AN INDICATORS SET FOR THE ENVIRONMENTAL ASSESSMENT OF URBAN EFFECTS OF LIGHT RAIL SYSTEM

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ABSTRACT

Several positives effects (environmental urban effects among others) can be produced by light rail system (LRS) development in metropolitan areas. Moreover, these effects are showed to different levels, such as, metropolitan and town level, or in the street where the LRS is proposed. Under this context, understanding better the impact of these externalities in the different spatial levels could be the best way to enhance a suitable integration of this transport system.

In this way, assessing the environmental effects in the street where LRS will travel, it can help to develop criteria which permit design the street as a transport public corridor with higher environmental efficiency values. In this way, this paper is presented an indicators set to assess the environmental integration of light rail systems at street (re)design level.

Finally, one example of the results of these indicators set will be showed in Metropolitan Area of Granada. This area is located in Andalusia's region in the south of Spain, and during the last years a LRS is being promoted by the regional and local governments.

INTRODUCTION

Not only are several researches studying the environmental consequences of mobility, but the majority of them agree to design cities and regions with mobility patterns less aggressive with the environment (Banister, 1999) (Priemus; Nijkamp and Banister, 2001) (May; Jopson and Matthews, 2003) (Bertolini; Clerq, and Straatemeir, 2008). In this way, the optimal environmental urban integration of new public transport systems is fundamental to achieve these objectives (Hull, 2008) (Stead, 2008), in special in metropolitan regions where the level of car dependence is higher than other regions are.

At the same time, LRS can be considered as alternative in order to improve the mobility in metropolitan regions, and it can be an important tool to make city (Lynch, 1981) (Priemus and Konings, 2001) (Trip, 2007) (Cascetta, and Pagliara, 2008), in special as a consequence of several positives environmental urban externalities which can be derived of its implementation, for instance: increases of pedestrian flows, a higher demand of green spaces or reduction of car transit in these areas (Hass-Klau and Crampton, 2002) (Hass-klau, Crampton, Carsten and Volker, 2003).

From this point of view, with combination of clear planning strategies between land use planning and implementation of LRS is more possible that metropolitan regions can be designed at personal scale, and with more environmental urban quality (Bovy, 2000) (Babalik-Sutcliffe, 2002) (Badland and Schofield, 2005) (Mackett, and Babalik-Sutcliffe, 2003) (May and Tigh, 2006) (Cervero and Murakami, 2009). So, the role of streets where LRS is designed are keys to achieve these objectives, and for this reason, promoting sets of indicators to assess the environmental urban effects of street´s (re)design (as consequence of LRS implementation) is a fundamental question to obtain a better integration of this public transport system (Ambrosino et al,1999) (Marsden, 2005) (Deakin, Mitchell and Nijkamp, 2007).

In this way, the importance of street´s design as a first step to achieve a good integration of LRS is based on following reasons:

1. Unlike a more conventional approach, the street must be understood as space and not mainly as a road (Marshall, 2003). Therefore, the modal design in the street is very important to regulate mobility flows and develop socialization spaces.

2. Looking for sustainable functionality of street, because not only must the street respond to traffic demands, but it must be also oriented to social and environmental demands (Banister, 2008).

3. The mobility environment which is predominant in the street (pedestrian, public transport or car environment), has an important influence in the urban structure of corridor resulted of LRS, in special to achieve a design of city at personal scale.

Under this context, the main objective of research is to propose a set of indicators to assess the environmental urban effects of street´s (re)design where LRS has been promoted. So, not only can these indicators assess the environmental urban effects of street´s (re)design, but they can be a good way to develop a set of references to propose design criteria in urban design projects. In the case of this paper, it will be developed a proposal of indicators which can carry out these objectives in the case of the street’s redesign in Metropolitan Area of Granada, where a LRS is being developed by Government of Andalusia.

CASE OF STUDY

This methodological approach will be developed in the street located in the main transit corridor in Granada Metropolitan Area (GMA) as a consequence of LRS’ implementation. The suitability of this street is based on following reasons:

1. The Regional Government is promoting a LRS, which is located in the main metropolitan transit corridor. Therefore, a redesign urban project for the street has been designed to incorporate this new transport infrastructure.

2. Nowadays, this transit corridor previously mentioned is the central structure of mobility in this region, and this role will be more important when LRS will have been opened.

3. Promoting mobility more sustainable through the urban redesign of this street is one of the most important goals in the political agenda of Andalusia Government.

Therefore, in this particular application of the indicators set designed, there are two alternatives or scenarios, on the one hand, the urban design of the street without LRS (current scenario) while the second scenario is the street designed with the LRS (future scenario). In this way, the main objective is to assess the environmental urban effects of redesign of street as a consequence of LRS proposed.

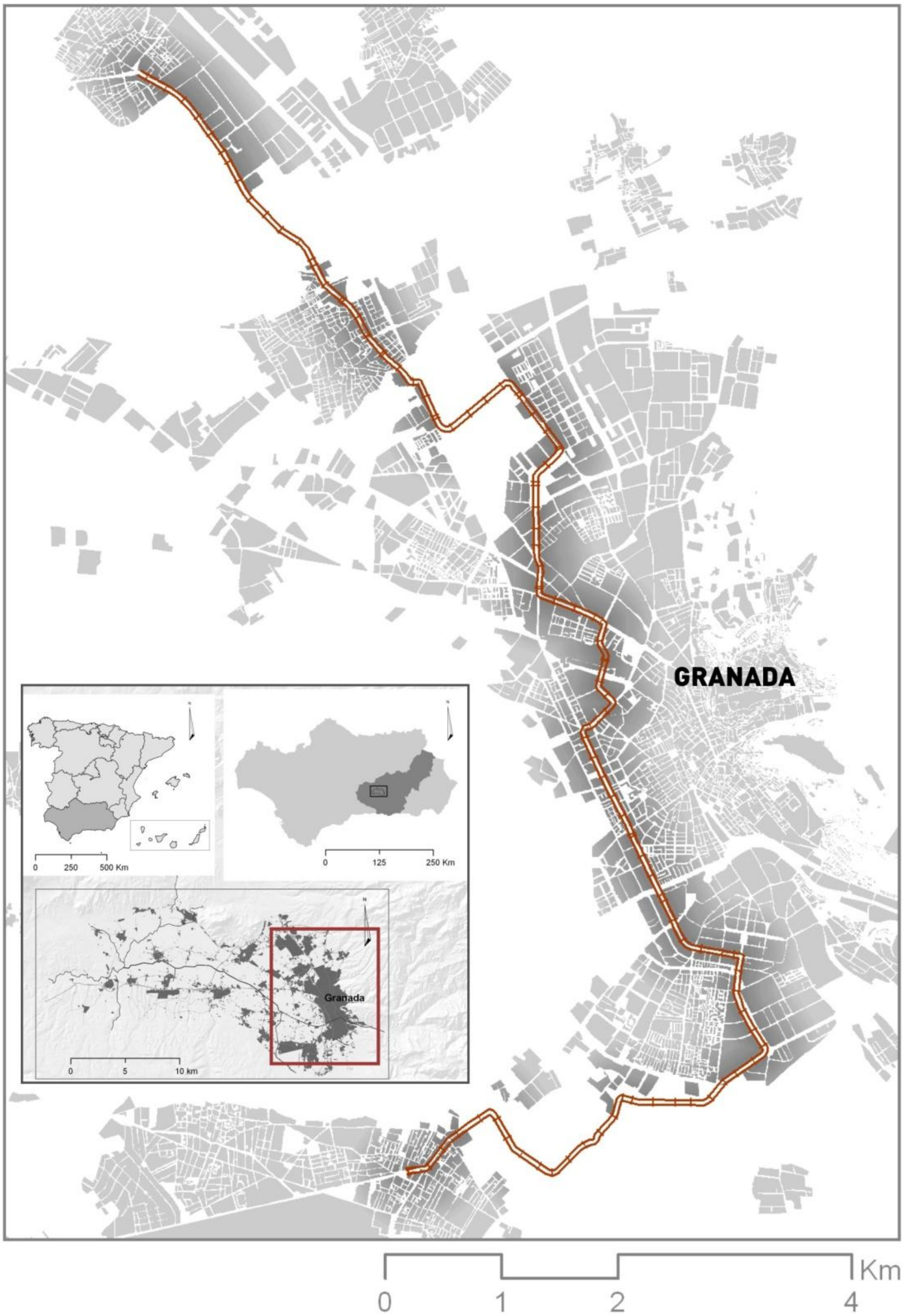

Figure 1. Location of LRS in the Metropolitan Area of Granada

METHOD

The main methodological steps are the following:

1. Defining environmental urban indicators
2. Methodological application in Metropolitan Area of Granada

Defining environmental urban indicators

Related to the introduction previously exposed, the indicators which will be proposed are useful to show some interesting information about the potential environmental urban effects of LRS in the street. Following with the context previously exposed, the indicators defined will assess the change between current scenario (corridor without LRS) and future scenario (corridor with LRS). So, the main environmental urban effects which pretend to be assessed by the indicators proposed are the following:

1. *Use of street by transport modes*, in special with the aim to assess the predomination of public or private use on the street. This question is very important, because one of main objective of LRS project is at the same time to recover a higher surface of street to public functions and reduce the surface used by private transport. This change in the street can not only be important for environmental aspects such as, noise or emissions, but it is a way to give the street a higher public function than it was.

2. *Comfortable street design* in relation with green and pedestrian space. One of the most important aspects to planning and design the street from a non conventional approach is related with the proposal of green and pedestrian spaces. In this way, these spaces can induce a friendlier design, where not only can the use of street be understood from a transit corridor perspective, but the street can be used as a socialization and leisure space too.

3. *Promotion of pedestrian routes*. This is an important question to get a higher pedestrian transit in the urban area where LRS has influence. From this point of view, promoting pedestrian routes is a fundamental aspect as a attraction factor to population.

4. *Permeability for pedestrians*. Another aspect related to the attraction of population in the street is the permeability, which explains the ease to cross the street to pedestrians. So, if the street can be crossed by pedestrians easier than it did previously to LRS implementation, the use of street by population can be higher.

The indicators proposed to assess the environmental urban effects previously exposed are the following:

1. *Modal split in the street*: where the distribution of the different transport motorized modes will be assessed in the two scenarios described in the corridor. The transport motorized modes in the case of study are: cars, buses and light rail. This indictor is used to measure the use level of street by transport modes.

2. *Green and pedestrian surface:* where the change in the green and pedestrian surface will be evaluated between the two scenarios, without and with LRS. These surfaces are very important to develop socialization spaces in the corridor and they have an important influence in the corridor land use. This indicator is especially proposed to assess the comfortable street design for pedestrians.

3. *Pedestrian effective surface:* this surface is doing reference to that part of the pedestrian surface where is produced the pedestrian transit, without reference to other pedestrian surfaces in the street such as, gardens or serfdom with residential and commercial buildings for example. As it can be observed, the pedestrian effective surface is very useful to measure the promotion of pedestrian routes as consequences of LRS project.

4. *Barrier effect for pedestrians (BEP)*: defined as the difficulty for pedestrians to cross the street. This indicator is expressed as barrier effect for pedestrians/m street and it is used to assess the permeability of street for pedestrians.

$$BEP = \sum (\vartheta * Street\ occupied)_{Transport\ mode} * WR$$

Where:

- ϑ , is the frequency of vehicles per minute per transport mode
- *Street occupied,* is the street occupied by the transport mode
- *WR,* is the width of roadway in the street

Methodological application in Metropolitan Area of Granada

Given the length of the corridor in Metropolitan Area of Granada, approximately 21km, it has been decided to divide the street in 25 sections, each of them defined by the street located between two adjacent light rail stations (see Figure 2). So, each of sections will be independently assessed for the two scenarios previously defined, without and with LRS.

Figure 2. Functional sections for the methodological application in the transit corridor

THE INDICATORS SET IN THE METROPOLITAN AREA OF GRANADA

In this part of research will be exposed the results of the indicators set previously described in the methodological part.

Modal split in the street

As it was previously exposed, the modal split in the street is doing reference to the surface distribution of different transport motorized modes per each scenario in evaluation, current and future scenario. From this point of view, this indicator is very interesting to measure the use level of street by these motorized modes, and therefore, measuring the predomination of public or private motorized use on the street.

Sections	Current scenario			Future Scenario			
	% Cars	% Buses	% Parking	% Cars	% Buses	% Parking	% LRS
1	99,78	0,00	0,22	59,35 ↓	0,00 =	0,81 ↑	39,84 ↑
2	100,00	0,00	0,00	59,59 ↓	0,00 =	0,00 =	40,41 ↑
3	100,00	0,00	0,00	55,83 ↓	0,00 =	0,00 =	44,17 ↑
4	92,58	0,00	7,42	43,63 ↓	0,00 =	6,50 ↓	49,87 ↑
5	95,45	0,00	4,55	20,12 ↓	0,00 =	0,13 ↓	79,75 ↑
6	81,29	0,00	18,71	53,05 ↓	0,00 =	4,10 ↓	42,86 ↑
7	85,63	0,00	14,37	67,08 ↓	0,00 =	0,00 ↓	32,92 ↑
8	80,20	0,00	19,80	63,63 ↓	0,00 =	0,00 ↓	36,37 ↑
9	86,35	0,00	13,65	65,13 ↓	0,00 =	0,00 ↓	34,87 ↑
10	95,14	0,00	4,86	66,18 ↓	0,00 =	0,00 ↓	33,82 ↑
11	74,68	13,80	11,52	15,70 ↓	26,41 ↑	0,92 ↓	56,97 ↑
12	80,57	3,33	16,10	50,27 ↓	2,07 ↓	4,64 ↓	43,02 ↑
13	44,95	0,00	55,05	0,00 ↓	0,00 =	0,00 ↓	100 ↑
14	88,21	0,00	11,79	63,52 ↓	0,00 =	0,96 ↓	35,52 ↑
15	85,79	0,00	14,21	81,26 ↓	0,00 =	18,74 ↑	0,00 =
16	88,01	0,00	11,99	85,33 ↓	0,00 =	14,67 ↑	0,00 =
17	87,98	0,00	12,02	96,28 ↑	0,00 =	3,72 ↓	0,00 =
18	91,86	0,00	8,14	60,91 ↓	0,00 =	2,32 ↓	36,77
19	62,96	0,00	37,04	49,68 ↓	0,00 =	17,23 ↓	33,09 ↑
20	68,50	0,00	31,50	48,97 ↓	0,00 =	20,99 ↓	30,04 ↑
21	90,61	0,00	9,39	55,65 ↓	0,00 =	2,77 ↓	41,58 ↑
22	85,00	0,00	15,00	54,47 ↓	0,00 =	6,96 ↓	38,57 ↑
23	100,00	0,00	0,00	68,94 ↓	0,00 =	0,00 =	31,06 ↑
24	94,38	0,00	5,62	49,69 ↓	0,00 =	0,00 ↓	50,31 ↑
25	86,98	0,00	13,02	40,27 ↓	0,00 =	0,00 ↓	59,73 ↑

Table 1. Modal split in the street per scenario

Related to the results shown in table 1 and figure 3 and 4, the car´s surface is more predominant in the current scenario than in the future scenario is. This situation shows a change in the use of the street by motorized transport modes, where a higher public use is got through in the street redesigned. Following with the argument exposed and having account the sum of car and parking surfaces in both scenarios, it can be observed as 100% of surface of motorized modes is used by cars in the majority of sections of current scenario (24 sections), while in the future scenario the average of surface occupied by cars and parking is 56.92%.

A negative aspect of this new design in the street is the limited promotion of Bus surface in the future scenario. Only two sections (section 11 and 12) have an exclusive surface to public buses, but in the future scenario this situation is not better, and the values of the exclusive bus surface is very similar to current scenario.

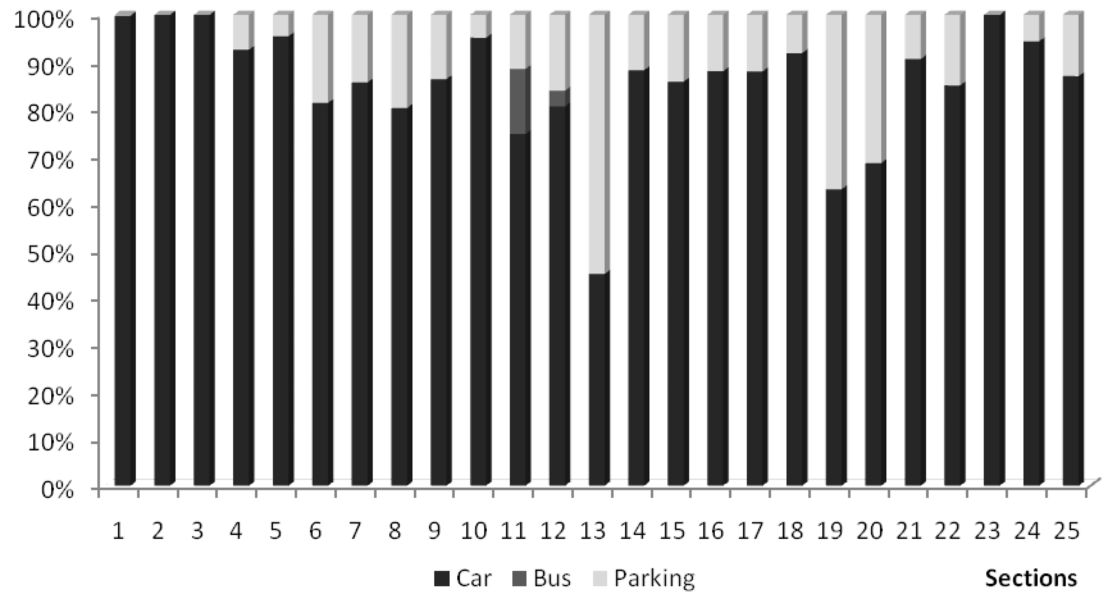

Figure 3. Modal split in current scenario

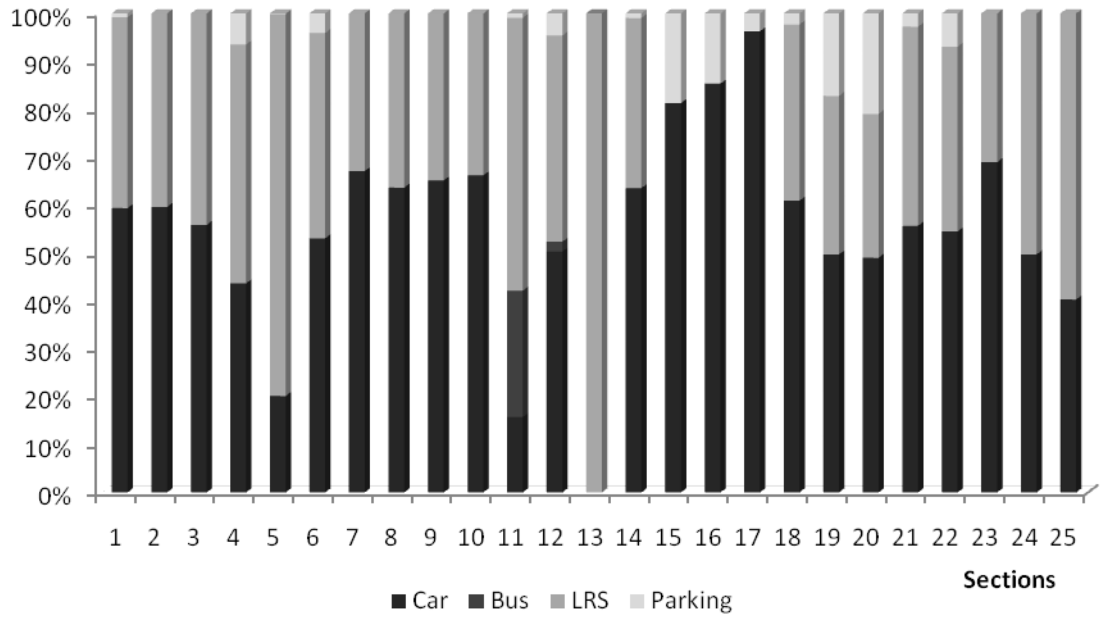

Figure 4. Modal split in future scenario

On the other hand, another positive change related to public use of street is the important reduction of parking´s surface in the majority of sections, in special in sections number 7, 8, 9 and 10. In these sections the average of parking's surface was 18% in current scenario while in future scenario this surface is removed.

Finally, some of sections with the most important change related to modal split of the street are sections 1, 2 and 3, where they only had car surface in current scenario, and in future scenario they have 43.6% of LRS surface, while the motorized surface of section number 13 is only occupied by LRS in the future scenario. On the other hand, in sections 15, 16, 17 the LRS is underground and for this reason the surface of LRS is not changed. Besides, the surface used by cars is only incremented in section 17.

Green and pedestrian surface

The green and pedestrian surface is the second environmental urban indicator proposed. Assessing the green and pedestrian surface is essential because these spaces in the street are very important to develop socialization and leisure spaces and to offer a more comfortable design to pedestrians. At the same time, they have a strong influence upon land use structure in transit corridor. The results of this indicator can be observed in table 2 and figure 5.

	Green + Pedestrian Surface (m^2)	
Sections	**Current scenario**	**Future scenario**
1	8392,59	17850,11 ↑
2	4739,10	11960,47 ↑
3	2263,36	4230,41 ↑
4	5760,93	5446,44 ↑
5	10171,73	8876,56 ↓
6	28677,17	25179,35 ↓
7	17188,43	15332,01 ↓
8	11178,49	10793,74 ↓
9	15089,00	13615,16 ↓
10	9410,18	8791,27 ↓
11	15288,03	14201,25 ↓
12	6076,84	8717,19 ↑
13	5860,61	7463,11 ↑
14	9006,26	9017,94 =
15	13076,72	19519,16 ↑
16	6930,23	10659,84 ↑
17	10737,67	12458,89 ↑
18	7213,50	5216,88 ↓
19	24487,35	21983,73 ↑
20	16833,13	13736,23 ↓
21	13759,77	10267,14 ↓
22	15529,39	11019,39 ↓
23	5409,92	6283,67 ↑
24	6039,40	8359,79 ↑
25	7695,83	13064,31 ↑

Table 2. Green and pedestrian surface per scenario

As is shown in the results, the total of green and pedestrian surface is increased in 17,822 m^2 (6,22%) with respect to current scenario. This increase is very significant in sections 1 and 2 where the future scenario proposes 16,678 m^2 of new surface. At the same time, sections number 15, 16 and 17 have a strong increase of green and pedestrian surface too, 11,893 m^2.

On the other hand, some sections have a reduction of green and pedestrian surface (in special from section 5 to 11). This reduction is important in sections number 6 where 3497 m^2 are lost with respect to current scenario. Another significant reduction of this indicator can be observed in sections 19, 20, 21 and 22, 13603,3 m^2.

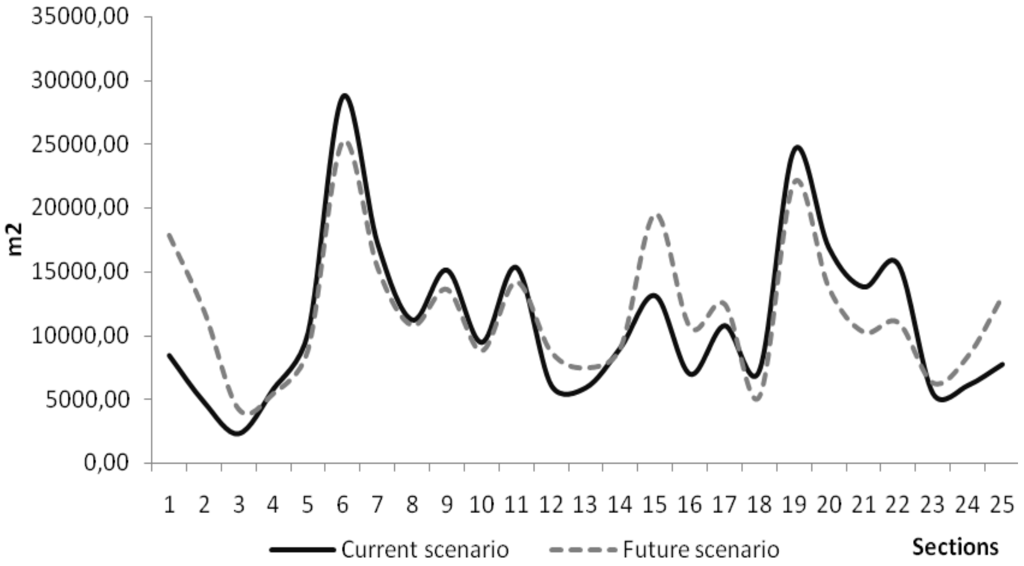

Figure 5. Variation of green and pedestrian surface per scenario

Pedestrian effective surface

This indicator is doing reference to that part of pedestrian surface where is produced the pedestrian transit, without reference to other pedestrian surfaces in the street such as, gardens or serfdom with residential or commercial buildings. The importance of this indicator is basically to assess the capacity of street to facilitate of population transit through developing pedestrian routes.

As is shown in table 3 and figure 6, the pedestrian effective surface is increased in total, 21,705m^2 (9.87%) with respect to current scenario. Jointly with the modal split analysis, it could be observed as the design of street in future scenario is more oriented to public transport and pedestrian transit than de street´s design was in current scenario.

	Pedestrian effective surface (m2)	
Sections	**Current scenario**	**Future scenario**
1	7284,73	11827,64 ↑
2	4393,00	4989,05 ↑
3	1528,56	3372,09 ↑
4	4797,30	5006,33 ↑
5	9626,15	3748,28 ↓
6	23930,78	22329,83 ↓
7	13915,51	14770,59 ↑
8	7721,63	8449,75 ↑
9	10670,08	10957,84 =
10	7143,60	7610,04 ↑
11	14044,40	12554,95 ↓
12	5974,45	7265,86 ↑
13	4920,06	6296,25 ↑
14	8359,66	8457,99 =
15	9168,13	19519,16 ↑
16	5580,13	10648,72 ↑
17	9164,27	11378,85 ↑
18	6217,25	5132,12 ↓
19	21719,37	19476,42 ↓
20	12663,05	8302,33 ↑
21	8835,51	8625,12 ↓
22	9291,90	8802,59 ↓
23	1163,78	2971,63 ↓
24	5347,12	7605,62 ↑
25	6309,33	11376,20 ↑

Table 3. Pedestrian effective surface per scenario

As is shown in table 3 some of representative sections where the effective surface for pedestrians has increased are sections 1, 2, 3, 4 (7191 m2). So, sections 15, 16 and 17 have the most increased of pedestrian effective surface, 17,634 m^2 (73%) with respect to current scenario. Finally, section 25 increases this indicator in 5,066 m^2, moreover, it is the only section completely pedestrian in the future scenario.

On the other hand, there are other sections where a decrease of pedestrian effective surface is produced, for instance, section number 5 and 6 where is lost 7478.72 m^2, or sections 18, 19, 20 and 21 where 15% of pedestrian effective surface is lost in the future scenario.

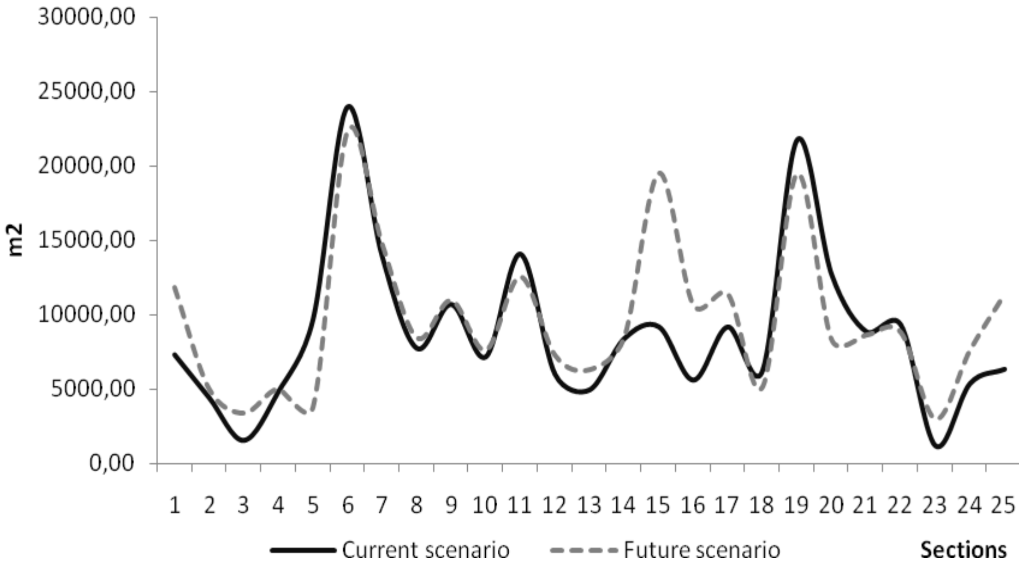

Figure 6. Variation of pedestrian effective surface

Barrier effect for pedestrians

Barrier effect for pedestrians (*BEP*) is defined as the difficulty for pedestrians to cross the street. So, it is expressed as barrier effect for pedestrians per meter in the street. Therefore, this indicator is very useful to assess the permeability of street for population, as it was explained in the methodology.

The expression which permits us to calculate the BEP is:

$$BEP = \sum (\vartheta * Street\ occupied)_{Transport\ mode} * WR$$

Where:

- ϑ , is the frequency of vehicles per minute per transport mode
- *Street occupied,* is the street occupied by the transport mode
- *WR,* is the width of roadway in the street

As is shown in table 4 and figure 7, the barrier effect for pedestrians decreases in average 1,79 BEP/m street (approximately 79%) with respect to current scenario. This situation is important because it shows the intention of the redesign project to facilitate a transit more oriented to pedestrians, in special through traffic reduction.

If it is done a comparison between the variables used to calculate the barrier effect for pedestrians, it could be observed as the most influential variable is traffic flows and in second position the space in the street used by car. For this reason, a reading about the influential of the new street project on use of car can be done, as a consequence of the results exposed in table 4 and figure 6. Furthermore, a more friendly street´s design for pedestrians is another consequence of the reduction of car traffic and space used by car in the street.

	Barrier effect for pedestrians (BEP/m)	
Sections	**Current scenario**	**Future scenario**
1	30,97	24,71 ↓
2	29,27	37,43 ↑
3	25,15	28,13 ↑
4	28,08	13,77 ↓
5	20,30	10,39 ↓
6	4,46	4,32 =
7	86,34	70,76 ↓
8	27,33	19,44 ↓
9	475,96	399,96 ↓
10	665,53	463,72 ↓
11	218,00	63,83 ↓
12	318,58	129,84 ↓
13	0,00	0,00 =
14	392,42	267,04 ↓
15	635,66	166,57 ↓
16	317,66	77,61 ↓
17	412,98	207,20 ↓
18	279,58	249,19 =
19	280,41	250,56 ↓
20	114,36	105,96 ↓
21	84,64	78,53 ↓
22	86,29	80,62 ↓
23	144,17	142,91 =
24	45,74	26,66 ↓
25	40,98	3,41 ↓

Table 4. Barrier effect for pedestrians per scenario

Some of sections where the barrier effects for pedestrians is more reduced are sections number 9 (-76 BEP/m), 11 (-154.17 BEP/m) and 12 (-188,74 BEP/m) among others. Moreover, the most important reduction is produced in section 15 (-469,09 BEP/m) and 16 (240,05 BEP/m).

Finally, the only sections where the barrier effect for pedestrians is increased are sections number 2 (8.16 BEP/m) and 3 (2.97 BEP/m) in the north of public transport corridor.

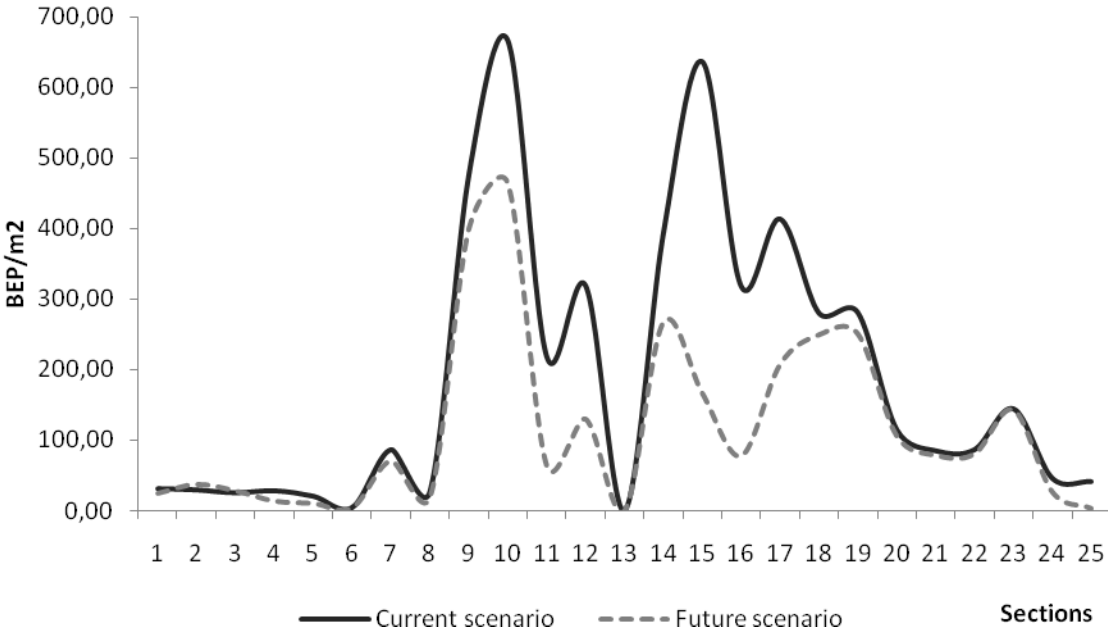

Figure 7. Variation of barrier effect for pedestrians

DISSCUSION

As it can be seen in the results previously exposed, some of the indicators proposed are good tools to assess the environmental urban goals selected in the methodological part (use of street by transport modes, comfortable design of street, promotion of pedestrian routes and permeability of street for pedestrians). In special, the modal split design of street and the barrier effects for pedestrians are the two indicators with the best interpretation of its results, in relation with the objective which was measured by their. In the particular case of results derived of green and pedestrian surface and pedestrian effective surface, they can give us an approximation about the objective which was assessed. For this reason, proposing new and complementary goals and indicators for future studies is a basic aspect, with the aim to improve the assessing done here. The formulation of new goals and indicators derived of them could permit to analyze other representative key aspect of (re)design street project. At the same time, they can also help us to measure with less uncertainty some goals defined in this paper, which have not been completely measured by the indicators selected, for instance, a comfortable street design or the promotion of pedestrian routes.

Related to the use of the indicators proposed, it would be necessary to explain that in Spanish context, developing indicators set which permit to assess different aspects of (re)design projects is a question very important for decision-making process, in special as a consequence of absence of methods to assess environmental urban costs and benefits of urban and street design project. Therefore, this set of indicators must be designed as a complementary tool with other dimensions of urban and street project, such as, economic, social or technologic dimension.

In the particular case of LRS project in Metropolitan Area of Granada, despite the majority of indicators used have positives results in relation with the environmental urban effects assessed, the different changes which have occurred in the street´s design project for decision-making process are result of political intentions, economic issues or technological decisions, but very little times these decisions has been a consequence of assessing the environmental urban effects of this LRS project, in special as a consequence of the absence of these sets of indicators. For this reason, it is thought that the result of the indicators proposed could be better than they are if this kind of methodologies was used for decision-making process, in special way in the case of the green and pedestrian surface and pedestrian effective surface.

Therefore, the utility of designing indicator sets to assess the environmental urban effects of street redesign projects for transit corridor is based on different aspect. For instance, assessing the different alternative for the decision-making process and looking for the best option which responds to transportation and environmental urban demands. From this point of view, the set of indicators can be used to develop a normative reference framework oriented to design a planning support system (PSS). In this way, these indicators could be used to design sustainability scenarios which can be used by planners to improve the final proposal in the street.

Another potential application of these indicators set is to develop design criteria with the aim to generate a street´s design friendlier and with more security for pedestrians, for instance, it could be designed secure intersections between LRS, cars and pedestrians in sections with small values of barrier effects for pedestrians (sections 9 and 10, see results).

CONCLUSIONS

Finally, after discussing the main results obtained, as well as, the main application of the indicators set in the case of urban design projects, in this last part, a guideline about the design of the set of indicators in the context described in this paper is presented:

1. It must be based on non convectional approach of metropolitan mobility. This is one of the most important aspects which must be considered when planner and/or researcher design set of environmental urban indicators as proposed here. This question implicate -among other things- to consider the street as a space and not as a road, to understand the relation between mobility and urban structure, to promote higher pedestrian use of street, or finally, to develop a planning of city at personal scale.

2. The set of indicators designed must try to introduce the environmental urban sustainability as a normative orientation in the (re)design of street in transit corridor. As a complementary way with other dimensions of urban and street project (technologic, social, economic, dimension, etc.) the set of indicators must be oriented to establish a normative framework, which can be based on the definition of critical environmental urban thresholds values for each key aspect of (re)design project.

3. It must promote an integrated decision-making process between urban design, corridor planning and transportation, with the aim to promote sustainable mobility patterns through the street design. One of the most important problem in the particular case of Spain is due the decision-making process is developed by different government bodies. Therefore, developing and integrated tool is a key aspect to promote a higher and more efficient coordination between these government bodies. At the same time, the set of indicators must also promote the dialogue between decisioners and practioners in the decision-making process, and in this way, a mobility patterns more sustainable can be got easier than they was,

4. The design of indicators set must be easy and flexible to users and especially useful in the urban integration of new transport infrastructure in the street. In this way, the set of indicators proposed must be exportable to other streets and metropolitan regions.

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