score (S [L] =) for this proposed project yields the score of 4.5 using Equation 7 and answering to the qualitative questions with no=0 to the first question, yes=1 to the second question, yes=1 to the third question, and yes=1 to the last question.

5.11. Evaluation of Results

Table 1 and Table 2 summarize and demonstrate all proposed projects described in detail earlier to improve safety and mobility of pedestrian and pedal-cyclists in ten understudied cities. As noted in Section 4 and formulated in Equation 8, the weighting scheme leveraged to yield the final score for each project. The weights assumed in this study are as follows:

- W_c (weight of crash) = 3,
- W_e (weight of safety effectiveness) = 3,
- W_m (weight of accessibility/connectivity) = 2,
- W_i (weight of implementation cost) = 2,
- W_q (weight of equity) = 2,
- W_d (weight of demand) = 2, and
- W_l = (weight of qualitative factors) = 1.

For instance, the second row of Table 1, the project with the ID number of 1, the installment of traffic signal and crosswalk in the City of Berwyn, yields the final score of 4.34 using the following equation which is the reversion of Equation 8:

$$\frac{(3*3)+(4.5*3)+(4.265*2)+(3.55*2)+(6*2)+(6*2)+(3*1)}{3+3+2+2+2+2+1} = 4.34$$

This weighting system focuses more on addressing safety (highest weights on pedestrian/cyclist crashes and safety effectiveness of proposed projects) than other factors such as connectivity, accessibility, project cost, and demand. The lowest weight (=1) is assigned to the qualitative factors. The table can be sorted in the descending order of total scores with the highest priority given to projects on top of the list. For instance, the following projects are among top 5 in Table 1.

- Project Id=3: Establish raised crosswalk/high visible crosswalk (Chicago); total score = 4.86
- Project Id=5: Extend Curb (Chicago); total score = 4.74
- Project Id=4: Extend Curb (Chicago); total score = 4.64
- Project Id =24: Pedestrian multi crossing (Oak Park); total score = 4.6
- Project Id =16: Pedestrian signal head and rephrasing (Harvey); total score = 4.59

Nonetheless, the selection of projects for funding is subject to the budget constraint. Consequently, the projects should be nominated for consideration that have high total scores and satisfy the available budget. The following section develops different scenarios to demonstrate the feasibility of the deployment of this methodology in practice.

TABLE 1 Proposed improvements and their ranking scores for pedestrian projects

ID	City	pedestrian Countermeasures	Comment	Pedestrian crash score (S[cr])	Equity Score (S[Q])	Demand Score (S[D])	Safety Effectiveness (S[E])	Mobility Score (S[M])	Cost Score (s[I])	Qualitative Score (S[L])	Total score
1	**Berwyn**	Pedestrian traffic signal and establish crosswalk	At Grove Ave. & Cermak	3	3.55	6	4.5	4.265	6	3	4.34
2	**Berwyn**	Install Hawk (High-Intensity Activated crosswalk beacon)	At 29th place & Oak Park Ave.	3	3.55	6	4	4.57	1	3	3.62
3	**Chicago**	Establish raised crosswalk or high visible crosswalk	At Harrison St. & Financial Pl.	5.29	3.95	4.89	5	3.935	6	4.5	4.86
4	**Chicago**	Extended Curb	At Damen Ave. and Armitage St.	5.29	3.95	4.89	5	6	3	3	4.64
5	**Chicago**	Extended Curb	At Chicago Ave. &Homan Ave.	5.29	3.95	4.89	5	6	3	4.5	4.74
7	**Chicago**	Extended Curb and provide raised median on main street	At Ashland Ave. & 76th St.	5.29	3.95	4.89	4.5	4.345	2	4.5	4.28
6	**Chicago**	Extended Curb and provide raised median on main street	At Ashland Ave. & 78th St.	5.29	3.95	4.89	4.5	4.075	2	4.5	4.25
8	**Chicago Heights**	Establish Crosswalk	At Main St. & 1st St.	3	4.42	1	4.5	4.5	1	3	3.16

9	**Chicago Heights**	Establish Crosswalk	At Main St. & East End Ave.	3	4.42	1	4	4.5	1	3	3.06
10	**Cicero**	Construct raised median	At Cicero Ave./22nd St.	2.43	4.10	5.45	5	4.445	1	4.5	3.79
11	**Cicero**	Construct raised median	At Austin Ave./22nd St	2.43	4.10	5.45	5	5.46	1	4.5	3.92
12	**Evanston**	Modify signal phasing for pedestrian and cyclist	At Dempster St. & Chicago Ave.	3.86	1.75	4.06	5	5.63	6	4.5	4.4
13	**Evanston**	Establish high visibility crosswalk and modify signal phasing	At Ridge Ave. & Davis St.	3.86	1.75	4.06	5	5.67	5	4.5	4.27
14	**Evanston**	Establish high visibility crosswalk and modify signal phasing	At Church St. & Sherman Ave.	3.86	1.75	4.06	5	5.545	5	3	4.15
15	**Evanston**	Establish high visibility crosswalk and modify signal phasing	At Davis St. & Benson Ave.	3.86	1.75	4.06	5	4.955	5	1.5	3.97
16	**Harvey**	Pedestrian signal head and rephasing	At Center Ave. & E 154th St.	5.29	6.00	1.21	5	5.265	5	3	4.59
17	**Harvey**	Establishment of median As refugee island	At 159th St. & Wood	5.29	6.00	1.21	5	5.23	3	3	4.32
18	**Harvey**	Establish HAWK and crosswalk	At 159th St. & Marshfield Ave.	5.29	6.00	1.21	4	5.1	1	3	3.83

19	**Maywood**	Establish HAWK and crosswalk	At 1st Ave. & School St.	3.86	4.30	3.45	4	4.53	1	4.5	3.64
20	**Maywood**	Curb extension (four approach)	At 5th Ave & Lake St.	3.86	4.30	3.45	5	4.79	3	3	4.04
21	**Niles**	Construct raised median (four approaches)	At Milwaukee Ave. & Oakton St	2.14	4.10	1.95	5	6	1	3	3.37
22	**Niles**	Construct raised median (two approach)	At Milwaukee Ave. & Ballard St	2.14	4.10	1.95	5	5.34	3	3	3.55
23	**Niles**	Construct raised median (four approaches)	At Greenwood Ave. & Ballard St.	2.14	4.10	1.95	5	6	1	3	3.37
24	**Oak Park**	Pedestrian multi crossing (high visibility crosswalk)	At Marion St. & North Blvd.	4.57	1.00	5.14	5	4.995	6	6	4.6
25	**Oak Park**	High visibility crosswalk	At Austin Blvd. & South Blvd.	4.57	1.00	5.14	5	5.075	6	4.5	4.51
26	**Oak Park**	Extended Curb (four approach)	At Austin Blvd. & Lake St.	4.57	1.00	5.14	5	5.28	3	4.5	4.14
27	**Skokie**	Extended Curb (four approach)	At Oakton st. & Niles St.	2.14	1.90	2.70	5	5.445	3	4.5	3.47
28	**Skokie**	Construct raised median (two approaches)	At Skokie Blvd. & Church St	2.14	1.90	2.70	5	5.5	3	3	3.38
29	**Skokie**	Construct raised median (four approaches)	At Church St. & Gross Point Rd.	2.14	1.90	2.70	5	5.36	1	3	3.09

TABLE 2 Proposed improvements and their ranking scores for pedal-cyclists projects

ID	City	Countermeasure	Comment	Pedal-cyclist Score (S[cr])	Equity Score (S[Q])	Demand Score (S[D])	Safety Effectiveness (S[E])	Mobility Score (S[M])	Cost Score (s[I])	Qualitative Score (S[L])	Total score
1	**Berwyn**	Establish bike lane	2-mile dedicated on-street bike lane S. Oak Park Ave.	3.43	3.55	6	6	4.76	4	4.5	4.63
2	**Berwyn**	Establish bike lane	1-mile Bike lane at 16th street	3.43	3.55	6	6	5.03	5	1.5	4.6
3	**Chicago**	Establish bike lane	6.2 mile of dedicated bike lanes at Irving Park Rd.	4.86	3.95	4.89	6	6	4	4.5	4.98
4	**Chicago**	Modify signal phasing (implement a leading pedestrian interval) OR Modify change plus clearance interval to ITE 1985 Proposed Recommended Practice	Install 7 pedal-cyclists signals at intersections	4.86	3.95	4.89	5	6	2	4.5	4.52
5	**Chicago Heights**	Establish bike lane	2.13 Mile of dedicated bike lanes at Chicago St.	2.57	4.42	1	6	5.065	4	6	4.05
6	**Chicago Heights**	Establish bike lane	1.72 mile of dedicated on-street bike lane at Lincoln Hwy.	2.57	4.42	1	6	5.23	4	3	3.87
7	**Cicero**	Establish bike lane	2-mile dedicated on-street bike lane at Cicero Ave.	2.14	4.10	5.45	6	4.445	4	3	4.23
8	**Evanston**	Establish bike Lane	1.5 mile of bike lane at Dempster St.	5.29	1.80	4.06	6	5.745	5	4.5	4.77

9	**Evanston**	Modify signal phasing and install signal for cycling	Signal for cyclists at two intersections	5.29	1.80	4.06	5	5.745	4	4.5	4.44
10	**Harvey**	Establish bike Lane	1.4 Mile of dedicated bike lane at 154th St.	3.29	6.00	1.21	6	5.82	5	1.5	4.36
11	**Maywood**	Establish bike lane	1.3 mile dedicated bike lane at Madison St.	3	4.30	3.45	6	5.145	5	4.5	4.49
12	**Niles**	Establish bike lane	3.8 miles of dedicated bike lane at Milwaukee Ave.	2.29	4.10	1.95	6	6	4	4.5	4.1
13	**Oak Park**	Establish bike lane	1.34 mile at Lake St.	4.29	1.00	5.14	6	5.435	5	3	4.47
14	**Skokie**	Establish bike lane	1 mile dedicated bike lane at Church St.	4	1.90	2.70	6	5.445	5	4.5	4.31
15	**Skokie**	Modify signal phasing and install signal for cycling	at McCormick Blvd. & Touhy Ave.	4	1.90	2.70	5	4.96	4	4.5	3.91
16	**Skokie**	Modify signal phasing and install signal for cycling	McCormick Blvd. & Main St.	4	1.90	2.70	5	5.41	4	6	4.07
17	**Skokie**	Modify signal phasing and install signal for cycling	McCormick Blvd. & Dempster St.	4	1.90	2.70	5	5.65	4	3	3.9

5.12. Scenario Development

As stated, the number of selected projects and the project category (pedestrian and cyclist) have related utterly to the available funding and agencies' policy to distribute funds among different categories. For instance, CMAP-CMAQ receives a number of improvement projects (manifested in the previous section and depicted in Table 1 and Table 2) from Municipal Conferences (Section 2.2). While most projects seem meritorious for funding, CMAP-CMAQ has only $800k fund to allocate to the improvement of pedestrian and cyclist facilities. The allocation policy dictates to assign $500k for pedestrian's facility and the rest ($300k) to cyclist's facilities.

Table 3 depicts projects in descending order of their total scores in compliance with the available fund. The construction/deployment costs of projects from Id #3 to Id #13 comply with the available budget with the total cost of $406,378. However the selection of another project (with Id #6) will generate deficit in the amount of $34,218 ($500k - $534,218). Two solutions can be offered: 1) select two immediate followers (projects Id#14 and Id#26), 2) re-scope the project #6 to fit the remaining budget.

Table 3 Selected pedestrian project for funding considering the budget constraint

ID	City	Pedestrian Countermeasures	Comment	Total score	Cost Value
3	Chicago	Establish raised crosswalk	Harrison/Financial Pl.	4.86	$ 3,200
5	Chicago	Extended curb	Chicago/Homan	4.74	$ 80,000
4	Chicago	Extended curb	Damon/Armitage	4.64	$ 80,000
24	Oak Park	Pedestrian multi crossing	Marion St./North Blvd.	4.60	$ 3,200
16	Harvey	Pedestrian signal head and rephasing	Center Ave./E 154 St.	4.59	$ 6,860
25	Oak Park	High visibility crosswalk	Austin Blvd./South Blvd.	4.51	$ 3,200
12	Evanston	Modify signal phasing	Dempster/Chicago	4.40	$ 3,660
1	Berwyn	Pedestrian traffic signal and establish crosswalk	Grove Ave./Cermak	4.34	$ 3,718
17	Harvey	Establishment of median	159^{th} St./Wood	4.32	$ 87,840
7	Chicago	Extended curb and provide raised median on main street	Ashland/76^{th}	4.28	$ 127,840
13	Evanston	Establish high visibility crosswalk and modify signal phasing	Ridge Ave./Davis	4.27	$ 6,860
6	Chicago	Extended curb and provide raised median on main street	Ashland/78^{th}	4.25	$ 127,840
14	Evanston	Establish high visibility crosswalk and modify signal phasing	Church/Sherman	4.15	$ 6,860
26	Oak Park	Extend curb (four approach)	Austin Blvd./Lake St.	4.14	$ 80,000

Table 4 Selected pedestrian project for funding considering the budget constraint

ID	City	Countermeasure	Comment	Total score	Cost value
3	Chicago	Establish bike lane	6.2 mile of bike lanes at Irving Park Rd.	4.98	$ 37,200
8	Evanston	Establish bike Lane	1.5 mile of bike lane at Dempster St.	4.77	$ 9,000
1	Berwyn	Establish bike lane	2-mile of bike lane at S. Oak Park Ave.	4.63	$ 12,000
2	Berwyn	Establish bike lane	1-mile of bike lane at 16th street	4.60	$ 6,000
4	Chicago	Modify signal phasing	Install 7 pedal-cyclists signals at intersections	4.52	$ 126,819
11	Maywood	Establish bike lane	1.3 mile of bike lane at Madison St.	4.49	$ 7,800
13	Oak Park	Establish bike lane	1.34 mile of bike lane at Lake St.	4.47	$ 8,040
9	Evanston	Modify signal phasing and install signal for cycling	Signals for cyclists at two intersections	4.44	$ 25,606
10	Harvey	Establish bike lane	1.4 Mile of bike lane at 154th St.	4.36	$ 8,400
14	Skokie	Establish bike lane	1 mile of bike lane at Church St.	4.31	$ 6,000
7	Cicero	Establish bike lane	2-mile of bike lane at Cicero Ave.	4.23	$ 12,000
12	Niles	Establish bike lane	3.8 miles of bike lane at Milwaukee Ave	4.10	$ 22,800
16	Skokie	Modify signal phasing and install signal for cycling	McCormick Blvd./Main St.	4.07	$ 12,803
5	Chicago Heights	Establish bike lane	2.13 miles of bike lanes at Chicago St.	4.05	$ 12,780

With the same token, projects designed and planned to improve cyclists' facilities (Table 2) are sorted in the descending order of their total scores and granted the fund in a compliance of the available budget ($300k). Table 4 depicts projects (from Id# 3 to Id# 16) that can be considered for funding. The total budget to fund these projects (from Id# 3 to Id #16) is about $294,468 ending to the surplus of $5,532 which can be salvaged in the next cycle of competition or leveraged to fund the next project, i.e. Id #5. In this case, the project has to be scaled down to satisfy the available budget. The agency policy will play an important role to plan for the remaining balance.

6. CONCLUSION

To facilitate decision makers in prioritizing improvement projects, the study developed a ranking methodology to develop a distinct score for each improvement project recommended to lessen the deficiencies of pedestrian/cyclist facility. The study delineated six determinants to examine the merit of each improvement project. All determinants were classified to six classes to warrant a homogenous comparison among all determinants. Different scaling systems were pursued to yield a determinant score. The final score of a project was yielded using the weighting scheme. To examine the applicability of the developed technique in practice, various pedestrian/cyclist improvement projects were proposed in ten cities (i.e. Berwyn, Chicago, Chicago Heights, Cicero, Evanston, Harvey, Maywood, Niles, Oak Park, and Skokie) located in Cook County in the State of Illinois where pedestrian/cyclist facility deficiencies were declared. Pursuing the developed methodology, the final score of each proposed project was computed. To detect the most meritorious projects for funding, projects were sorted in descending order of their scores. Projects must be selected in a way to satisfy the budget constraint. A scenario was developed to illustrate the applicability of the developed methodology in practice. This scenario mimicked the condition when an agency had limited budget to allocate funds to pedestrian/cyclist projects planned and designed in under study cities. The agency's policy is a key factor to administer funds which cannot be apportioned due to the insufficiency of fund.

The study presented a seamless adaptation of scoring and scaling system on some determinants to rank improvement projects which have not been considered by other studies. It is essential to assure decision makers that projects designed to improve safety and mobility of pedestrians and cyclists are impactful and there are evidences to substantiate the claims. The project safety effectiveness (measured by CMF) determinant had been delineated to satisfy this need. The study presented different scaling system to score determinants for homogenous comparisons. Furthermore, the paper stated its reasoning to select an appropriate scaling technique which fitted data robustly. While the study attempted to tackle some gaps detected in current studies/practices, there are some challenges to adopt the existing approach. CMF has not been developed for many countermeasures, but it is in a dynamic and speedy process of development. Maintenance and operation costs are not readily available for all projects to be contained in the project cost determinant.

The scope of the study can be enhanced to delineate a differential threshold for highly comparable projects (tiebreaker rule) scored closely considering the budget constraint. In addition, there is an opportunity to select the apt projects by constructing the link between existing funds and selected projects to maximize benefits and minimize remaining fund using the optimization technique.

REFERENCE

AAHSTO. Highway safety manual. FHWA. 1st Edition. 2010.

AASHTO. A policy on geometric designs of highways and streets. 6th Edition. ISBN: 978--56051-508-1. 2011.

Active transportation alliance. http://www.activetrans.org . Accessed February 2014.

Baier N., and Gogoi R. Lee County MPO bicycle-pedestrian prioritization and funding project selection process recommendations. Jacobs & Alta planning-design. Florida. 2013.

CH2MHill, MNDOT, and LRRB. Minnesota's Best Practices for Pedestrian/Bicycle Safety. MnDOT Office of Traffic. Safety and Technology. REPORT 2013-22. 2013.

City of Mesa. Annual pedestrian crash analysis. Mesa, AZ. 2009.

Congestion management and air quality improvement program. http://www.cmap.illinois.gov/mobility/strategic-investment/cmaq. Chicago Metropolitan Agency for Planning – CMAP. Accessed February 2014.

Designing Complete Streets. http://www.knoxtrans.org/plans/complete_streets/Octpres_pt2.pdf. Knoxville regional transportation planning organization. Accessed March 2015.

ESRI. http://support.esri.com/en/knowledgebase/techarticles/detail/26442 . Accessed March 2015.

European commission. SafetyNet pedestrians & cyclists. Directorate – General transport and energy. 2009.

Federal Highway Administration. BikeSafe: Bicycle Countermeasure Selection System. FHWA-SA-05-006. 2006.

FHWA. Pedestrian Safety Guide for transit agencies. FHWA-SA-07-017. 2008.

FHWA. http://safety.fhwa.dot.gov/PED_BIKE/univcourse/swless09.cfm. Accessed June 2015.

Heydecker B.G., and Robertson S.A. Evaluation of pedestrian priority zones in the European area – Report to the Korea Transport Institute KoTI. Center for transport studies. University College London. 2009.

Highway Safety Research Center. How to develop a pedestrian safety action plan. North Carolina. NHTSA- FHWA-SA-05-12. 2009.

Jenks G.F. The Data Model Concept in Statistical Mapping. International Yearbook of Cartography 7: 186-190. 1967.

Lagerwey P., Hintze M., Elliott J., Toole J., and Schneider R. Pedestrian and bicycle transportation along existing roads – Activetrans priority tool guidebook. NCHRP Report 803. 2015.

Martin A. Pedestrian attitudes, behavior and road safety. Report PPR241. London road safety unit. 2006.

Metropolitan Planning Organization. San Antonio – Bexar County pedestrian safety action plan. http://tooledesign.com/projects/bicycle-and-pedestrian-plans/san-antonio-pedestrian-master-plan. Accessed February 2014.

Natarajan S., Demetsky M., and Lantz K. Framework for selection and evaluation of bicycle and pedestrian safety projects in Virginia. Virginia transportation research council. http://www.virginiadot.org/vtrc/main/online_reports/pdf/08-r8.pdf. 2008.

Nelson A., and Scholar V. Livable Copenhagen: The design of bicycle city. Center for public space research. University of Washington Seattle. 2006.

New York City Department of Transportation. Commuter Cycling Indicator. http://www.nyc.gov/html/dot/html/bicyclists/nycbicyclescrct.shtml. Accessed June 2015.
NHTSA-FARS. http://www-fars.nhtsa.dot.gov/Main/index.aspx . FHWA. Accessed Oct 2014.
NHTSA-FHWA. How to develop a pedestrian safety action plan. FHWA-SA-05-12. 2012.
Northwest Municipalities Conferences – NWMC. http://nwmc-cog.org/Shared-Content/Welcome.aspx . Accessed February 2014.
NYC. The New York City Pedestrian Safety Study & Action Plan: Technical supplement. NY. 2010.
NZ transport agency. Pedestrian planning and design guide. Wellington. New Zealand. 2009.
Pedestrian and bicyclist information center. http://www.pedbikeinfo.org/pbcat_us/index.cfm. Accessed February 2014.
Pedsafe. Pedestrian safety guide and countermeasure selection system. http://www.pedbikesafe.org/PEDSAFE/ . FHWA. Accessed June 2014.
Pucher J., Buehler R., Merom D., and Bauman A. Walking and cycling in the United States 2001-2009: Evidence from the national household travel surveys. American Journal of public Health. Doi: 10.2105/AJPH.2010.300067. 2011.
Road and traffic authority. How to prepare a pedestrian access and mobility plan – an easy three stage guide. New South Wales (NSW) – Australia. ISBN 0 7313 0133 1. RTA/Pub: 02.024. 2002.
Schneider R., Arnold L.S., and Ragland D. Pilot model for estimating pedestrian intersection 20 crossing volumes. Journal of the Transportation Research Board. Volume 2198, pp. 41-51, 21. 2010.
Shin H.W., Kim Y. O., and Kim A. H. A study on the correlation between pedestrian network and pedestrian volume according to land use pattern. Proceedings of 6th international space Symposium. Istanbul. 2007.
Smart growth America. http://www.smartgrowthamerica.org/complete-streets. Accessed March 2014.
Smart Growth America. http://www.smartgrowthamerica.org/research/survey-finds-americans-want-greater-investment-in-public-transit , Accessed March 2015.
Southwest conference of mayors – SWM. http://www.swmayors.com/. Accessed February 2014.
Stern B., Ysakowski, Y., and Hurni, L. Statistics for Thematic Cartography. Geographic Information Technology Training Alliance (GITTA). 2006.
Todd Litman et al. Pedestrian and bicycle planning guide to best practices. Victoria transport policy institute. 2009.
Town of Farmville. Comprehensive Pedestrian Plan. North Carolina. 2013.
UNC highway safety research center. Costs for pedestrian and bicyclists infrastructure improvements. Federal highway administration – FHWA. 2013.
UNC. http://www.cmfclearinghouse.org/ . FHWA. Accessed Oct 2014.
UNC. http://www.cmfclearinghouse.org/resources_develop.cfm. FHWA. 2014.
UNC. Westat. VHB. Pedestrian safety program strategic plan-Final background review. FHWA. 2010.
United State Census Bureau. http://factfinder.census.gov/ . Accessed June 2015
USDOT. Case study No 1. Reasons why bicycling and walking are and are not used more extensively as travel modes. Publication No. FHWA-PD-92-041. Washington DC. 1992.

USDOT. National Household Travel Survey, Our Nation's Travel. Federal Highway Administration. Washington DC. 2010.

Walkability research. http://www.walkscore.com/professional/walkability-research.php. Accessed June 2014.

West central Municipality Conference-WCMC. http://www.westcook.org/wcmc. Accessed February 2014.

APPENDIX 1 SAFETY EFFECTIVENESS CLASSIFICATION

As one can observe from Table A-1, a large gap among some CMF derives the author to leverage Jenks Natural breaks. A vital point behind this classification is to minimize value differences between data in the same class and highlight the differences among classes. This significant attribute underscores safety countermeasures with high impacts and discerns them from countermeasures with the lower safety impacts.

This tactic is an iterative process to find the smallest variance in a class. The calculation must be iterated using different breaks in the dataset to determine the set of breaks with the smallest class variance. The process is initiated by dividing the ordered data into arbitrary groups. The following four steps are repeated for each new group till the Goodness of Variance Fit (GVF) is maximized (Jenks 1967, ESRI accessed 2015):

1. Computation: Calculate the sum of Squared deviations from the Array Mean (SDAM). Note that, the SDAM is constant and does not change unless the data changes.
2. Computation: Calculate the sum of Squared Deviations Between Classes (SDBC).
3. Result: Calculate the GVF by subtracting the squared deviations between classes (SDBC) from the squared deviations from the array mean (SDAM) and divided by SDAM, i.e. (SDAM – SDBC)/SDAM.
4. Analysis: After inspecting each of the SDBC, a decision is made to move one unit from the class with the largest SDBC toward the class with the lowest SDBC to increase GVF.

New class deviations are then calculated, and the process is repeated till the sum of the within class deviations reaches a minimal value or the GVF value closes to one.

This procedure is performed on the CMF dataset presented in Table A-1 and the following SDAM and SDBC are yielded and the closest GVF to one is reached. Subsequently, the S [E] score is concluded and demonstrated in Figure 11.

SDAM = 145.242

SDBC = 9.324 ➔ GVF = (145.242 – 9.324)/145.242 = 0.936

Table A-1: Safety effectiveness classification using Jenks Natural Breaks

Jenks Classification				
CMF	SDAM	classes	SDBC	S[E] Class
0	0.985	0.16213	0.02629	6
0	0.985		0.02629	6
0	0.985		0.02629	6
0	0.985		0.02629	6
0	0.985		0.02629	6
0.06	0.869		0.01043	6
0.1	0.796		0.00386	6
0.12	0.761		0.00177	6
0.12	0.761		0.00177	6
0.14	0.726		0.00049	6
0.15	0.709		0.00015	6
0.18	0.660		0.00032	6
0.19	0.644		0.00078	6
0.19	0.644		0.00078	6
0.22	0.596		0.00335	6
0.26	0.536		0.00958	6
0.27	0.522		0.01164	6
0.27	0.522		0.01164	6
0.27	0.522		0.01164	6
0.28	0.507		0.01389	6
0.3	0.479		0.01901	6
0.3	0.479		0.01901	6
0.309	0.467		0.02157	6
0.37	0.387	0.658183	0.08305	5
0.37	0.387		0.08305	5
0.38	0.375		0.07739	5
0.4	0.351		0.06666	5
0.41	0.339		0.06159	5
0.41	0.339		0.06159	5
0.41	0.339		0.06159	5
0.42	0.328		0.05673	5
0.45	0.294		0.04334	5
0.46	0.283		0.03928	5
0.47	0.273		0.03541	5
0.487	0.255		0.02930	5
0.487	0.255		0.02930	5
0.49	0.252		0.02829	5
0.49	0.252		0.02829	5
0.5	0.242		0.02502	5
0.54	0.205		0.01397	5
0.54	0.205		0.01397	5
0.55	0.196		0.01170	5
0.55	0.196		0.01170	5
0.554	0.192		0.01085	5

0.56	0.187		0.00964	5
0.56	0.187		0.00964	5
0.57	0.178		0.00778	5
0.577	0.172		0.00659	5
0.58	0.170		0.00611	5
0.59	0.162		0.00465	5
0.596	0.157		0.00387	5
0.6	0.154		0.00339	5
0.6	0.154		0.00339	5
0.608	0.148		0.00252	5
0.61	0.146		0.00232	5
0.61	0.146		0.00232	5
0.61	0.146		0.00232	5
0.61	0.146		0.00232	5
0.62	0.139		0.00146	5
0.62	0.139		0.00146	5
0.62	0.139		0.00146	5
0.63	0.131		0.00079	5
0.63	0.131		0.00079	5
0.63	0.131		0.00079	5
0.63	0.131		0.00079	5
0.63	0.131		0.00079	5
0.63	0.131		0.00079	5
0.639	0.125		0.00037	5
0.65	0.117	0.819515	0.02874	4
0.65	0.117		0.02874	4
0.661	0.110		0.02513	4
0.67	0.104		0.02235	4
0.67	0.104		0.02235	4
0.68	0.098		0.01946	4
0.68	0.098		0.01946	4
0.69	0.091		0.01677	4
0.7	0.085		0.01428	4
0.7	0.085		0.01428	4
0.7	0.085		0.01428	4
0.7	0.085		0.01428	4
0.705	0.083		0.01311	4
0.709	0.080		0.01221	4
0.71	0.080		0.01199	4
0.711	0.079		0.01178	4
0.711	0.079		0.01178	4
0.72	0.074		0.00990	4
0.724	0.072		0.00912	4
0.734	0.067		0.00731	4
0.74	0.064		0.00632	4
0.76	0.054		0.00354	4
0.76	0.054		0.00354	4

0.76	0.054		0.00354	4
0.77	0.049		0.00245	4
0.78	0.045		0.00156	4
0.8	0.037		0.00038	4
0.8	0.037		0.00038	4
0.81	0.033		0.00009	4
0.81	0.033		0.00009	4
0.811	0.033		0.00007	4
0.82	0.030		0.00000	4
0.83	0.026		0.00011	4
0.83	0.026		0.00011	4
0.83	0.026		0.00011	4
0.838	0.024		0.00034	4
0.839	0.024		0.00038	4
0.84	0.023		0.00042	4
0.84	0.023		0.00042	4
0.85	0.020		0.00093	4
0.855	0.019		0.00126	4
0.86	0.018		0.00164	4
0.86	0.018		0.00164	4
0.86	0.018		0.00164	4
0.861	0.017		0.00172	4
0.87	0.015		0.00255	4
0.87	0.015		0.00255	4
0.884	0.012		0.00416	4
0.9	0.009		0.00648	4
0.91	0.007		0.00819	4
0.92	0.005		0.01010	4
0.92	0.005		0.01010	4
0.93	0.004		0.01221	4
0.94	0.003		0.01452	4
0.941	0.003		0.01476	4
0.943	0.002		0.01525	4
0.955	0.001		0.01836	4
0.967	0.001		0.02175	4
0.968	0.001		0.02205	4
0.97	0.000		0.02265	4
0.97	0.000		0.02265	4
0.973	0.000		0.02356	4
0.978	0.000		0.02512	4
0.984	0.000		0.02706	4
1	0.000		0.03257	4
1.006	0.000	1.218875	0.04532	3
1.01	0.000		0.04363	3
1.01	0.000		0.04363	3
1.01	0.000		0.04363	3
1.01	0.000		0.04363	3

1.014	0.000		0.04197	3
1.018	0.001		0.04035	3
1.02	0.001		0.03955	3
1.026	0.001		0.03720	3
1.03	0.001		0.03567	3
1.03	0.001		0.03567	3
1.031	0.001		0.03530	3
1.038	0.002		0.03272	3
1.04	0.002		0.03200	3
1.042	0.002		0.03128	3
1.05	0.003		0.02852	3
1.05	0.003		0.02852	3
1.065	0.005		0.02368	3
1.07	0.006		0.02216	3
1.09	0.010		0.01661	3
1.1	0.012		0.01413	3
1.1	0.012		0.01413	3
1.12	0.016		0.00978	3
1.12	0.016		0.00978	3
1.13	0.019		0.00790	3
1.19	0.039078		0.00083	3
1.21	0.047385		0.00008	3
1.237	0.059869		0.00033	3
1.24	0.061346		0.00045	3
1.25	0.0664		0.00097	3
1.27	0.077107		0.00261	3
1.27	0.077107		0.00261	3
1.28	0.082761		0.00374	3
1.28	0.082761		0.00374	3
1.28	0.082761		0.00374	3
1.281	0.083337		0.00386	3
1.3	0.094668		0.00658	3
1.31	0.100922		0.00830	3
1.33	0.114029		0.01235	3
1.36	0.13519		0.01992	3
1.37	0.142644		0.02284	3
1.37	0.142644		0.02284	3
1.37	0.142644		0.02284	3
1.37	0.142644		0.02284	3
1.4	0.166204		0.03281	3
1.42	0.182912		0.04045	3
1.43	0.191565		0.04457	3
1.43	0.191565		0.04457	3
1.43	0.191565		0.04457	3
1.44	0.200419		0.04890	3
1.47	0.22818		0.06306	3
1.48	0.237834		0.06819	3

1.48	0.237834		0.06819	3
1.48	0.237834		0.06819	3
1.49	0.247687		0.07351	3
1.509	0.26696		0.08417	3
1.57	0.334	1.861862	0.08518	2
1.57	0.334		0.08518	2
1.57	0.334		0.08518	2
1.63	0.407		0.05376	2
1.66	0.446		0.04075	2
1.67	0.459		0.03681	2
1.67	0.459		0.03681	2
1.69	0.487		0.02954	2
1.704	0.506		0.02492	2
1.73	0.544		0.01739	2
1.73	0.544		0.01739	2
1.74	0.559		0.01485	2
1.75	0.574		0.01251	2
1.77	0.605		0.00844	2
1.77	0.605		0.00844	2
1.77	0.605		0.00844	2
1.8	0.652		0.00383	2
1.8	0.652		0.00383	2
1.81	0.669		0.00269	2
1.81	0.669		0.00269	2
1.82	0.685		0.00175	2
1.82	0.685		0.00175	2
1.93	0.879		0.00464	2
2.03	1.077		0.02827	2
2.07	1.161		0.04332	2
2.08	1.183		0.04758	2
2.29	1.684		0.18330	2
2.53	2.364		0.44641	2
3.21	4.918		1.81748	2
6.19	27.016	7.475	1.65123	1
8.76	60.337		1.65123	1

APPENDIX 2 COST CLASSIFICATION

To detect the most apt technique to classify the project implementation cost into six classes, Quartile and Natural breaks/Jenks techniques are leveraged as the projects costs are sporadic and the existence of outliers is expected. Table A-2 illustrates the results of deployment of both techniques on the costs of purposed projects. While some costs are categorized under same class in both techniques (see column 5 and 6 of Table A-2), the class disparity among other costs can be observed.

The application of Quartile technique on available data concludes the following key attributes ending to the results of Table A-2, column 6:

Min: \$3200; First Quartile: \$7800; Median/Second Quartile: \$24,203;

Third Quartile: \$127,585; Fourth Quartile/Max: \$194,645;

Whiskers (+/-): \$179,587;

The application of Jenks technique on available data concludes the following key attributes ending to the results of Table A-2, column 5:

SDAM = 232,169,051,239

SDBC = 1,509,150,007 ➔ GVF = (232,169,051,239 – 1,509,150,007)/ 232,169,051,239 = 0.994

Note that, the Quartile technique did not classify any costs under the score of 1 and 6 (Extreme high and low costs). While no large gaps can be observed within the costs categorized under each class using quartile technique, most harmony can be observed among costs within each class under Jenks technique. The high GVF is an evidence of this claim. Therefore, the Natural Breaks/Jenks technique is deduced as the most apt technique to classify the project costs.

Table A-2 Cost Score Classification using Jenks and Quartile Methods

Cost	SDAM	Class Average	SDCM	Jenks Tech.	Quartile Tech.
$ 3,200	4252790461	3396	38252	6	5
$ 3,200	4252790461		38252	6	5
$ 3,200	4252790461		38252	6	5
$ 3,660	4193005713		69917	6	5
$ 3,718	4185509497		103895	6	5
$ 6,000	3895435296	7268	1607824	5	5
$ 6,000	3895435296		1607824	5	5
$ 6,860	3788823809		166464	5	5
$ 6,860	3788823809		166464	5	5
$ 6,860	3788823809		166464	5	5
$ 6,860	3788823809		166464	5	5
$ 7,800	3673986975		283024	5	5
$ 8,040	3644950132		595984	5	4
$ 8,400	3601610868		1281424	5	4
$ 9,000	3529954761		2999824	5	4
$ 10,320	3374845726	17111	46122825	4	4
$ 12,000	3182474227		26126193	4	4
$ 12,000	3182474227		26126193	4	4
$ 12,780	3095077688		18760842	4	4
$ 12,803	3092546056		18564217	4	4
$ 12,803	3092546056		18564217	4	4
$ 12,803	3092546056		18564217	4	4
$ 22,800	2080584303		32360412	4	4
$ 25,606	1832516943		72150350	4	3
$ 37,200	974277738		403552705	4	3
$ 80,000	134248780	82940	8643600	3	3
$ 80,000	134248780		8643600	3	3
$ 80,000	134248780		8643600	3	3
$ 80,000	134248780		8643600	3	3
$ 80,000	134248780		8643600	3	3
$ 87,840	377391917		24010000	3	3
$ 87,840	377391917		24010000	3	3
$ 87,840	377391917		24010000	3	3
$ 126,819	3411246795	127500	463033	2	2
$ 127,840	3531518125		115758	2	2
$ 127,840	3531518125		115758	2	2
$ 175,680	11506118670	184023	69599696	1	2
$ 175,680	11506118670		69599696	1	2
$ 175,680	11506118670		69599696	1	2
$ 175,680	11506118670		69599696	1	2
$ 175,680	11506118670		69599696	1	2
$ 191,445	15136839573		55095632	1	2
$ 191,445	15136839573		55095632	1	2
$ 192,145	15309574182		65977333	1	2
$ 192,145	15309574182		65977333	1	2
$ 194,645	15934483503		112840549	1	2