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Development of social criteria for the social life cycle assessment of railway infrastructures

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The sustainable design of infrastructures requires the consideration of the economic, environmental, and social impacts. Since the establishment of the Paris Agreement, significant efforts have been made on the methodologies to assess infrastructures' economic and environmental life cycle impacts. However, evaluating the social dimension in the design of infrastructures still requires significant development. The present communication proposes a set of social indicators oriented towards the life cycle assessment of railway infrastructures. In particular, the evaluation of the social impacts of a conventional ballasted rail track is presented. A multi-criteria decision-making procedure-based indicator is then proposed to help decide on the most advantageous track design in social terms.

Keywords: Multi-criteria Decision-making; Sustainability; Life cycle assessment; Railway; Social impacts

1. Introduction

Since the establishment of the Sustainable Development Goals (SDG) back in 2015, great concern has arisen on the environmental and economic evaluation of infrastructures (Pang et al., 2015; Safi et al., 2015; Pons et al., 2020). The construction sector is recognized as one of the main environmental stressors existing, and therefore the key to achieving the SDGs that our society aspires to see fulfilled by 2030. However, it is well known that sustainability and the sustainable design of products of any kind must also consider its third, usually neglected dimension, namely the society itself (Hendiani et al. 2019). Although social aspects and criteria are usually accounted for when it comes to reach strategic decisions in a macro-scale territorial planning dimension, a serious knowledge gap exist on the development of effective and objective criteria at the micro-scale of infrastructure design.

While the economic and environmental design of infrastructures has become highly standarised throughout the last years, there is still an important gap when it comes to the social life cycle assessment (SLCA) of products. So, beside the environmental ISO 14040 and ISO 14044 standards that set the basis for the environmental (and to some extent condition the economic) life cycle assessments, to date only the ‘Guidelines for social life cycle assessment of products’ (UNEP/SETAC, 2009) exist to aid designers perform SLCA. Currently, an ISO-standard is being developed by ISO technical committee *ISO/TC 207/SC 5* to establish a standarised framework for the social assessment of products. However, this standard is still in a very early stage of development.

Consequently, significant and consistent research has been conducted on the economic and environmental evaluation and optimization of structures (Torres-Machí et al., 2015; Molina-Moreno et al., 2017; Navarro et al., 2019), but very little has been published to date about the social design of infrastructures (Gervásio & da Silva, 2013). In fact, the abovementioned

‘Guidelines’ claim for the urgent application of life cycle-based social assessment of products in order to further develop this recent methodology and help SLCA show its practicability and validity. Since the ‘Guidelines’ where published, several efforts have been made to apply them in several case studies considering a variety of products such as fertilizers (Martínez-Blanco et al., 2014), electronics (Wilhelm et al., 2015) or products from the food industry (De Luca et al., 2015) among others. Considering the complete life cycle of infrastructures, and to the best of our knowledge, those ‘Guidelines’ have only been applied so far in the design of bridge structures (Navarro et al., 2018).

The present communication proposes a set of objective and quantitative criteria to evaluate the social impacts of a railway infrastructure through its life cycle, based on the set of social criteria previously proposed by (Navarro et al., 2018) to evaluate bridge structures. Based on such criteria set, a social life cycle assessment is conducted here on three different track alternatives for a railway infrastructure. In the absence of SLCA standards, the present social assessment accounts for the main steps and concepts included in the environmental LCA framework established in ISO 14040 and ISO 14044. The most socially beneficial design alternative is then chosen considering an Analytic Network Process (ANP) based ranking.

2. Materials and Methods

2.1 Social Life Cycle Assessment

The present SLCA is based on the methodology provided in the environmental standards ISO 14040 and ISO 14044 for the life cycle assessment of products. According to those standards, any life cycle assessment should be based on a four-step process, where the scope, the inventory, the assessment technique and the results are presented.

The scope of this analysis is the evaluation of the life cycle social impacts of a 1 km long section of the highspeed railway twin-track providing connection between Madrid and Oropesa (Spain), for a life span of 100 years (Indraratna et al., 2011). Three design alternatives are considered. First, a ballast track is chosen, which consists of an aggregate-based substructure and precast concrete sleepers. This solution is representative for the conventional railway track solution in Spain (Villalba Sanchis et al, 2021). The second alternative consists of a ballastless track, namely the so-called Beatty Embedded Slab Track (BBEST hereafter). This alternative consists of a reinforced concrete slab with the sel rails embedded in it. The third design alternative assumed for the present social assessment is the Rheda 2000 solution, which is also a ballastless design composed by a concrete sub-base and precast sleepers fixed on its surface. For every sleeper-based alternative, sleepers are assumed to be spaced 650 mm apart from each other, and CEN60-E1 rails are assumed. BBEST design uses different rail profiles, namely BB14072 profiles.

The assessment comprises a cradle to grave approach, where every activity that results in identical impacts between alternatives, as well as those whose impact is negligible, has been cut-off from the analysis (Martínez-Blanco et al., 2014). In particular, the product system under evaluation includes the impacts related to the production activities for every material involved in the construction and maintenance of each alternative, as well as those derived from the construction and maintenance of each of them.

2.2. Definition of social criteria

To objectively evaluate the social performance of each alternative along their life cycle, a set of quantitative criteria shall be defined. For the present analysis, a set of six criteria has been selected, depending on the relevant stakeholder affected. The selection of the stakeholders is in accordance with those defined in the ‘Guidelines’, from which three have been relevant for the present analysis.

The first category of impacts includes the workers involved in the different production centers considered in the product system. Based on (Navarro et al., 2014), a set of four criteria has been assumed that considers the main relevant aspects affecting employment conditions in Spain, namely fair salary, gender discrimination, workers' safety, and unemployment. To account for the social context in these four employment-related fields, four indicators are developed that serve to weight the amount of employment generated by each activity of the product system. So, if the activity variable is measured by 'hours of work generated', those hours are transformed into effective working hours that take into consideration the context of the production sites involved. So, in social terms, it shall not count the same an hour of work generated in a region with high unemployment rate than the same hour generated in a region where unemployment is almost inexistent. The present criteria set tries to reward those alternatives that contribute to reduce unemployment in regions with high unemployment rates, generate employment in regions where workers are paid fairly, where gender inequalities are reduced, and where workers' safety is guaranteed.

The indicator to account for fair salary conditions is defined as:

$$X_{salary} = (s - S_{min})/(S_{max} - S_{min}) \quad (1)$$

where s stands for the mean salary at the location of the production center, and S_{max} and S_{min} stand, respectively, for the maximum and minimum mean regional salary along the Spanish territory.

The indicator that affects the working hours generated to consider the regional unemployment conditions is defined as:

$$X_{local\ empl.} = (ur - Ur_{min})/(Ur_{max} - Ur_{min}) \quad (2)$$

where ur is the regional unemployment rate at the activity location, and Ur_{max} and Ur_{min} stand, respectively, for the maximum and minimum regional unemployment rates along the Spanish territory.

To account for the contribution of the activity variable to diminish the gender gap, the following indicator is considered:

$$X_{gender\ discl.} = 0.5 \cdot \min\{1-|Ur_m/Ur_{mean}-1|;1-|Ur_w/Ur_{mean}-1|\} + 0.5 \cdot \min\{1-|S_m/S_{mean}-1|;1-|S_w/S_{mean}-1|\} \quad (3)$$

where Ur_m and Ur_w stand, respectively, for the men's and women's mean unemployment rates at the location of the production center, Ur_{mean} stand for the mean unemployment rate at the activity location, S_m and S_w stand respectively for the men's and women's mean salary at the region where the activity takes place, and S_{mean} stand for the mean salary at that region.

At last, the safety conditions of the workers involved in the product system for each alternative are accounted for using the following indicator:

$$X_{safety.} = 1 - (ar - Ar_{min})/(Ar_{max} - Ar_{min}) \quad (4)$$

where ar stands for the accident rate for the specific activity at the location of the production center, and Ar_{max} and Ar_{min} stand, respectively, for the maximum and minimum regional accident rate for the specific activity along the Spanish territory.

On the other hand, the construction and maintenance of any infrastructure also contributes to the economic development of the regions involved in its product system (UNEP/SETAC, 2009). The activity variable that allows to measure such impact is the economic inflows that occur when the materials and construction services are paid to the respective providers. However, following the same principles as above, the increase in the economic wealth of a region is greater, for the same amount of economic flow, when the region is poorer than if its status is already economically good. To account for such positive social effect, the following indicator is defined that serves to weight the economic inflows to the different production centers:

$$X_{econ.\ devel.} = 1 - (gdp - GDP_{min})/(GDP_{max} - GDP_{min}) \tag{5}$$

where gdp stand for the Gross Domestic Product of the region where the particular activity takes place, and GDP_{max} and GDP_{min} stand, respectively, for the maximum and minimum regional Gross Domestic Product along the Spanish territory.

The last stakeholder included in the present assessment includes both the users of the railway system as well as the people living in the area of the construction site. The greater the maintenance needs required by an alternative, the greater the detriment to the comfort and accessibility of rail users. In addition, the greater the number of maintenance activities required by an alternative, the greater externalities derived from dust, noise or vibrations will affect the local communities. Such impact on the public opinion should be avoided. To reward those alternatives with reduced maintenance, following impact score is defined:

$$X_{public\ opinion.} = 1 - N/\max\{N_i\} \tag{6}$$

where N is the number of maintenance activities required by the alternative under assessment, and $max\{N_i\}$ is the maximum number of maintenance operations required among the alternatives under study.

The inventory data including the activity variables for each alternative along the production, stage of their life cycles are included in table 1. The amount of employment generated, and the economic flows provided are associated to the functional unit (F.U.) described above of 1000 m long track.

Table 1. Activity variables and system boundaries for the production stage

Material		Production Center	Quantity/m	Employment Generated/F.U.	Economic Flow/F.U.
Conventional ballast track					
Sub-ballast	Aggregates	Toledo	7200 kg/m	90 h	39978 €
Sleepers	Concrete	Jaén	770 kg/m	138.6 h	-
	Steel	Jaén	18.8 kg/m	7.8 h	-
	Manufacture	Jaén	1.5 units/m	1061.5 h	106553 €
Ballast		Cáceres	5304 kg/m	66.3 h	50559 €
Rails		Valladolid	240 kg/m	99.3 h	41220 €
RHEDA 2000					
Sub-ballast	Aggregates	Toledo	4000 kg/m	50 h	22210 €
	Cement	Toledo	266 kg/m	43.9 h	7873 €
	Steel	Toledo	56 kg/m	23.2 h	34720 €
Sleeper	Concrete	Jaén	536 kg/m	96.5 h	-
	Steel	Jaén	9 kg/m	3.7 h	-
	Manufacture	Jaén	1.5 units/m	1061.5 h	106553 €
In-situ concrete	Concrete	Toledo	258 kg/m	46.5 h	8379 €
	Steel	Toledo	43 kg/m	17.8 h	26772 €

Rails		Valladolid	240 kg/m	99.3 h	41220 €
BBEST					
Sub-ballast	Aggregates	Toledo	1890 kg/m	23.6 h	10494 €
	Cement	Toledo	250 kg/m	41.3 h	7399 €
	Steel	Toledo	26.5 kg/m	11 h	16430 €
In-situ concrete	Concrete	Toledo	2672 kg/m	481 h	86573 €
	Steel	Toledo	232 kg/m	96 h	143840 €
Grout, Seal		Guadalajara	110 kg/m	19.8 h	116600 €
Rails		Valladolid	296 kg/m	122.4 h	41220 €

The inventory data including the activity variables for each alternative along the construction and maintenance stage of their life cycles are included in table 2. Again, the amount of employment generated, and the economic flows provided are associated to the functional unit (F.U.) described above of 1000 m long track.

Table 2. Activity variables and system boundaries for the construction and maintenance stages

Construction/Maintenance operation	Quantity/m	Employment Generated/F.U.	Economic Flow/F.U.
Conventional ballast track – Construction stage			
Sub-ballast spreading	7200 kg/m	1181 h	46759 €
Ballast spreading	5304 kg/m	2358.9 h	78166 €
Rail and sleeper installation	-	5066.2 h	51647 €
Rail welding	0.0139 units/m	144.4 h	3400 €
Conventional ballast track – Maintenance stage (100 years)			
Ballast leveling and damping/4 yrs.	-	575 h	80500 €
Dynamic stabilization/4 yrs.	-	50 h	33500 €
Ballast spreading/4 yrs.	265.2 kg/m	59054.8 h	160908 €
Ballast spreading/12.5 yrs.	1591.2 kg/m	19030.1 h	308943 €
Sub-ballast spreading/25 yrs.	7200 kg/m	4900.5 h	346950 €
Ballast spreading/25 yrs.	5304 kg/m	9580 h	514905 €
RHEDA 2000 – Construction stage			
Sub-ballast spreading	4000 kg/m	656.1 h	25977 €
Rail and sleeper installation	-	5066.2 h	51646 €
Rail welding	0.0139 units/m	144.1 h	3400 €
In-situ concreting	0.10 m^3/m	64.7 h	2350 €
Reinf. steel installation	43.1 kg/m	991.3 h	23705 €
RHEDA 2000 – Maintenance stage (100 years)			
Rail maintenance/25 yrs.	296 kg/m	19769.7 h	310360 €

BBEST – Construction stage			
In-situ concreting	1.07 m³/m	668.0 h	24283 €
Reinf. steel installation	232 kg/m	5336.0 h	127600 €
Grout and sealing	110 kg/m	22000.0 h	28366 €
Rail installation	-	820 h	2850 €
Rail welding	0.0139 units/m	144.1 h	3400 €
BBEST – Maintenance stage (100 years)			
Rail maintenance/25 yrs.	296 kg/m	19769.7 h	310360 €

The inventory data required to evaluate the social context-based indicators presented above is provided in table 3.

Table 3. Parameters defining the social context of each production center

	Toledo	Jaén	Cáceres	Valladolid	Guadalajara
GDP (x10³ €)	915658	593510	675880	716945	335948
Mean unemployment rate (%)	14.08	20.37	17.64	8.47	10.83
Men’s mean unempl. rate (%)	9.16	14.81	16.98	8.4	7.86
Women’s mean unempl. rate (%)	19.98	27.6	18.46	8.56	14.42
Mean salary (€)	18230	14261	15869	21380	21128
Men’s mean salary (€)	20085	15371	17115	23985	23852
Women’s mean salary (€)	15777	12807	14417	18400	17877
Accident Rate – Construction	8.73	6.44	6.13	5.62	9.91
A.R.- Specialized construction activities	7.67	5.65	5.38	4.94	8.71
A.R.- Industry	6.90	5.09	4.84	4.44	7.84
A.R. - Metalworking	8.10	5.97	5.69	5.21	9.20
A.R. – Extractive industry	7.27	5.36	5.11	4.68	8.26

2.3. Analytic Network Process based indicator

To rank the different design alternatives according to their social performance, taking into account the six social criteria presented above, the ANP is used (Saaty, 2004). ANP is a Multi-Criteria Decision-Making (MCDM) technique meant to generalize the well-known Analytic Hierarchy Process (AHP) developed by Saaty back in the 80’s (Saaty, 1980). While AHP relies on a hierarchical relation between criteria to determine their weights, ANP works in a network, allowing for the definition of more complex relations between them and being thus more accurate for complex problems such as sustainability-oriented decision problems.

Following the ANP technique, criteria and alternatives are grouped into so-called clusters. The method allows to consider relations between clusters in both directions, i.e. the method allows to model if elements in a cluster are influenced by some or all of the elements from another cluster, and vice versa. In addition, ANP also allows to model the relations that might exist between the elements in a cluster. Both types of relations are called internal and external influences. The construction of the relational network that represents the decision problem is an essential step in applying ANP. The decision maker needs to determine which alternatives and criteria will have an influence on his/her decision, to group them in clusters, and determine the relations that exist between them according to his/her expertise and vision of the problem. Such model is then represented in the form of a relational supermatrix, whose elements are filled with 1 or 0 values depending on whether or not there is a relation between row and column elements or not.

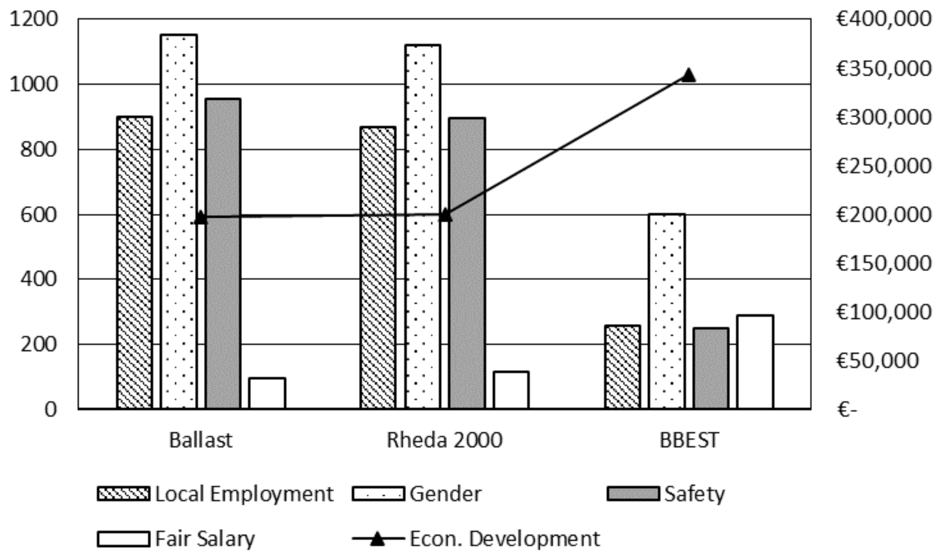
Once the relational supermatrix is filled, the expert needs to substitute each 1 with the actual relation that exists between rows and columns. To do so, the conventional AHP method is used to determine how much more affect each of the elements from each row filled with a 1 to the particular element in the column under analysis. The resulting supermatrix is called unweighted supermatrix. The resulting matrix is not stochastic, i.e., the elements of each column does not sum 1. To obtain a stochastic supermatrix, the elements of each column shall be multiplied by the weight of the cluster they belong to, which is obtained again by means of a conventional application of the AHP method.

The resulting weighted supermatrix is the basis for the last step of the method, which consists in powering the weighted supermatrix so many times as needed until every column is identical. The elements of such so-called limiting supermatrix provide not only the resulting weights of each criterion, but also the scoring of each alternative according to such criteria weights.

3. Results

Following the SLCA methodology described above, the social impacts for the three different life cycle stages considered in the present analysis are calculated for the three track design alternatives (figures 1 to 3). It is observed that, as far as the production stage is concerned, the alternative BBEST scores very little if compared to ballast-based and Rheda 2000 alternatives in generating quality employment. However, the economic flows derived from such alternative are significantly higher than for the other two alternatives (figure 1).

Figure 1: Social impacts associated to material production



However, when it comes to the social impacts associated to the construction stage (figure 2), it is precisely BBEST the alternative that both generates more employment and contributes more to the economic development of regions.

At last, the impacts derived from the maintenance along 100 years for each of the three design alternatives, are presented in figure 3. It is noted that the high maintenance needs required by the conventional ballasted track contribute to an employment generation sustained along a great time laps, contributing to increasing the economic wealth of the affected activity locations by more than 300% if compared to RHEDA 2000 and BBEST solutions. However, The positive impact on the public opinion derived from the absence of maintenance is zero for the conventional track, according to the impact indicators set proposed here. On the contrary, RHEDA 2000 and BBEST alternatives, with almost no significant affection to the users and local communities along their life cycle, score almost 1 for this decision criterion.

Figure 2: Social impacts associated to the construction stage

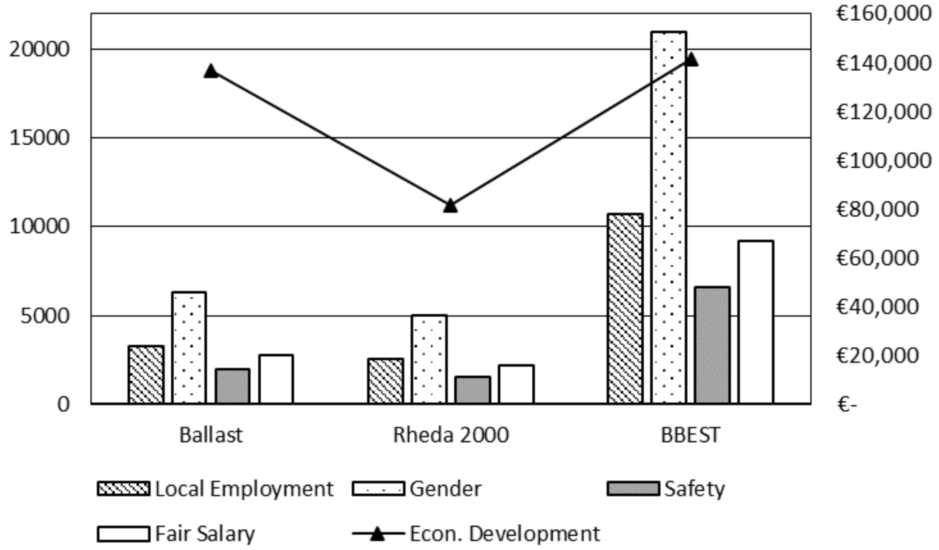
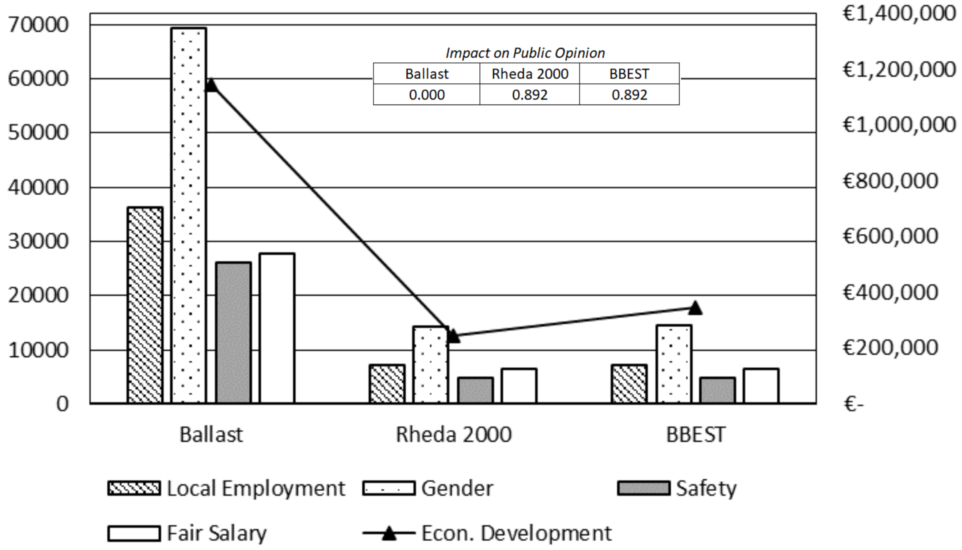


Figure 3: Social impacts associated to the maintenance stage



Once the social impacts are calculated for each stage and alternative, the ANP-based decision model shall be constructed. Three experts have been involved in the development of the network. A brief description of each of them is presented in table 4.

For the present decision-making problem, four clusters are defined: the first includes the three design alternatives, the second the four employment-related criteria, the third the socio-economic criterion and the last the impact on public opinion. By definition, alternatives always influence criteria and vice versa. Thus, the respective supermatrix cells are filled with 1. Here, there is no relation assumed between alternatives. Those relations, as well as the relations that might exist between criteria, are presented in figure 4 only for expert 1. In the following, only tables for expert 1 will be presented, for the sake of simplicity.

Table 4. Description of the panel of experts

	Expert 1	Expert 2	Expert 3
Years of profesional experience	8	21	17
Advanced degree	PhD	PhD	MSc
Expertise level in construction design	8/10	10/10	10/10
Expertise level in structural design	10/10	8/10	10/10
First author in JCR articles	9	14	4

Once the model is constructed, and following the ANP procedure, the cells filled with 1 in the influential supermatrix are then substituted by the actual influence that row elements have on column elements in order to construct the unweighted supermatrix shown in figure 5. As the social criteria set considered in the present analysis is a set of quantitative criteria, the first 3 rows and 3 columns can be completed directly from the impact values presented in figures 1 to 3.

Figure 4: ANP-based decision model for the social assessment of railway tracks

	Ballast	Rheda 2000	BBEST	Local Employment	Gender	Safety	Fair Salary	Econ. Development	PublicOpinion
Ballast	0	0	0	1	1	1	1	1	1
Rheda 2000	0	0	0	1	1	1	1	1	1
BBEST	0	0	0	1	1	1	1	1	1
Local Employment	1	1	1	0	1	1	1	1	0
Gender	1	1	1	0	0	0	0	0	1
Safety	1	1	1	0	0	0	0	0	1
Fair Salary	1	1	1	0	0	0	0	1	0
Econ. Development	1	1	1	1	0	0	1	0	0
PublicOpinion	1	1	1	0	1	0	0	0	0

Figure 5: Unweighted supermatrix

	Ballast	Rheda 2000	BBEST	Local Employment	Gender	Safety	Fair Salary	Econ. Development	PublicOpinion
Ballast	0	0	0	0.5837	0.5768	0.6070	0.5545	0.5214	0
Rheda 2000	0	0	0	0.1534	0.1532	0.1501	0.1569	0.1856	0.5
BBEST	0	0	0	0.2630	0.2700	0.2429	0.2886	0.2930	0.5
Local Employment	0.2360	0.2367	0.2372	0	1	1	1	1	0
Gender	0.1240	0.1230	0.1199	0	0	0	0	0	0.7
Safety	0.3294	0.3510	0.3727	0	0	0	0	0	0.3
Fair Salary	0.3106	0.2893	0.2702	0	0	0	0	1	0
Econ. Development	1	1	1	1	0	0	1	0	0
PublicOpinion	1	1	1	0	1	0	0	0	0

To get a stochastic, weighted supermatrix, the influence that each cluster has on each of the rest needs to be determined. This can be done using the conventional AHP technique, and considering only the pairwise comparison of those clusters whose elements are related (figure 6).

Figure 6: Influence of each cluster on the rest

<table>
<tr><th></th><th>Ballast</th><th>Rheda 2000</th><th>BBEST</th><th>Local Employment</th><th>Gender</th><th>Safety</th><th>Fair Salary</th><th>Econ. Development</th><th>PublicOpinion</th></tr>
<tr><th>Ballast</th><td colspan="3" rowspan="3">0</td><td colspan="4" rowspan="3">0.4854</td><td rowspan="3">0.800</td><td rowspan="3">0.667</td></tr>
<tr><th>Rheda 2000</th></tr>
<tr><th>BBEST</th></tr>
<tr><th>Local Employment</th><td colspan="3" rowspan="4">0.0540</td><td colspan="4" rowspan="4">0.2193</td><td rowspan="4">0.200</td><td rowspan="4">0.333</td></tr>
<tr><th>Gender</th></tr>
<tr><th>Safety</th></tr>
<tr><th>Fair Salary</th></tr>
<tr><th>Econ. Development</th><td colspan="3">0.5891</td><td colspan="4">0.1551</td><td>0</td><td>0</td></tr>
<tr><th>PublicOpinion</th><td colspan="3">0.3568</td><td colspan="4">0.1401</td><td>0</td><td>0</td></tr>
</table>

Once those relations are quantified, the stochastic, weighted decision supermatrix can be obtained (figure 7), as a previous step to calculating the criteria weights and alternative scores.

Figure 7: Stochastic weighted supermatrix

	Ballast	Rheda 2000	BBEST	Local Employment	Gender	Safety	Fair Salary	Econ. Development	PublicOpinion
Ballast	0	0	0	0.4424	0.3314	0.4181	0.3131	0.3476	0
Rheda 2000	0	0	0	0.1162	0.0880	0.1034	0.0886	0.1238	0.3333
BBEST	0	0	0	0.1993	0.1551	0.1673	0.1629	0.1953	0.3333
Local Employment	0.0128	0.0128	0.0128	0	0.2596	0.3112	0.2551	0.1667	0
Gender	0.0067	0.0066	0.0065	0	0	0	0	0	0.2333
Safety	0.0178	0.0190	0.0201	0	0	0	0	0	0.1
Fair Salary	0.0168	0.0156	0.0146	0	0	0	0	0.1667	0
Econ. Development	0.5891	0.5891	0.5891	0.2421	0	0	0.1804	0	0
PublicOpinion	0.3568	0.3568	0.3568	0	0.1659	0	0	0	0

The last step of the ANP procedure consists in powering the previous supermatrix until it converges to the so-called limiting supermatrix, for which every column is identical. The limiting supermatrix for the present decision-problem is provided in figure 8.

Figure 8: Decision model limiting supermatrix (normalized)

	Ballast	**Rheda 2000**	**BBEST**	**Local Employment**	**Gender**	**Safety**	**Fair Salary**	**Econ. Development**	**PublicOpinion**
Ballast	***0.410***	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410
Rheda 2000	***0.254***	0.254	0.254	0.254	0.254	0.254	0.254	0.254	0.254
BBEST	***0.336***	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336
Local Employment	***0.131***	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131
Gender	***0.062***	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
Safety	***0.037***	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
Fair Salary	***0.084***	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084
Econ. Development	***0.439***	0.439	0.439	0.439	0.439	0.439	0.439	0.439	0.439
PublicOpinion	***0.248***	0.248	0.248	0.248	0.248	0.248	0.248	0.248	0.248

From the results, it is observed that, for the particular case assessed here, and according to the expert's vision of the problem, greater relevance is given to the impacts that each alternative can have on the economic development of regions (with a normalized relevance around 43%) and on the positive public opinion (relevance around 25%), rather than on the generation of quality employment-related impacts. With such relevance values, the track alternative that contributes best in social terms along an analysis period of 100 years is the conventional ballast track (social score of 41%), closely followed by the BBEST alternative (social score of 34%).

4. Conclusions

The social assessment of infrastructures in the design phase is, to date, a major challenge that still needs to be solved in order to achieve the SDGs by 2030. Since the construction sector is recognized as a major tool to boost regional economies and generate employment, designing infrastructures that maximize such positive impacts on the society emerges as an essential means of bringing us closer to the sustainable future to which we all aspire. However, the absence of standards that set a consistent framework for the definition of quantitative and objective social indicators poses an urgent need for engineers to develop such criteria for evaluating their designs.

The present communication focuses on the social life cycle assessment of railway infrastructures. To that end, a set of six quantitative social criteria has been developed, covering aspects such as employment generation and its quality (gender discrimination, fair salary, safety and fight against unemployment), the economic development of regions, and the affection to public opinion derived from track maintenance operations. Such quantitative set allows not only for the optimization of track designs in social terms, but also for the selection of the design alternatives that most contribute to the social development of the regions affected by them. As a case study, a social life cycle assessment of three different twin-track design alternatives, namely a conventional ballasted track, and the ballastless solutions Rheda 2000 and BBEST, is presented. The analysis comprises the social impacts along the production, construction and maintenance life cycle stages, covering a period of analysis of 100 years.

Given the complex relations that might exist between social criteria, the final assessment of the alternatives has been conducted based on the MCDM technique called ANP, which allows for the modelling of such influences assuming a network-oriented approach. It shall be noted that the results obtained in the present communication are limited by the fact that a reduced panel of three experts has been involved in the construction of the ANP network. Results have shown that, for the particular case study analyzed, the conventional ballasted track solution provides better results than RHEDA 2000 and BBEST designs, as it provides a sustained source of quality employment generation and economic flows on the regions involved within the boundaries of the product system defined here.

5. References

De Luca, A.I., Iofrida, N., Strano, A., Falcone, G., Gulisano, G. (2015). Social life cycle assessment and participatory approaches: a methodological proposal applied to citrus farming in Southern Italy. *Integrated Environmental Assessment and Management*, *11*, 383–396.

Gervásio, H., da Silva, L.S., 2013. Life-cycle social analysis of motorway bridges. *Structure and Infrastructure Engineering*, *9*, 1019–1039.

Hendiani, S., Bagherpour, M. (2019). Developing an integrated index to assess social sustainability in construction industry using fuzzy logic. *Journal of Cleaner Production, 230,* 647-662.

Indraratna, B., Salim, W,. Rujikiatkamjorn, C. (2011) Advanced Rail Geotechnology-Ballasted Track, CRC Press (2011)

Martínez-Blanco, J., Lehmann, A., Muñoz, P., Antón, A., Traverso, M., Rieradevall, J., Finkbeiner, M. (2014). Application challenges for the social life cycle assessment of fertilizers within life cycle sustainability assessment. *Journal of Cleaner Production, 69*, 34–48.

Molina-Moreno, F., García-Segura, T., Martí, J.V., & Yepes, V. (2017). Optimization of Buttressed Earth-Retaining Walls using Hybrid Harmony Search Algorithms. *Engineering Structures*, *134*, 205-216.

Torres-Machí, C., Chamorro, A., Pellicer, E., Yepes, V., & Videla, C. (2015). Sustainable pavement management: Integrating economic, technical, and environmental aspects in decision making. *Transportation Research Record*, *2523*, 56-63.

Navarro, I.J., Yepes, V., & Martí, J.V. (2018). Social life cycle assessment of concrete bridge decks exposed to aggressive environments. *Environmental Impact Assessment Review*, *72*, 50-63.

Navarro, I.J., Martí, J.V., & Yepes, V. (2019). Reliability-based maintenance optimization of corrosion preventive designs under a life cycle perspective. *Environmental Impact Assessment Review*, *74*, 23-34.

Pang, B., Yang, P., & Wang, Y. (2015). Life cycle environmental impact assessment of a bridge with different strengthening schemes. *International Journal of Life Cycle Assessment, 20*, 1300.

Pons, J.J., Villalba Sanchis, I., Insa Franco, R., & Yepes, V. (2020). Life cycle assessment of a railway tracks substructures: comparison of ballast and ballastless rail tracks. *Environmental Impact Assessment Review*, *85*, 106444.

Safi, M., Sundquist, H., Karoumi, R. (2015). Cost-efficient procurement of bridge infrastructures by incorporating life-cycle cost analysis with bridge management systems. *Journal of Bridge Engineering, 20*.

Saaty, T. L., *The analytic hierarchy process*, New York, NY: McGraw-Hill, 1980.

Saaty, T.L. (2004). Fundamentals of the analytic network process — Dependence and feedback in decision-making with a single network. *Journal of Systems Science and Systems Engineering*, *13*, 129-157.

UNEP/SETAC, 2009. Guidelines for Social Life Cycle Assessment of Products, United Nations Environment Program. In: Paris SETAC Life Cycle Initiative United Nations Environment Programme.

Wilhelm, M., Hutchins, M., Mars, C., Benoit-Norris, C. (2015). An overview of social impacts and their corresponding improvement implications: a mobile phone case study. *Journal of Cleaner Production*, *102*, 302–315.

Villalba Sanchis, I,. Insa Franco, R,. Marínez Fernández, P,. Salvador Zuriaga, P. (2021). Experimental and numerical investigations of dual gauge railway track behaviour, *Construction and Building Materials, 299.*

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