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TRANSPORT SUSTAINABILITY INDEX OF MAIN ARTERIALS AT HILLA CASE STUDY (SAFETY AND ENVIRONMENTAL ASPECTS)

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Abstract: In recent works on the Internet of Vehicles, “intelligent” and “sustainable” have been the significant in the case of transportation. Maintaining sustainability is always a challenge. Sustainability can be achieved not only by the use of pollution-free vehicular systems, but also by maintenance of road traffic safety or prevention of accidents or collisions. Quantifying the sustainability of urban transport is important as evidenced by a growing number of studies to measure sustainability in transportation. This paper dealt with the challenge of measuring transport sustainability based on the long environmental and safety indicators. To overcome the issue of using too many indicators for evaluation, this paper develops a method for obtaining a composite transport sustainability index for limited sources and time for collecting data. Seven sustainability indicators relevant to urban transport which deal with environmental and social (safety) aspects were selected depending on available data. The indicators were integrated to environmental, social (safety) sub-indices and then to a composite index, in a way that overcomes the limitations on normalization, weighting and aggregation. It is an attempt to quantify transport sustainability for arterials streets within the Hilla network which provides information about current situation of urban transport in different parts of the city. The value of I_{CST} (composite index of transport sustainability) for main arterials at Hilla city (as case study) equal to 0.648, 0.542 and 0.462 for 40^{th}, 60^{th} and 80^{th} streets respectively. The value I_{CST} is the highest at 40th street (inner Hilla city – the best case) and the lowest at 80th street (outer Hilla the worst case).

Keywords: *Sustainability , Index, Indicators, Arterials*

دليل استدامة النقل لطرق شريانية رئيسية في الحلة كدراسة حالة (اعتبارات بيئية والسلامة)

الخلاصة: في جميع الاعمال الحديثة المتصلة بحركة المركبات فان مصلحات كالمستدام او الذكي لها اهمية في مجال النقل. وان تأمين الاستدامة دائما ما يعتبر تحدياً فالاستدامة تتحقق ليس باستخدام نظام مركبات خالي من التلوث وانما بترميم السلامة المرورية للطريق او منع الحوادث فيه. ان احتساب الاستدامة للنقل الحضري مهم جدا لتنامي اعداد الدراسات الخاصة بقياس الاستدامة في النقل. ان هذا البحث يتناول تحديات قياس الاستدامة النقل اعتمادا على مؤشرات بيئية ومؤشر السلامة فقط وذلك بسبب محدودية المصادر والوقت للمعلومات المتوفرة. ولغرض تلافي مؤشرات كثيرة للتقييم فان هذا البحث تعامل مع طريقة لإيجاد الدليل المركب لاستدامة النقل. سبعة مؤشرات استدامة مرتبطة بالنقل الحضري متعلقة باعتبارات بيئية او اجتماعية (السلامة المرورية) تم اختيارها اعتمادا على المعلومات المتوفرة، ان هذه المؤشرات تم تجميعها الى اكثر من دليل ثانوي ومن ثم الى دليل مركب واحد، وذلك من خلال توحيدها لقيم بدون وحدات ثم اعطاء اوزان لكل منها وتجميعها. هي محاولة لاحتساب استدامة النقل للطرق الشريانية ضمن شبكة طرق الحلة ولاعطاء معلومات عن الواقع الحالي للنقل الحضري في مواقع مختلفة من المدينة. تم ايجاد قيم الدليل المركب لاستدامة النقل لطرق شريانية رئيسية منتخبة في مدينة

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الحلة (كدراسة حالة) وكانت مساوية الى (0.648 ، 0.542 و 0.462) لكل من طرق ما تسمى بـ(40 ، 60 و 80) على التوالي. ان قيم الدليل المذكور كانت اعلاها في شارع 40 (اقرب الى مركز الحلة) وهي الحالة الافضل واقلها في شارع 80 (ابعد من مركز الحلة) وهي الحالة الاسوأ.

1. Introduction

Enhancement of urban network's performance is a challenging task. Many cities are trying to increased roads network to reduce congestion. However those expansions probably will not help to solve the problem. Beside the fact that expansion of road network's capacity is expensive and would be constrained by land limitation, it might stimulate a large amount of new demand.[1]

Congestion is an unavoidable aspect of most urban cities. However, there is a level at which congestion starts to detract from livability, increases transport costs and affects the reliability of travel for public transport.[2]

There is no single, simple solution to managing congestion. Sustainable management of congestion will require an integrated approach involving greater use of public transport and higher occupancy vehicles, farsighted land use planning, changes in behaviour by road users and businesses, and changes to how roads are managed.[1]

Better management of the traffic operation on the existing road network requires a new approach (sustainable management) to network planning that ensures the most effective use is made of the limited road space available.

Typically, congestion is associated with a reduction in the normal capacity of a road due to high traffic volumes, traffic incidents, adverse weather and roadworks.[1].

Various characteristics of sustainability and the advantages and disadvantages of existing transportation systems are analyzed, which provides a clear suggestion for effective sustainable transportation planning aimed at the maintenance of an eco-friendly environment and road traffic safety, which, in turn, would lead to a sustainable transportation system.[2]

Sustainability indicators are variables selected and defined to measure progress toward a performance target. The indicators may reflect the decision-making process (the quality of planning), responses (travel patterns), physical impacts (emission and accident rates), effects these have on people and the environment (injuries and deaths, and ecological damages), and their economic impacts (costs to society due to crashes and environmental degradation).

A sustainability index included indicators (pollutant, noise effect, accidents and travel delay) that reflect various levels of analysis, but it is important to take their relationships into account in evaluation to avoid double-counting.[3]

Table (1) lists indicators within different categories of sustainable transport planning concern. The shaded ones were selected for research:

There is debate as to whether motorized mobility (such as annual vehicle-mileage) should be considered a sustainable transportation indicator.[3]

Table 1. Main sustainability indicators. [3]

a- Economic indicators

Indicator	Description	Direction
Commute Time	Average door-to-door commute travel time.	Less is better
Employment Accessibility	Number of job opportunities and commercial services within 30-minute travel distance of residents.	More is better
Vehicle travel	Per capita motor vehicle-mileage, particularly in urban-peak conditions.	Less is better
Mode share	Portion of travel made by efficient modes: walking, cycling, rideshare, public transit and telework.	More is better
Congestion delay	Per capita traffic congestion delay.	Less is better.
Energy efficiency	• Per capita transport energy consumption • Per capita use of imported fuels.	Less is better.

b- Social indicators

Indicator	Description	Direction
Safety	Per capita crash disabilities and fatalities.	Less is better
Fitness	Portion of population that walks and cycles sufficient for fitness and health (15 minutes or more daily).	More is better

c- Environmental indicator

Indicator	Description	Direction
Climate change emissions	Per capita fossil fuel consumption, and emissions of CO_2 and other climate change emissions.	Less is better
Other air pollution	Per capita emissions of "conventional" air pollutants (CO, VOC, NOx, particulates, etc.)	Less is better
Noise pollution	Portion of population exposed to high levels of traffic noise.	Less is better
Land use impacts	Per capita land devoted to transportation facilities.	Less is better

Sustainable transportation indicators are an important tool for enhanced transportation planning. There is currently no standard set of sustainable transportation indicators. A variety of indicators are used, some of it we believe are particularly appropriate and useful for planning and policy analysis. It would be highly desirable for transportation professional organizations to develop standardized, "baseline" indicator sets, with consistent definitions and collection methods, suitable for comparing impacts and trends between different organizations, jurisdictions and times. This can include some indicators suitable for all situations, and others for specific needs and conditions.[3]

Social impacts include equity, human health, community livability (local environmental quality and safety as experienced by residents and visitors). Environmental impacts include various types of air pollution (including gases that contribute to climate change), noise, water pollution, depletion of non-renewable resources and wildlife deaths from collisions.[4]

Environmental and social (safety) dimensions are regarded on of double-bottom-line principle of sustainability. The basic nature of transportation is to fulfill the mobility of passengers and goods, and the first primary factor of transportation is its capacity.

Transport capacity firstly manifests as the amount of vehicles, the length of transport lines and so on. The second primary factor is service quality like connectivity, accessibility, as well as fare.[5]

The sustainability of transportation covers several different aspects of value judgments relating to transportation technology, sociology, economy, and environment protect.[5].

2. Safety and Environmental Aspects

2.1. *Traffic Safety*

Traffic accidents are a human target that kills 1.2 million people worldwide annually. The cost of traffic accident are huge and recent estimates 4.3% of GDP. (Gross Domestic Products). An accidents reduction cost can be done in two ways either by reducing the number of accidents or by mitigating the concepts of existing accidents.

2.2. *Traffic Gas Emission*

One-fifth of the carbon dioxide (CO_2), one third of chlorofluoro- carbons (CFCs), and half of nitrogen oxides (NO_x) in the atmosphere related to transport activities. Transportation has significant economic, social and environmental impacts and is an important factor in sustainability.[6]

Gas emission depends on speed, acceleration and vehicle performance level (performance index for passenger car unit and trucks).

The fuel consumption and emission change according to speed rate: for idling rate ≤ 50% of total emission, for accelerating rate = 35-40% of total emission and for decelerating rate ≤ 10% of total emission.[6]

CO emission of the big vehicle, buses and trucks (diesel fuel) equal only 1/11 of that for small cars (benzene fuel). [7]

Motor vehicles produce various harmful air emissions. Some impacts are localized, so where emissions occur affects their costs, while others are regional or global, and so location is less important. Emission control technologies have reduced emission rates of some but not all pollutants such as particulates.[8]

The following factors affect emission rates: [8]

- Older vehicles have less effective emission control systems. Vehicles with faulty emission control systems have high emissions.
- Emission rates tend to be relatively high when engines are cold.
- Faster accelerations tend to increase emission rates.
- Emissions per mile increase under hilly and stop-and-go conditions, and at low and high speeds.

A possible explanation of this result is compared to the traffic signal, the roundabout tends to reduce vehicle maneuvering, which contributes significantly to delay (and therefore to travel time), but is characterized by the lowest emission levels among the operational modes making up a typical driving cycle (idling, acceleration, cruise, deceleration). [9]

This paper considered performance of two alternative intersection configurations (roundabout and fixed-time signal control) in terms of vehicular emissions. Vehicular emissions of NOx, SO_2 and total carbon were considered in the analysis. [9]

One of the finding of the research is that the roundabout generally outperformed the fixed-time traffic signal in terms of vehicle emissions, although the difference between the two types of control was much smaller in terms of environmental impacts than in terms of operational traffic performance. That agrees with [9].

2.3. *Traffic Noise*

Traffic noise depends on first engine noise, inlet and exhaust noise, cooling fan system transmission noise and road surface noise. Second traffic volume and travel speed, traffic compassion (the noise increase by increment of truck percentage), at intersection (the noise increased due to change in speed rate). Third, space dimension of road way. The noise increased by the decrement of width and increment of building height.[4]

The big vehicle (like buses and trucks with diesel fuel) causes traffic noise equal to 115% of that for small cars (benzene fuel). [7]

3. Hilla main Arterials Network as A Case Study

3.1. *Geographic Location of Hilla City*

Iraq's southern city of Hilla, lying on the Sha't Al-Hilla, the eastern branch of the Euphrates River, is about 110 km south of Baghdad, about 60 km to the north of the holy city of Najaf and about 40 km to the south-east of the holy city of Karbalah. The City is situated approximately in the middle of Mesopotamia, mainly on the west bank of Sha't Al-Hilla. It extends from the ruins of Babylon on the north, to the storage area in the south, from Hilla Irrigation Canal on the west, to Sha't Al-Hilla in the east. It is located on 32.29 degrees north of the equator, and 44.28 degrees east of Greenwich. Al-Hilla lies in an area that has been very important in Iraqi and Mesopotamian history. Hilla City developed near the ancient city of Babylon, the ruins of which lies 8 km to the north of the existing city center. Kish and Borsippa, as other ruined ancient cities are in the nearby area, as shown in plate 1.

3.2. *Existing Condition of Main Urban Arterials*

From the site investigation (researcher field survey by cooperation with affiliate at Municipally Directorate for local network can be assessment the following points:

- Severe traffic congestion during peak periods, due to lack of traffic management.
- Lack of road markings particularly at approaches of intersections.

- Incompatibility of certain intersections with safety provision and traffic operations.
- Insufficient, poor and unorganized public transportation.
- Lack of organized and proper pedestrian facilities, especially at street crossings for all arterials.
- Deterioration of the conditions of sidewalks and roads.
- Illegal parking and lack of parking provisions.

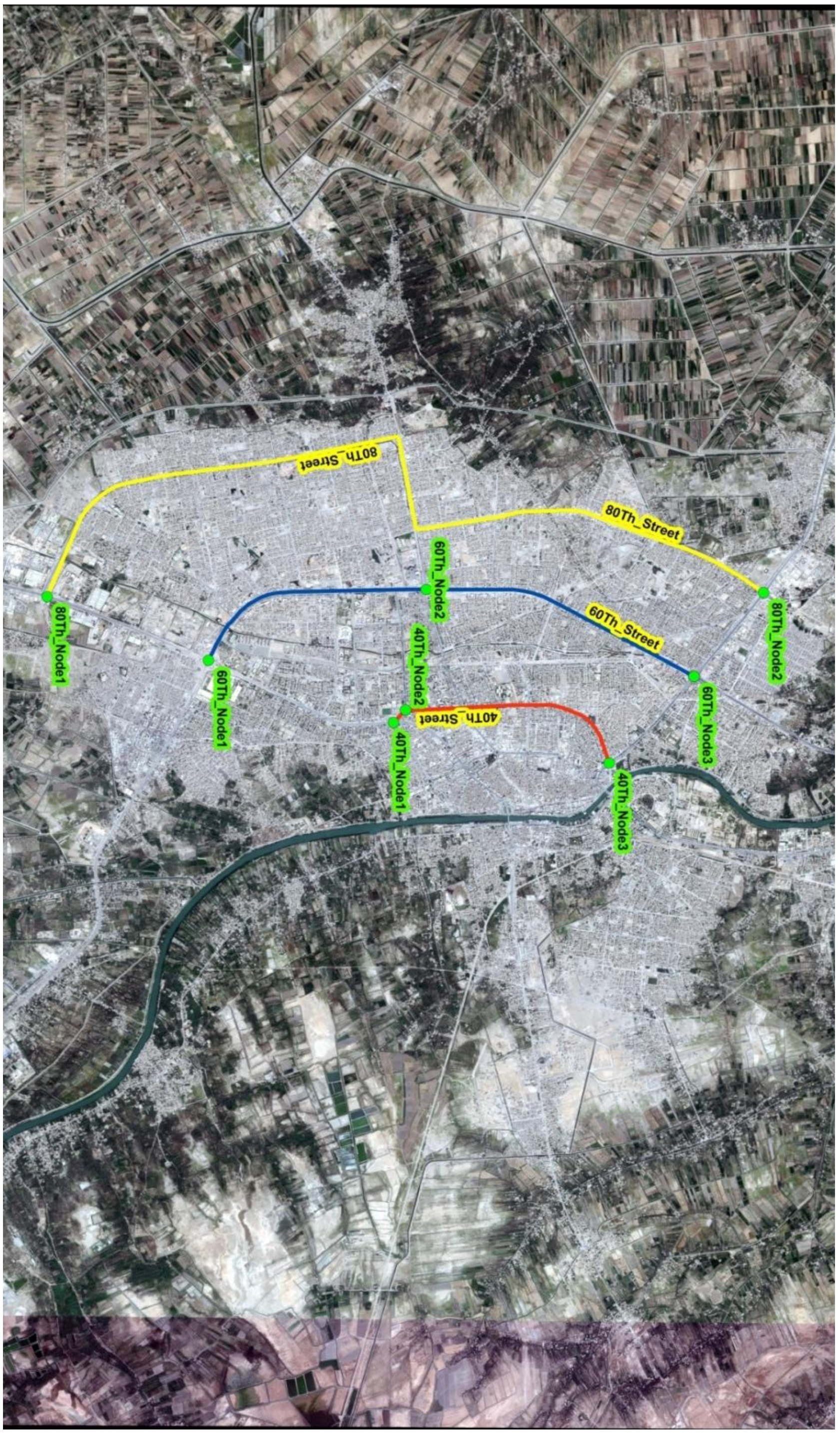

Plate 1. Hilla City Maps.

3.3. *Suggested Alternatives with Respect to Arterials Case Study*

3.3.1. *Alternative A: Consolidation and Infill*

Consolidation and redevelopment of existing infrastructure is generally preferred to expansion of settlements as far as journey length and general cost of trip making on roads is concerned. The negative aspects of consolidation and infill are found in the high pollution and noise due to high traffic intensities. In the case of Hilla ciry, this may be a very significant impact, given the relatively narrow roads and dusty surroundings.

3.3.2. *Alternative B: Linear Development or Satellite Expansion*

Formal high density development will occur along main highways while enclaves progressively densify but with a sub-optimum infrastructure and land use. The linear development along highways will create traffic congestion and concentrate pollution in the corridor. But the overall emissions and noise in the city will be less than those in Alternative A.

3.3.3. *Alternative C: Radial Development Alternative*

The radial development of new areas to the west will result in expansion of the road network in a web fashion to connect the existing with the planned developments. The impact on length of new roads and average journey lengths is high, having to negotiate a radial grid to make a trip that would otherwise be through a straight line, while the impact in terms of pollution and traffic congestions is low with the spatial dispersion of activity centres.

3.3.4. *Alternative D: Consolidation and Expansion towards East of the River*

This alternative combines the two scenarios depicted in alternatives A and C. However, the consolidation of already developed areas is to a lesser extent, which reduces the negative impacts on congestion and pollution, accompanied with an increase in trip lengths, especially in achieving the connection with the new developments in the east. Additional river crossings would be needed. In general, the negative and positive impacts of this alternative would balance each other and the outcome would be a medium overall performance of the road network in serving the transportation needs in a safe, efficient and environmentally friendly manner.

4. Safety and Environmental Data (Description and Analysis)

For the case under study case, data is collected for 3 main arterials at Hilla called 40^{th} (as minor arterial), 60^{th} and 80^{th} (as major arterials) as shown in the attached map.

Operating data (traffic volume and maneuvering) of segments and intersections along the arterials, is collected depending on researcher video photo using Dorone, rent for this purpose and analysis with AM peak (8:00-9:00) for period (1 to 31 December, 2017). While environmental data (Gas) emission like CO_2 and another air pollutants like lead, SO_2, CO, NO_x), is collected also for intersections by cooperation with environment office in Hilla city (the device: exhaust gas analyzer). As well as the reading of traffic noise (the device: sound level meter – Svam-955). While the data of observed accidence is collected by cooperation with police office in Hilla.

These all data (operation, environmental safety) can be seen in Table (2):

Table (2): Site data for main arterials

Arterial	*Node*	*Total entry flow vph*	*Noise (L_{eq}) dB*	*Accidents per year*		*Lead $\mu g/m^3$*	*SO_2 ppb*	*CO ppm*	*NO_x ppb*	*CO_2 ppm*
				predicted	**observed**					
40th L=3024m w= 40m three lanes in each direction (lane width: 3.65 meter)	1 (round about)	6210	71.13	5	11	1.6	53	36	41.5	250
	2 (signalized)	4280	72.7	4	3	1.72	60	40	43.4	270
	3 (signalized)	7120	75.3	8	17	1.5	55	38	67.2	376
	segment (1→2)	2912	69.1	3	7					
	segment (2→3)	3465	70.2	5	5					
60th L=6450m w= 60m three lanes in each direction (lane width: 3.75 meter)	1 (interchange)	4835	76.5	4	12	1.22	32.2	22	26.6	275
	2 (interchange and at grade intersection)	4325	76.25	3	19	1.66				
	3 (interchange and at grade intersection)	5210	79.1	5	23	2.07	46.5	31.1	33.5	378
	segment (1→2)	3560	71.09	5	41					
	segment (2→3)	4400	72.04	6	11					
80th L= 10605m w= 60m three lanes in each direction (lane width: 3.65 meter)	1 (at grade intersection)	5940	74.2	5	14	2	32.2	39.9	87.3	418.2
	2 (at grade intersection)	3790	69.8	3	5	1.55	25.3	30.5	67	405
	segment (1→2)	3550	68.6	5	39					

Noise L_{eq} (Iraqi limit = 55 dB)
Lead **(**Iraqi suggested limit = 2 microgram/m^3)
SO_2 (Iraqi suggested limit = 40 ppb)
CO (Iraqi suggested limit = 35 ppm)
NO_x (Iraqi suggested limit = 50 ppb)
CO_2 (Iraqi suggested limit = 300 ppm)

(suggested air quality specification for EPA, 2009, Environmental Minstry).

Noise as environmental indicator show higher values above adopted limit along all arterials (especially at signalized nodes).

Observed accidents as social (safety) indicator show higher values than these which predicted (calculated) depending on HSM (2010) [11], especially at intersections and significantly at 80th arterial segments.

While the other environmental indicators like CO_2 and other pollutant are almost above the acceptable control limits, especially intersections, significantly at signalized ones, due to traffic concentration at the AM peak period (rather than round about ones).

5. Recommendation for Improving Arterials Case Study

1- The greater use of public transport and high occupancy vehicle and change in road operation to improve performance by making existing road operation better.
2- Improving efficiency of transportation system and reduce pollution.

These facts can be achieved through adopting the following points depending on the final transport master of upgrading the master plane of Hilla city 2006-2030:

- Defining road hierarchy in order to rationalize circulation patterns and road attributes within and at the periphery of the study area.
- Installing traffic signals where appropriate, as proper intersection control improves traffic performance and level of service. (especially at main access points along 80th street)
- Upgrading the geometry of certain intersections to meet safety standards and improve traffic operations.
- Reinforcing and organizing public transportation means proper and station at network.
- Enhancing pedestrian safety by providing proper pedestrian facilities especially at street crossings.
- Provision of parking lots/garages and improving parking management to control on-street parking along (40th street) and specially near intersections.
- Providing traffic solutions to main attraction points and major traffic generators (at 60th street).
- Upgrading road network as well as sidewalks and cycle walks
- Reinforcing and organizing freight transport sector. (at alternate ring roads)
- Using vehicles with clear fuel like electric fuel.

6- Transport Sustainability Index

Aggregating individual indicators into a composite index is a practical approach for sustainability evaluation. It measures multi-dimensional aspects of sustainability that can- not be captured completely by individual indicators alone. The opponents of composite index believe that composite index is not reliable because its construction is subjective. Moreover, no single index can answer all questions and there is a need for multiple indicators.[10]

Composite sustainability index: Composite indices are very essential for decision making since they limit the number of presented information and allow for quick and easy comparisons. The process of calculating the composite index in this study was divided into several parts. At first, prominent indicators are selected in environmental, social (safety) aspects. Then indicators with different measurements units were normalized. Weighting selected indicators, relevant indicators were first aggregated into two-sub-indices and finally integrated to a composite transport sustainability index.[10] As shown in figure (1).

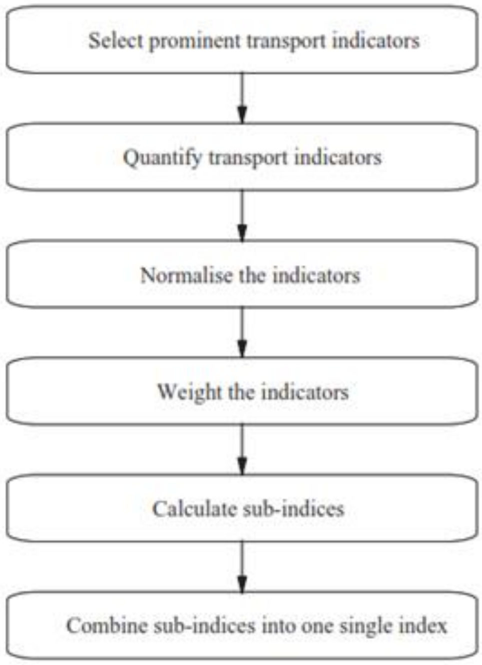

Figure (1): Procedure for calculating composite transport sustainability index. [10]

Environmental, and safety transport sustainability has become a central concern of urban design in the past decade to provide a comparative analysis of different Hilla city. Sub-indices are integrated into a single composite index. Aggregating indicators into a single index in this study is a simplified and quantified expression of overall transport sustainability in Hilla. The index is derived by applying normalization, weighting and aggregation methods. Using opinions for weighting indicators provides a proper way to resolve co-linearity issue and consequently avoids double counting among indicators and provides an unbiased measure of the transport sustainability.

It is an attempt to quantify transport sustainability for Hilla arterials which provides information about current situation of urban transport in different parts of the city to limit emissions and resource consumption; or it is expected to provide access for people, and enhance human health.

For calculating transport sustainability index for main arterials 40th, 60th and 80th streets the following weights are suggested based on opinions (depending their damage effects) by analysis of questioner results, which was made for specialists at all concern offices for Hilla city.

- For environmental aspects:
  GHG emission (CO_2) = 0.3
  Other air pollutant SO_2 = 0.1
  NO_x = 0.1
  CO = 0.1
  Lead = 0.1

Noise = 0.3

- For sub-indices

  Environmental aspects = 0.7

  Social (safety) aspect = 0.3

Transport indicators contains different type of information (emission, safety, noise) there for before indicators aggregation it is necessary to transform them to number without any dimension (normalization). Indicators (as selected in the research) whose increasing values have negative impact on sustainability were normalized using equation below: [10]

$$I_i = \frac{I_{max} - I}{I_{max} - I_{min}}$$

Where:

I_i: any calculated sub index like I_{noise} ……etc. shown in Table (3) below:

While the calculations of indices $I_{environment}$, $I_{accedent}$ and composite index, depending on the weights mentioned above for normalized selected indicators. [10]

Table (3): Environmental normalized indicators for all arterials

Arterials	I_{noise}	I_{CO2}	I_{SO2}	I_{NOx}	I_{Lead}	I_{CO}
40^{th}	0.70	0.71	0.12	0.60	0.54	0.11
60^{th}	0.39	0.55	0.60	0.89	0.49	0.72
8^{th}	0.78	0.04	0.90	0.17	0.35	0.27

$I_{Accident}$ = 0.85 for 40^{th} street.
= 0.52 for 60^{th} street.
= 0.57 for 80^{th} street.
$I_{environment}$ = 0.560 for 40^{th} street.
= 0.552 for 60^{th} street.
= 0.415 for 80^{th} street.
I_{CST} = 0.648 for 40^{th} street.
= 0.542 for 60^{th} street.
= 0.462 for 80^{th} street.

The value I_{CST} is the highest at 40th street (inner Hilla) and the lowest at 80th street (outer Hilla). The main reason, the better access to facilities by walking and public transport. The 40th street length is less than others which causes less transport energy consumption and pollutions.

7. Conclusion

According to the analysis of the collected data for main arterials at Hilla city, we can concluded the following:

1- The main arterials have not good condition in transportation at Hilla city and there are some suggested alternatives to treat them.
2- For now condition of the arterials, the environmental parameters show almost higher values above the adopted limits. Also the social (safety) indicators show

higher values than these predicted depending on HSM (2010) ch12 (predictive method for urban and sub-urban arterials).

3- Environmental indicators like noise and CO_2 and other pollutant are almost above the control limits, especially intersections, significantly at signalized ones, due to traffic concentration at the AM peak period (rather than round about ones).

4- The values of I_{CST} for main arterials at Hilla (as case study) equal to 0.648, 0.542 and 0.462 for 40th, 60th and 80th streets respectively.

5- The value I_{CST} is the highest at 40th street (inner Hilla) and the lowest at 80th street (outer Hilla).

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